GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: July 1, 1971

Georgia Institute of Technology Science Information Research

Project Title: Center

Project No: B-1808* G-34-604

Principal Investigator: Dr. Vladimir Slamecka

Sponsor: National Science Foundation

Agreement Period: From July 1, 1971 Until June 30, 1972

Grant GN-655, Amendment No. 3

Type Agreement: NSF Funds (B-1803) Ga. Tech Cont. (B-1800)

Amount: $197,717 Total Budget

*Project B-1808 is an add-on to project B-1804; the Personal Services funds in B-1808 are subject to Retirement charges whereas in B-1804, they are not subject to these charges.

Reports Required:

Annual Report - due July 1, 1972
Final Report - upon completion of project

Sponsor Contact Person (s):

Mr. Ronald E. Kerstiens
Assistant Grant Manager, Area 4
Grants and Contracts Office
National Science Foundation
Washington, D.C. 20550

Assigned to: School of Information and Computer Science

COPIES TO:

Principal Investigator
School Director
Dean of the College
Director, Research Administration
Director, Financial Affairs (2)
Security-Reports-Property Office
Patent Coordinator

Library
Rich Electronic Computer Center
Photographic Laboratory
Project File
Other

RA-3 (6-71)
Project Title: Georgia Institute of Technology Science Information Research Center

Project No: G-36-604 (Formerly B-1803)

Principal Investigator: Dr. Vladimir Sloaneck

Sponsor: National Science Foundation

Effective Termination Date: 9-30-75 (Grant Expiration)

Clearance of Accounting Charges: by 9-30-75


NOTE: See also companion accounts G-36-602 & 603.

Assigned to School of Information & Computer Science

COPIES TO:

Principal Investigator
School Director
Dean of the College
Office of Financial Affairs (2)
Patent and Inventions Coordinator
Research Services/Photo Lab

Library, Technical Reports Section
Office of Computing Services
Terminated Project File No.
Other
November 8, 1971

Dr. Edward C. Weiss  
Program Director  
Research and University Information  
Systems Program  
Office of Science Information Service  
National Science Foundation  
Washington, D. C. 20550

Dear Dr. Weiss:

The School of Information and Computer Science, Georgia Institute of Technology, is pleased to submit the quarterly administrative report on NSF Grant GN-655 for the period of July 1 through September 30, 1971.

On behalf of the faculty of the School of Information and Computer Science and the Administration of the Georgia Institute of Technology, I should like to sincerely thank the National Science Foundation for this continuing support to the School under NSF Grant GN-655.

Sincerely,

Vladimir Slamecka  
Director

Enclosures (7)

cc:  President, Georgia Institute of Technology  
Dean, General College  
Director, Research Administration
QUARTERLY ADMINISTRATIVE REPORT
NO. 9
NSF GRANT GN-655

(July - September 1971)

School of Information and Computer Science
Georgia Institute of Technology
Atlanta, Georgia
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<td></td>
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</tbody>
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INTRODUCTION

The School of Information and Computer Science, Georgia Institute of Technology, is pleased to submit its ninth quarterly administrative report under NSF Grant GN-655 Amendment No. 4, covering the 3 month period extending from July 1 through September 30, 1971.

The report begins with a review of selected activities. Two subsequent sections of the report then review senior project personnel and project support and expenditures. A list of published reports and presentations supported in part by the Grant since July 1, 1971 concludes the report.
RESEARCH

This section reviews selected aspects of the School's research-related activities which are supported partially by NSF Grant GN-655, but have not as yet resulted in publication. Published reports for the period covered by the report are listed on page 10.

American Bar Association-Committee on Law and Technology
State of the Art Conference on the Use of Computers in Legal Research

Preliminary plans are being made to co-sponsor, with the American Bar Association's Committee on Law and Technology, a state-of-the-art conference on the use of computers in legal research. The conference is tentatively scheduled for March 16, 17, and 18, 1972.

State of Georgia Government Reorganization Study

The State Government of Georgia called upon the School of Information and Computer Science to provide expertise to assist Governor Carter's state government reorganization team. Mr. Alton P. Jensen, Senior Research Engineer, School of Information and Computer Science, was subsequently appointed to direct the reorganization team's analysis of EDP facilities and operations in the Government and agencies of the State of Georgia. The appointment, without extra compensation, was made effective July 1, 1971. The reorganization study is scheduled for completion in early October.

Regional Center for Information Science

On July 7, 11, and 12, 1971, Dr. Vladimir Slamecka, Professor and Director, School of Information and Computer Science, presented to the Governor and Community Leaders of Georgia the concept of a "Regional Center for Information Science." On the basis of the presentation, a State task group was appointed to further investigate the desirability and feasibility of such a center. On August 18, 1971 the task group submitted a proposal to the Governor, highly endorsing the establishment of a "Regional Center for Information Science" in the State of Georgia.
On August 18, 1971, Dr. Vladimir Slamecka and Mr. Alton P. Jensen of the School of Information and Computer Science gave a demonstration of the School's Audiographic Learning Facility (ALF) to Governor Jimmy Carter of the State of Georgia. Governor Carter was impressed with the system and stated that he would like to see the new technique put into use in the State's public schools. Subsequent discussions by Governor Carter with Mr. Jack Nix, State Superintendent of Schools, led to a second demonstration of the system for Mr. Nix. Mr. Nix formally asked Governor Carter for State support to implement the system on an experimental basis. Governor Carter subsequently promised $100,000 of State funds, in addition to help in generating more money.

A presentation was also made to 180 superintendents of the school system of the State of Georgia, and negotiations are underway to place ALF equipment into several of such systems.

**Information Processing Laboratory**

A complete list of current equipment, equipment maintenance contracts and equipment rentals associated with the School's Laboratory appears on pages 23 through 26 of the 1970/71 Annual Administrative Report [1].

In order to extend the services of the laboratory, as well as to meet requirements associated with the planned increase in computer power, the School has employed a full-time Computer/Electronic Technician and a full-time Systems Analyst/Programmer, effective July 1 and October 1, 1971, respectively.

The School has received several bids in response to its recent request for quotations to furnish the School's laboratory with a second processing unit. The required specification for the unit was given on pages 3 & 4 of the Quarterly Administrative Report No. 7. Having made preliminary reviews of quotations received, the School is presently completing a comprehensive evaluation of the following systems:
It is anticipated that a formal contract will be issued for one of these systems by December 1.

**Seminars**

<table>
<thead>
<tr>
<th>Date</th>
<th>Lecturer</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 25, 1971</td>
<td>Dr. Miroslav Valach</td>
<td>&quot;Cybernetics&quot;</td>
</tr>
<tr>
<td></td>
<td>Professor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>School of Information</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and Computer Science</td>
<td></td>
</tr>
<tr>
<td>September 20, 1971</td>
<td>ICS Senior Faculty</td>
<td>&quot;Research in Information and Computer Science&quot;</td>
</tr>
<tr>
<td>September 30, 1971</td>
<td>Capt. R. C. Roehrkassee</td>
<td>&quot;Abstract Digital Computers and Automata&quot;</td>
</tr>
<tr>
<td></td>
<td>Ph.D. Candidate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>School of Information</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and Computer Science</td>
<td></td>
</tr>
</tbody>
</table>
SENIOR PERSONNEL

Following is a list of senior personnel supported in part by NSF Grant GN-655 for the period extending from July 1, 1971 to September 30, 1971. The levels of involvement are not indicated; as a rule they depend on the research topic in question, and on other academic assignments.

Professors:           Associate Professors:
Dr. Lucio Chiaraviglio Dr. Philip J. Siegmann
Dr. James Gough, Jr.  Dr. Pranas Zunde
Dr. Vladimir Slamecka  
Dr. Miroslav Valach

Assistant Professors:  Senior Research Engineer:
Dr. John M. Gwynn, Jr. Mr. A. P. Jensen
Dr. M. D. Kelly
Mr. D. H. Kraus
Dr. D. E. Rogers
Dr. W. I. Grosky

Additions

William I. Grosky, Assistant Professor of Information and Computer Science.

Dr. Grosky joined the staff of the School of Information and Computer Science on September 1, 1971, as a full-time Assistant Professor of Information and Computer Science. Dr. Grosky received his M.S. degree in applied mathematics from Brown University in 1968, and his Ph.D. in Engineering and Applied Science from Yale University in 1971. His present interests are in the fields of computability theory, automata theory, and mathematical logic.

Deletions

Dr. Richard L. Hawkey
Dr. Joseph J. Talavage
PROJECT SUPPORT/EXPENDITURES*

This section of the report summarizes the financial budget of NSF Grant GN-655, and gives a detailed account of the manpower budget.

Financial

On July 23, 1971, the Institute was granted an additional $170,000 as supplemental support of its project entitled "Georgia Institute of Technology, Science Information Research Center." These monies, awarded as Amendment No. 4 to the Grant, represent the balance of funding of the Center for 1971/72. Table 1 gives the financial breakdown of the supplemental award.

Table 1. Budget of NSF Grant GN-655 Amendment No. 4 (1971/72)

| Budget Category         | NSF Approved Funding | Proposed Georgia Tech Matching Contribution** | Total Budget  
|-------------------------|----------------------|-----------------------------------------------|---------------
| Salaries & Wages        | $95,994              | $52,133                                       | $148,127      
| Equipment               |                      |                                               |               
| Permanent               | -                    | -                                             | -             
| Books                   | -                    | -                                             | -             
| Expendable Supplies***  | 9,640                | 2,834                                         | 12,474        
| Travel                  | 1,133                | 1,133                                         | 2,266         
| Computer Time           | 2,452                | -                                             | 2,452         
| Subtotal                | 109,219              | 56,100                                        | 165,319       
| Overhead (57% of Salaries and Wages) | 54,717 | 29,716 | 84,433        
| Retirement (7.65% of Applicable Salaries and Wages) | 6,064 | 3,089 | 9,153         
| Grand Total             | $170,000             | 88,905                                        | 258,905       

*The data in this section is based on departmental records of the School, not on the official records of the Georgia Institute of Technology.

**The proposed Georgia Institute of Technology matching contribution will be administered in accordance with current foundation policy as set forth in Important Notice 31, dated September 3, 1970.

***Includes publication costs.
The funds awarded under NSF Grant GN-655, as amended, now total $1,289,825. As of October 1, 1971, the Georgia Institute of Technology has contributed $635,643 as a matching contribution to the Grant.

Tables 2 and 3 incorporate Amendment No. 4 into the original grant as amended by Amendments 1, 2, and 3. Tables 2 and 3 show, respectively, the final NSF and GIT category allocations along with the expenditures and balance of funds in each of the categories as of October 1, 1971.

Table 2. GN-655 Financial Summary (NSF Funding) (July 1, 1967-October 1, 1971)

<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Funding</th>
<th>1967/69</th>
<th>1969/70</th>
<th>1970/71</th>
<th>7/1/71-9/30/71</th>
<th>Expenditures/Encumbrances</th>
<th>Total</th>
<th>Balance as of October 1, 1971</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaries &amp; Wages</td>
<td>$680,902</td>
<td>$155,077</td>
<td>$137,297</td>
<td>$163,570</td>
<td>$ 31,013</td>
<td>$486,957</td>
<td></td>
<td>$ 193,945</td>
</tr>
<tr>
<td>Equipment</td>
<td>3,000*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,000*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Books</td>
<td>84,770</td>
<td>14,264</td>
<td>5,699</td>
<td>64,807</td>
<td>-</td>
<td>84,770</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endorable Supplies**</td>
<td>51,012</td>
<td>6,746</td>
<td>16,641</td>
<td>10,402</td>
<td>2,001</td>
<td>35,790</td>
<td>15,222</td>
<td>35,290*</td>
</tr>
<tr>
<td>Travel</td>
<td>13,000</td>
<td>4,150</td>
<td>953</td>
<td>2,329</td>
<td>254</td>
<td>7,686</td>
<td>5,314</td>
<td></td>
</tr>
<tr>
<td>Computer Time</td>
<td>19,326</td>
<td>4,514</td>
<td>4,465</td>
<td>1,441</td>
<td>1,848</td>
<td>12,268</td>
<td>7,058</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$889,300</td>
<td>$184,777</td>
<td>$165,067</td>
<td>$242,566</td>
<td>$35,116</td>
<td>$627,526</td>
<td>$261,774</td>
<td></td>
</tr>
</tbody>
</table>

| Research Planning Study | $388,114 | $88,394 | $78,228 | $93,235 | $17,677 | $277,534 | 110,580 | 1,710* |

| Research Planning Study | $10,701 | -       | -       | -       | 749     | 749      | 9,952   |        |

| Total                  | $1,289,825| $273,171| $243,295| $335,801| $53,542 | $905,809 | $384,016|

Research Planning Study Includes Publication Costs
### Table 3. GN-655 Financial Summary (Georgia Tech Matching Contribution)  
(July 1, 1967 - October 1, 1971)

<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Contribution</th>
<th>Expenditures/Encumbrances</th>
<th>Balance as of October 1, 1971</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1967/69</td>
<td>1969/70</td>
<td>1970/71</td>
</tr>
<tr>
<td>Salaries &amp; Wages</td>
<td>$413,315</td>
<td>$141,027</td>
<td>$95,257</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent</td>
<td>$81,780</td>
<td>$81,780</td>
<td>-</td>
</tr>
<tr>
<td>Books</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplies **</td>
<td>$17,787</td>
<td>$1,939</td>
<td>5,884</td>
</tr>
<tr>
<td>alis</td>
<td>5,522</td>
<td>-</td>
<td>2,000</td>
</tr>
<tr>
<td>otter</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>utne</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$518,404</td>
<td>$224,746</td>
<td>$103,141</td>
</tr>
<tr>
<td>Overhead (57% of Salaries &amp; Wages)</td>
<td>$235,590</td>
<td>80,386</td>
<td>54,296</td>
</tr>
<tr>
<td>Retirement (7.65% of applicable Salaries &amp; Wages)</td>
<td>$5,452</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>$759,446</td>
<td>$305,132</td>
<td>$157,437</td>
</tr>
</tbody>
</table>

This analysis does not show the additional matching contribution by the Georgia Institute of Technology in the amount of $104,000 toward the purchase, through its library, of library materials related to information and computer science during the first four year period of the grant.

*Includes publication costs.*
Manpower

Table 4 compares the planned 5 year manpower effort under NSF Grant GN-655 against the actual expended manpower as of October 1, 1971 (in terms of EFT*).

Table 4. Comparison of Planned and Expended Manpower (GN-655) (July 1, 1967-October 1, 1971)

<table>
<thead>
<tr>
<th>Manpower Category</th>
<th>GN-655 Budgeted EFT**</th>
<th>1967/69</th>
<th>1969/70</th>
<th>1970/71</th>
<th>7/1-9/30/71</th>
<th>Total</th>
<th>October 1, 1971</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Investigator</td>
<td>2.50</td>
<td>1.13</td>
<td>.75</td>
<td>1.00</td>
<td>.12</td>
<td>3.00</td>
<td>(.50)***</td>
</tr>
<tr>
<td>Faculty Associate</td>
<td>34.50</td>
<td>12.73</td>
<td>5.46</td>
<td>6.91</td>
<td>1.53</td>
<td>26.63</td>
<td>7.87</td>
</tr>
<tr>
<td>Non-Faculty Professionals (other)</td>
<td>21.00</td>
<td>2.36</td>
<td>5.17</td>
<td>2.81</td>
<td>.39</td>
<td>10.73</td>
<td>10.27</td>
</tr>
<tr>
<td>Graduate Students</td>
<td>16.00</td>
<td>5.09</td>
<td>3.32</td>
<td>4.68</td>
<td>.97</td>
<td>14.06</td>
<td>1.94</td>
</tr>
<tr>
<td>Pre-Baccalaureate Students</td>
<td>3.00</td>
<td>.07</td>
<td>.41</td>
<td>.62</td>
<td>.20</td>
<td>1.30</td>
<td>1.70</td>
</tr>
<tr>
<td>Technical</td>
<td>2.00</td>
<td>.29</td>
<td>1.00</td>
<td>.94</td>
<td>-</td>
<td>2.23</td>
<td>(.23)***</td>
</tr>
<tr>
<td>Secretary</td>
<td>12.50</td>
<td>3.65</td>
<td>2.66</td>
<td>2.71</td>
<td>.66</td>
<td>9.68</td>
<td>2.82</td>
</tr>
<tr>
<td>Clerical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>91.50</td>
<td>25.32</td>
<td>18.77</td>
<td>19.67</td>
<td>3.87</td>
<td>67.63</td>
<td>23.87</td>
</tr>
</tbody>
</table>

*1.00 Indicates Full-Time for 1 Fiscal Year


***Over expenditure.
LIST OF PUBLICATIONS AND PRESENTATIONS
(July 1 - September 1971)

Administrative Reports

1. "1970/71 Annual Summary Report, NSF Grant GN-655." Atlanta, Ga.,
   Georgia Institute of Technology (School of Information and Computer
   Science), August 20, 1971, 31 p. (Annual Administrative Report to
   Dr. Edward C. Weiss, NSF).

Presentations

2. Jensen, A. P., and Slamecka, V. "Georgia Tech's Audiographic
   Learning Facility." Presentation to the Governor of Georgia,
   Atlanta, Ga., August 18, 1971.

3. Jensen, A. P., and Slamecka, V. "Georgia Tech's Audiographic
   Learning Facility." Presentation to the State Superintendent
   of Schools, and Superintendents of the School Systems of Georgia,
   Atlanta, Ga., September 30, 1971.

4. Slamecka, V. "Regional Center for Information Sciences." Pre-
   sentation to the Governor and Community Leaders of Georgia,
   Atlanta, Ga., July 7, 11 & 12, 1971.

Published Papers

5. Slamecka, V., Jensen, A. P., and Zunde, P. "An Audiographic
   Repository of Knowledge for Conversational Learning." Educational

   Progress." Information Storage and Retrieval. Vol. 7, pp. 103-
   109 (1971).

7. Zunde, P. "Interaction in Linear Dynamical Systems l." Information
   and Control Vol. 18, No. 5 (1971).

Research Reports

   Institute of Technology (School of Information and Computer

   On the Combinatory Definability of Hardware and Software. Atlanta,
   Ga., Georgia Institute of Technology (School of Information and

Thesis

    Atlanta, Ga., Georgia Institute of Technology, 1971. 78 p.
    (Ph.D. Thesis).
May 8, 1972

Dr. Edward C. Weiss  
Program Director  
Research and University Information  
Systems Program  
Office of Science Information Service  
National Science Foundation  
Washington, D. C. 20550

Dear Dr. Weiss:

The School of Information and Computer Science, Georgia Institute of Technology, is pleased to submit the quarterly administrative report on NSF Grant GN-655 for the period of January 1 through March 31, 1972.

On behalf of the faculty of the School of Information and Computer Science and the Administration of the Georgia Institute of Technology, I should like to sincerely thank the National Science Foundation for this continuing support to the School under NSF Grant GN-655.

Sincerely,

Vladimir Slamecka  
Director

Enclosures (7)

cc: President, Georgia Institute of Technology  
Dean, General College  
Director, Research Administration
QUARTERLY ADMINISTRATIVE REPORT
No. 11
NSF GRANT GN-655

(January-March 1972)

School of Information and Computer Science
Georgia Institute of Technology
Atlanta, Georgia
INTRODUCTION

The School of Information and Computer Science is pleased to submit its eleventh quarterly administrative report under NSF Grant GN-655 Amendment No. 4, covering the 3 month period extending from January 1 through March 31, 1972.

The report begins with a brief report, for information purposes, on the proposed B.S. degree program in information and computer science. Three subsequent sections of the report then review selected research activities, senior project personnel, and project support and expenditures. A list of published reports and presentations supported in part by the Grant since January 1, 1972 concludes the report.
ATTACHMENT: B.S. PROGRAM IN INFORMATION AND COMPUTER SCIENCE
The School of Information and Computer Science has received Institutional approval to offer an undergraduate program leading to the degree of Bachelor of Science in Information and Computer Science. Pending final approval by the Board of Regents of the University System of Georgia, the program and the degree will be offered through the ICS School, beginning Fall Quarter 1972.

The primary objectives of the proposed undergraduate degree program are the following:

1. To provide quality education in response to the determined manpower requirements in the information processing professions in the State of Georgia and nationally:

2. To provide undergraduate education in an important new discipline of science and technology, in agreement with the role of the Georgia Institute of Technology within the University System of Georgia.

3. To strengthen and support educational programs of other academic departments of the Institute in a most cost-effective manner.

4. To improve the quality and level of existing graduate programs of the School of Information and Computer Science.

5. To complete the most comprehensive sequence of educational programs and opportunities in information and computer science available in the Southeast.

The proposed B.S. program of the School of Information and Computer Science will complete a rather unique, coordinated sequence of educational programs in information and computer science in the Atlanta area, extending from high school education through a doctoral program. The School of Information and Computer Science of Georgia Tech was instrumental in developing this sequence of programs, and assisting in its implementation particularly at the high school level.

---

The description of a new academic program is included in this report because of the eventual impact of this program on research activities in information science at the School.
Table 1 provides the estimated enrollment of B. S. majors in information and computer science at the Georgia Institute of Technology.

Table 1. Majors in Information/Computer Science
Estimated Enrollment, 1973-1976

<table>
<thead>
<tr>
<th>FISCAL YEAR</th>
<th>HEADCOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>50</td>
</tr>
<tr>
<td>1974</td>
<td>150</td>
</tr>
<tr>
<td>1975</td>
<td>250</td>
</tr>
<tr>
<td>1976</td>
<td>400</td>
</tr>
</tbody>
</table>

A summary of degree requirements and courses of the proposed program is attached.
RESEARCH

This section reviews selected aspects of the School's research and other related activities which have not as yet resulted in publication. Published reports for the period covered by the report are listed on page 11.

Conferences

March 16-18, 1972 State of the Art Conference on the Use of Computers in Legal Research. A state-of-the-art national conference on contemporary uses of computers in retrieving material for legal research was held on the Georgia Tech campus on March 16-18, 1972. The conference, sponsored jointly by the American Bar Association and the School of Information and Computer Science, had an attendance of over 220. The participants represented commercial, governmental and academic organizations currently engaged in legal research programs using computer techniques. The following topics were covered by invited speakers:

Law Searching by Computer - An Introduction
An Interactive Full-Text Retrieval System (STAIRS)
Justice Retrieval and Inquiry System (JURIS)
Legal Information Thru Electronics (LITE)
Documentation Automatic Text -- University of Montreal (DATUM)
Queen's University Institute for Computing and Law (QUIC/LAW)

In addition the following workshop sessions were held:

Financial Considerations and Feasibility - Bar Associations
Financial Considerations and Feasibility - Private Firms
User Training and Acceptability
Systems Design and Research Techniques

The conference, well received by its attendees, was the first national conference bringing together those active in the development of computerized legal research systems and the lawyers and governmental officials who have an interest in using such services. It is the intention of the American Bar Association to hold a second national conference on the Ga. Tech campus.
Approved Ph.D. Dissertation Topics

An Adaptive Microscheduler for a Multiprogrammed Computer System. The objective of this research project is to develop a means of optimizing the performance of a computer through the use of adaptive resource allocation microscheduling techniques. The method of attack entails the detailed design of such a technique, along with its verification in a given environment by simulation. This technique is based upon defining an objective function connecting the relevant variables of the system according to some policy describing the gain of the system. This function is then used as a goal toward which the microscheduler may work, using parametric moving averages, predictor-corrector trend detection, and variable-period correction application. The simulation will compare the proposed microscheduler with several others under several different objective functions. (Edgar M. Pass*, J.M. Gwynn, Jr., M. D. Kelly)

Abstract Computers and The Semantics of Programming Languages. The objective of this project is to establish a general semantic framework in which properties of programs and the processes they specify may be discussed. The methodology consists in transferring, intact, the formal tools of model theory (the general semantic theory in logic) to the semantics of programming languages. Programs will be described and constructed from a first-order language. Alternatives to "truth" values will be axiomatically proposed and termed "success" values. With each choice of success values will be associated: (a) a class of abstract computers $(S,r)$ which "execute" successful processes; (b) an algebraization of semantic inferential structure (either a Brouwerian algebra or its dual, a pseudo-Boolean algebra) which reflects the range of semantic interpretations of sets of programs. This later "calculus of systems" is related to the classes of $(S,r)$ computers algebraically. (Richard A. DeMillo*, Lucio Chiaraviglio, J. M. Gwynn, Jr.)

Abstract Computers and Degrees of Unsolvability. The objective of this project is to identify a class of Abstract Digital Computers which represent degrees of undecidability. The structure of the base algebras of these distinguished ADC's should represent the structures of the theories of degrees, and the relations between degrees should be reflected in the morphic relationships among representative ADC's.

*Ph.D. Student
It is hoped that the objective can be achieved by considering the natural structure of degrees. The equational calculus EC for degrees has as its structure a free Boolean algebra $F$. The structure of the theory of each degree representable in EC is a Boolean algebra isomorphic to a quotient of $F$, the quotient achieved by considering the ideal determined by the representative of the degree in $E_G$. In this construction, smaller degrees are embeddable in larger degrees. (Joseph R. Horgan*, Lucio Chiaraviglio, John M. Gwynn, Jr.)

Information Processing Laboratory

No significant changes have been made with respect to the purpose, configuration and operating policies of the laboratory as originally detailed in the School's published internal research memorandum The Laboratory for Information and Computer Science. (GITIS-68-01).

<table>
<thead>
<tr>
<th>Date</th>
<th>Lecturer</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 11, 1972</td>
<td>Mr. Richard A. DeMillo</td>
<td>&quot;Abstract Computers and the Semantics of Programming Languages&quot;</td>
</tr>
<tr>
<td></td>
<td>Ph.D. Student</td>
<td></td>
</tr>
<tr>
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<td>School of Information and Computer Science</td>
<td></td>
</tr>
<tr>
<td>January 13, 1972</td>
<td>Mr. Joseph R. Horgan</td>
<td>&quot;Abstract Computers and Degrees of Unsolvability&quot;</td>
</tr>
<tr>
<td></td>
<td>Ph.D. Student</td>
<td></td>
</tr>
<tr>
<td></td>
<td>School of Information and Computer Science</td>
<td></td>
</tr>
<tr>
<td>February 4, 1972</td>
<td>Dr. Thomas G. Windeknecht</td>
<td>&quot;Mathematical Theory of General Systems&quot;</td>
</tr>
<tr>
<td></td>
<td>Professor of Electrical Engineering, Michigan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technological University</td>
<td></td>
</tr>
<tr>
<td>February 13, 1972</td>
<td>Dr. Vladimir Slamecka</td>
<td>&quot;Programs of the School of Information and Computer Science&quot;***</td>
</tr>
<tr>
<td></td>
<td>Professor and Director</td>
<td></td>
</tr>
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<tr>
<td>February 14, 1972</td>
<td>Dr. William Goffman</td>
<td>&quot;Quantitative Studies in the Development of Science Information&quot;</td>
</tr>
<tr>
<td></td>
<td>Dean, School of Library Science, Case Western</td>
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</tr>
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<td></td>
<td>Reserve University</td>
<td></td>
</tr>
</tbody>
</table>

*Ph.D. Student
**Radio Broadcast, WGST, Atlanta, Georgia
February 24, 1972  
Mr. Alton P. Jensen  
Sr. Research Engineer  
School of Information  
and Computer Science  
"Audio-Graphic Learning Facilities"

March 2, 1972  
Mr. Morgan L. Stapleton  
Ph.D. Student  
School of Information  
and Computer Science  
"An Experimental Methodology Utilizing Semantic Measures of Information with Application to the Processing of Grammatical Transformations"

March 6, 1972  
Dr. Chan Mo Park  
Assistant Professor  
Computer Science Center  
University of Maryland  
"Biomedical Information Processing Systems"

March 28, 1972  
Dr. Vladimir Slamecka  
Professor and Director  
School of Information  
and Computer Science  
"Manpower Assessment and the Professional Challenge"

March 29, 1972  
Dr. Miroslav Valach  
Professor  
School of Information  
and Computer Science  
"A Method for the Determination of Isomorphic Structures"

March 31, 1972  
Mr. Stephen R. Kennedy  
Ph.D. Candidate  
Cornell University  
"The Interface Between Operations Research and Information Processing"

*Panel Discussion, Atlanta ACM Section of the Mid-Southeast Chapter*
SENIOR PERSONNEL

Following is a list of senior personnel supported in part by NSF Grant GN-655 for the period extending from January 1, 1971 to March 31, 1972. The levels of involvement are not indicated; as a rule they depend on the research topic in question, and on other academic assignments.

Professors:

Dr. Lucio Chiaraviglio
Dr. James Gough, Jr.
Dr. Vladimir Slamecka
Dr. Miroslav Valach

Associate Professors:

Dr. Philip J. Siegmann
Dr. Pranas Zunde

Assistant Professors:

Dr. W. I. Grosky
Dr. John M. Gwynn Jr.
Dr. M. D. Kelly
Mr. D. H. Kraus
Dr. D. E. Rogers

Additions
(None)

Deletions
(None)
PROJECT SUPPORT/EXPENDITURES

This section of the report summarizes the financial budget of NSF Grant GN-655, and gives a detailed account of the manpower budget.

Financial

Tables 2 and 3 show, respectively, NSF and GIT category allocations under NSF Grant GN-655 as amended by Amendment No. 4, along with the expended and balance of funds in each of these categories as of April 1, 1972.

Table 2. GN-655 Amendment No. 4
Financial Summary (NSF Funding)
(July 1, 1967-April 1, 1972)

<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Funding 1967/69</th>
<th>Expenditures/Encumbrances 1969/71 7/1/71-12/31/71 1/1/72-3/31/72</th>
<th>Balance as April 1, 1972</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaries &amp; Wages</td>
<td>$680,902</td>
<td>$155,077</td>
<td>$300,867</td>
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<tr>
<td>Equipment</td>
<td>84,770</td>
<td>14,264</td>
<td>25,708</td>
</tr>
<tr>
<td>Books</td>
<td>2,000</td>
<td>26</td>
<td>29</td>
</tr>
<tr>
<td>Expendable Supplies***</td>
<td>51,012</td>
<td>6,746</td>
<td>27,043</td>
</tr>
<tr>
<td>Travel</td>
<td>13,000</td>
<td>4,150</td>
<td>3,282</td>
</tr>
<tr>
<td>Computer Time</td>
<td>19,326</td>
<td>4,514</td>
<td>5,906</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$889,300</td>
<td>$184,777</td>
<td>$362,835</td>
</tr>
<tr>
<td>Overhead (57% of Salaries and Wages)</td>
<td>388,114</td>
<td>88,394</td>
<td>171,463</td>
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<tr>
<td>Retirement (7.65% of Applicable Salaries and Wages)</td>
<td>10,701</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$1,289,825</td>
<td>$273,171</td>
<td>$534,298</td>
</tr>
</tbody>
</table>

* The data in this section is based on departmental records of the School of Information and Computer Science, not on the official records of the Georgia Institute of Technology.
* Research Planning Study
* Includes Publication Costs
Table 3. GN-655 Amendment No. 4
Financial Summary (Ga. Tech. Contribution)
(July 1, 1967 - April 1, 1972)

<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Contribution</th>
<th>Expenditures/Encumbrances</th>
<th>Balance as of April 1, 1972</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1967/69</td>
<td>1969/71</td>
<td>7/1/71-12/31/71</td>
</tr>
<tr>
<td>Salaries &amp; Wages</td>
<td>81,780</td>
<td>81,780</td>
<td>-</td>
</tr>
<tr>
<td>Equipment</td>
<td>5,522</td>
<td>-</td>
<td>3,522</td>
</tr>
<tr>
<td>Computer Time</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>$518,404</td>
<td>$224,746</td>
<td>$194,658</td>
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<tr>
<td>Overhead (57% of Salaries and Wages)</td>
<td>235,590</td>
<td>80,386</td>
<td>102,764</td>
</tr>
<tr>
<td>Retirement (55% of Salaries and Wages)</td>
<td>5,452</td>
<td>-</td>
<td>3,247</td>
</tr>
<tr>
<td>Total</td>
<td>$759,446</td>
<td>$305,132</td>
<td>$297,422</td>
</tr>
</tbody>
</table>

This analysis does not show the additional matching contribution by the Georgia Institute of Technology in the amount of $104,000 toward the purchase, through its library, of library materials related to information and computer science during the first four year period of the grant.

Includes Publication Costs.
Manpower

Table 4 compares the planned 5 year manpower effort under NSF Grant GN-655 against the actual expended manpower as of April 1, 1972. (in terms of EFT*).

Table 4. Comparison of Planned and Expended Manpower (GN-655)  
(July 1, 1967 - April 1, 1972)

<table>
<thead>
<tr>
<th>Category</th>
<th>GN-655 Budget EFT**</th>
<th>1967/69</th>
<th>1969/71</th>
<th>7/1-12/31/72</th>
<th>1/1/72-3/31/72</th>
<th>Total</th>
<th>Balance as of April 1, 1972</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Investigator</td>
<td>2.50</td>
<td>1.13</td>
<td>1.75</td>
<td>.24</td>
<td>.13</td>
<td>3.25</td>
<td>(.75)***</td>
</tr>
<tr>
<td>Faculty Associate</td>
<td>34.50</td>
<td>12.73</td>
<td>12.37</td>
<td>3.93</td>
<td>2.19</td>
<td>31.22</td>
<td>3.28</td>
</tr>
<tr>
<td>Non-Faculty Professionals (other)</td>
<td>21.00</td>
<td>2.36</td>
<td>7.98</td>
<td>.57</td>
<td>.13</td>
<td>11.04</td>
<td>9.96</td>
</tr>
<tr>
<td>Graduate Students</td>
<td>16.00</td>
<td>5.09</td>
<td>8.00</td>
<td>2.09</td>
<td>1.20</td>
<td>16.38</td>
<td>(.38)***</td>
</tr>
<tr>
<td>Pre-Baccalaureate Students</td>
<td>3.00</td>
<td>.07</td>
<td>1.03</td>
<td>.32</td>
<td>.16</td>
<td>1.58</td>
<td>1.42</td>
</tr>
<tr>
<td>Technical</td>
<td>2.00</td>
<td>.29</td>
<td>1.94</td>
<td>-</td>
<td>-</td>
<td>2.23</td>
<td>(.23)***</td>
</tr>
<tr>
<td>Secretarial</td>
<td>12.50</td>
<td>3.65</td>
<td>5.37</td>
<td>1.31</td>
<td>.59</td>
<td>10.92</td>
<td>1.58</td>
</tr>
<tr>
<td>Total</td>
<td>91.50</td>
<td>25.32</td>
<td>38.44</td>
<td>8.46</td>
<td>4.40</td>
<td>76.62</td>
<td>14.88</td>
</tr>
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</table>

* 1.00 Indicates Full-Time for 1 fiscal year.

** Includes Ga. Tech matching contribution. Does not include .50 EFT budgeted for the Research Planning Study.

*** Overexpenditure.
LIST OF PUBLICATIONS AND PRESENTATIONS  
(January 1 - March 31, 1972)

**Administrative Reports**

   Atlanta, Ga., Georgia Institute of Technology (School of  
   Information and Computer Science), February 1, 1972. 11p.

**Papers Presented**

2. Jensen, A. P. "Georgia Tech's Audiographic Learning Facility."  
   Paper presented to the Directors of Vocational Technical Schools,  
   Georgia State Department of Education, Atlanta, Georgia, January  
   3, 1972.

   Paper presented at the IEEE Workshop on Pattern Recognition  
   Applied to Man and His Environment, Hot Springs, Va., February  

4. Jensen, A. P. "Georgia Tech's Audiographic Learning Facility."  
   Paper presented at the Ga. Tech Student Chapter of the ACM,  
   Atlanta, Georgia, February 24, 1972.

5. Jensen, A. P. "Georgia Tech's Audiographic Learning Facility."  
   Paper presented at the March meeting of the Association for  

6. Jensen, A. P. "Data Communications and the Dial Network."  
   Paper presented at the Computer Users Forum and Exposition,  
   sponsored by Computerworld, Atlanta, Georgia, March 15, 1972.

**Published Papers**

   Tape Information Services." In: The Management of Information  
   Council for Science and Technology, 1972 (COSATI Report 72-1),  
   pp. 124-132.

   Tool?" Proceedings-1971 ACM National Conference, Chicago, Illinois,  

9. Slamecka, V. "O modelu powszechnego systemu informacji w  
   zastosowaniu do nauczania" (On the Design of General-purpose  
   Information Systems). Osrodek Dokumentacji i Informacji Naukowej  


Accepted for Publication

ATTACHMENT

B.S. PROGRAM IN INFORMATION AND COMPUTER SCIENCE
B.S. PROGRAM IN INFORMATION AND COMPUTER SCIENCE

Table 1 shows the proposed four-year program of study leading to the designated degree of Bachelor of Science in Information and Computer Science.

The program meets the core curriculum requirements of the University System of Georgia, the Georgia Institute of Technology, and of the Institute's General College. It is in concert with the forthcoming recommendations for academic degree programs (majors) in computer science being formulated by the University System of Georgia Advisory Council (Academic Committee on Computer Science and Systems Analysis). Furthermore, the program follows the standards and recommendations established by the leading professional societies, the Association for Computing Machinery and the American Society of Information Science.

A minimum of 194 credit hours is required for graduation, including 54 hours of electives. It is intended that up to 24 of these elective hours be taken in one of the "areas of concentration", the purpose of which is to provide students with either relatively advanced marketable knowledge and skills, or preparation for graduate work. Examples of the subject areas of concentration are:

- Theory of information processes
- Systems theory
- Theory of problem solving
- Artificial intelligence
- Logic and computability theory
- Linguistics
- Computer systems design
- Software systems design
- Numeric computation
- Natural language processing
- Biomedical information systems
- Learning systems design
- Management information systems design
- Etc.

The program design is highly hospitable to diverse, multidisciplinary educational objectives: Its format permits students to include as free electives "minor" areas of study offered through other departments of the Georgia Institute of Technology; and, with some additional work, to meet the requirements of a "double major".

Table 2 lists undergraduate courses offered by the School of Information and Computer Science. Course outlines are available upon request.
### TABLE 1. Undergraduate Curriculum in Information and Computer Science

#### Freshman Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem 104-5 a)</td>
<td>4-3-5</td>
</tr>
<tr>
<td>Math 107-8-9</td>
<td>5-0-5</td>
</tr>
<tr>
<td>Eng 107-8-9</td>
<td>3-0-3</td>
</tr>
<tr>
<td>P.T. Electives b)</td>
<td>0-4-1</td>
</tr>
<tr>
<td>ICS 110</td>
<td>3-0-3</td>
</tr>
<tr>
<td>ICS 101</td>
<td>2-0-2</td>
</tr>
<tr>
<td>Electives c)</td>
<td>2-0-2</td>
</tr>
<tr>
<td></td>
<td><strong>17-7-19</strong></td>
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</table>

#### Sophomore Year

<table>
<thead>
<tr>
<th>Course</th>
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<tbody>
<tr>
<td>Phys 227</td>
<td>4-3-5</td>
</tr>
<tr>
<td>Phys 228</td>
<td>4-3-5</td>
</tr>
<tr>
<td>Phys 229</td>
<td>4-3-5</td>
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<td>Math 207</td>
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<td>3-0-3</td>
</tr>
<tr>
<td>Ling 303</td>
<td>1-0-1</td>
</tr>
<tr>
<td>ICS 201</td>
<td>3-0-3</td>
</tr>
<tr>
<td>ICS 205</td>
<td>3-0-3</td>
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<tr>
<td>Technical Information Resources</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td><strong>16-3-17</strong></td>
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</tbody>
</table>

#### Junior Year

<table>
<thead>
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<th>Course</th>
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</thead>
<tbody>
<tr>
<td>Math 309</td>
<td>3-0-3</td>
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<tr>
<td>Econ 201-2-3</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Ling 402</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Math 315 d)</td>
<td>5-0-5</td>
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<tr>
<td>ISE 400</td>
<td>3-0-3</td>
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<tr>
<td>ICS 355</td>
<td>3-0-3</td>
</tr>
<tr>
<td>ICS 345</td>
<td>3-0-3</td>
</tr>
<tr>
<td>ICS 301</td>
<td>3-0-3</td>
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<tr>
<td>ICS 302</td>
<td>3-0-3</td>
</tr>
<tr>
<td>ICS 452</td>
<td>3-0-3</td>
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<td>Electives e)</td>
<td>3-0-3</td>
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<tr>
<td></td>
<td><strong>15-0-15</strong></td>
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</tbody>
</table>

#### Senior Year

<table>
<thead>
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<th>Course</th>
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<tr>
<td>ICS 436</td>
<td>3-0-3</td>
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<tr>
<td>ICS 481-2</td>
<td>3-0-3</td>
</tr>
<tr>
<td>ICS 490</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Electives e)</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td><strong>15-0-15</strong></td>
</tr>
</tbody>
</table>

---

a) With the consent of the School, these courses may be substituted by other empirical science courses relevant to the student's program.
b) Two of the following three courses shall be taken: P.T. 102, P.T. 103, P.T. 104. A maximum of 3 credits of Physical Training may be applied toward the B.S. degree.
c) Free elective courses, to be taken at any time during the course of study. If basic ROTC is selected to satisfy these six credit hours, it must be scheduled beginning the first quarter of Freshman year.
d) May be substituted by ISyE 335.
e) Electives in the Junior and Senior year will include 24 credit hours in one of several areas of specialization recommended and approved by the School of Information and Computer Science.
Table 2. Undergraduate Courses in Information and Computer Science

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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</thead>
<tbody>
<tr>
<td>ICS 101</td>
<td>Introduction to Algorithms and Computing</td>
</tr>
<tr>
<td>ICS 110</td>
<td>Information, Computers, Systems: An Introduction</td>
</tr>
<tr>
<td>ICS 145</td>
<td>Fundamentals of Semiotics</td>
</tr>
<tr>
<td>ICS 151</td>
<td>Digital Computer Organization and Programming</td>
</tr>
<tr>
<td>ICS 201</td>
<td>Computer Programming</td>
</tr>
<tr>
<td>ICS 295</td>
<td>Computer Organization and Programming</td>
</tr>
<tr>
<td>ICS 215</td>
<td>Technical Information Resources</td>
</tr>
<tr>
<td>ICS 301</td>
<td>Computer Systems I</td>
</tr>
<tr>
<td>ICS 302</td>
<td>Computer Systems II</td>
</tr>
<tr>
<td>ICS 306</td>
<td>Survey of Programming Languages</td>
</tr>
<tr>
<td>ICS 310</td>
<td>Computer-Oriented Numerical Methods</td>
</tr>
<tr>
<td>ICS 323</td>
<td>Introduction to Cybernetics</td>
</tr>
<tr>
<td>ICS 340</td>
<td>Philosophy of Grammar</td>
</tr>
<tr>
<td>ICS 341</td>
<td>Introduction to Computational Linguistics</td>
</tr>
<tr>
<td>ICS 345</td>
<td>Introduction to Mathematical Logic</td>
</tr>
<tr>
<td>ICS 346</td>
<td>Proof Theory</td>
</tr>
<tr>
<td>ICS 355</td>
<td>Information Structures and Processes</td>
</tr>
<tr>
<td>ICS 404</td>
<td>Topics in Linguistics</td>
</tr>
<tr>
<td>ICS 406</td>
<td>Computing Languages</td>
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<tr>
<td>ICS 407</td>
<td>Data Management Systems</td>
</tr>
<tr>
<td>ICS 408</td>
<td>Introduction to Compilers</td>
</tr>
<tr>
<td>ICS 409</td>
<td>Introduction to Mathematical Linguistics</td>
</tr>
<tr>
<td>ICS 410</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>ICS 411</td>
<td>Artificial Intelligence and Heuristics</td>
</tr>
<tr>
<td>ICS 415</td>
<td>The Literature of Science and Engineering</td>
</tr>
<tr>
<td>ICS 424</td>
<td>Elements of Information Theory</td>
</tr>
<tr>
<td>ICS 426</td>
<td>Theory of Abstract Machines</td>
</tr>
<tr>
<td>ICS 432</td>
<td>Data Communications</td>
</tr>
<tr>
<td>ICS 433</td>
<td>Basic ADP Systems Design</td>
</tr>
<tr>
<td>ICS 436</td>
<td>Information Systems</td>
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<tr>
<td>ICS 437</td>
<td>Science Information Systems</td>
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<tr>
<td>ICS 438</td>
<td>Health Information Processing</td>
</tr>
<tr>
<td>ICS 445</td>
<td>Logistic Systems</td>
</tr>
<tr>
<td>ICS 446</td>
<td>Formal Semantics</td>
</tr>
<tr>
<td>ICS 447</td>
<td>Theory of Computability</td>
</tr>
<tr>
<td>ICS 452</td>
<td>Logic Design and Switching Theory</td>
</tr>
<tr>
<td>ICS 453</td>
<td>Information Storage and Retrieval</td>
</tr>
<tr>
<td>ICS 456</td>
<td>Introduction to Operating Systems</td>
</tr>
<tr>
<td>ICS 458</td>
<td>Computer Systems</td>
</tr>
<tr>
<td>ICS 481</td>
<td>Introduction to Information Processes I</td>
</tr>
<tr>
<td>ICS 482</td>
<td>Introduction to Information Processes II</td>
</tr>
<tr>
<td>ICS 490</td>
<td>Selected Topics in Information and Computer Science</td>
</tr>
<tr>
<td>ICS 495/6/7</td>
<td>Design Project I, II, III</td>
</tr>
</tbody>
</table>
1971/72
ANNUAL SUMMARY REPORT
(Quarterly Administrative Report No. 12)

NSF Grant GN-655

September 25, 1972

Science Information Research Center
School of Information and Computer Science
Georgia Institute of Technology
Atlanta, Georgia 30332
PREFACE

The School of Information and Computer Science, Georgia Institute of Technology, is pleased to submit the administrative portion of its Annual Report on NSF Grant GN-655 (Georgia Tech Science Information Research Center) for the one-year period extending from July 1, 1971 through June 30, 1972.

This report begins with a brief review of the present status of the School's academic programs. Three subsequent sections of the report then review, respectively, selected aspects of the School's research program, research personnel, and project support and expenditures. A bibliography listing administrative reports, proposals, papers presented, published papers, books, research reports and completed theses since July 1, 1971 concludes the report.

Appendix I provides a list of students enrolled in the graduate programs of the School of Information and Computer Science during the 1971/72 fiscal year.


The staff and administrators of the Georgia Tech Science Information Research Center wish to express their grateful appreciation to the Office of Science Information Service, NSF, for its support and interest in the School's research programs.

Vladimir Slamecka
Project Director, Grant GN-655

September 25, 1972
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ATTACHMENT II GRADUATE PROGRAM in BIOMEDICAL INFORMATION and COMPUTER SCIENCE
ATTACHMENT III PROGRAMS and PROCEDURES
ATTACHMENT IV REVIEW OF RESEARCH PROGRESS
ACADEMIC PROGRAMS

The school year 1971/72 marks the ninth year of existence and operation of the graduate School of Information and Computer Science.

Degree Programs and Enrollment. The 1971/72 part-time and full-time enrollment in the degree programs of the School of Information and Computer Science was 252, a 36 per cent increase over the enrollment for 1970/71. Of these students, 152 were enrolled in the School's daytime Master's degree program, 35 in the School's evening Master's degree program, 13 in the School's off-campus Master's program (offered at the Lockheed-Georgia Company in Marietta, Georgia), 35 in the School's Ph.D. program, and 17 in the School's Cooperative College-School Summer Institute.

The School's Elective Undergraduate Curriculum, offered to undergraduate students of the Institute who pursue information and computer science either as an element of their field of study or in preparation for graduate work in ICS, had a total course enrollment of 1,100.

The School awarded a total of 67 Master of Science degrees and 1 Doctor of Philosophy degree during Fiscal Year 1972.

Evening Graduate Program. In response to a large demand from the professional community a part-time evening program leading to the M.S. degree in Information and Computer Science was started in the Winter Quarter 1972. The program, with an initial enrollment of 35, is designed to develop and extend professional competence in the engineering analysis, design and management of advanced information and computer systems. The requirements for the program are identical to the School's regular day-time program.

Off-Campus Graduate Degree Program (Lockheed-Georgia). Fall Quarter 1971 marked completion of the School's Off-Campus Graduate Degree Program at the Lockheed-Georgia Company. Of the 25 employees of the Lockheed-Georgia Company enrolled in the program, 13 successfully completed the requirements and were awarded an M.S. Degree in Information and Computer Science. Two graduate courses per quarter were offered at the Lockheed facilities over a
two-year period beginning with the 1970 Winter Quarter.

Summer Institute in Information and Computer Science. Through the support of the National Science Foundation under Grant GW-6483, the School conducted, in Summer 1971, a second cooperative program with the Atlanta Public School System to prepare high school teachers in the foundations of information and computer science. Under the program, 17 qualified high school teachers of the Atlanta Public School System attended a six-week institute at Georgia Tech. A similar institute was held in the Summer of 1970.

Classroom presentations for the second institute were offered in part via the School of Information and Computer Science Audiographic Learning Facility (ALF).

Continuing Education Courses. Zunde, P., Associate Professor, School of Information and Computer Science.


Graduate Program in Biomedical Information and Computer Science. Beginning Fall Quarter 1972, the School of Information and Computer Science, in association with the Emory University School of Medicine, will implement a joint Graduate Program in Biomedical Information and Computer Science. The program will lead to the degrees of Doctor of Philosophy and Master of Science in Information and Computer Science awarded through the Georgia Institute of Technology.

The Program Director is Dr. Vladimir Slamecka, Director and Professor of the School of Information and Computer Science, and the Emory Coordinator is Dr. Perry Sprawls, Associate Professor of Radiology, Emory University School of Medicine, Atlanta, Georgia.

The new academic program is especially suited to persons holding advanced degrees in medicine, biomedicine or the life sciences who wish to pursue interdisciplinary professional or research careers in biomedical information work or computing.
After graduation, persons holding the professional Master of Science degree may expect to find employment in the design or management of information and computer systems in medical centers and research organizations, hospitals, medical schools, biomedically-oriented hardware and software organizations, and in public health agencies at all levels of government.

Graduates of the research-oriented doctoral program will qualify to pursue careers in academic and research centers, or engage in high level planning and policy-making of health care activities.

The new graduate program is sponsored in part by NIH grant LM 00147 from the National Library of Medicine. The grant provides funds for a limited number of stipends for qualified M.S. and Ph.D. candidates who demonstrate their intention to pursue a career in biomedical information and computer science.

B.S. Degree Program in Information and Computer Science. The School of Information and Computer Science has received approval to offer an undergraduate program leading to the degree of Bachelor of Science in Information and Computer Science. The program and the degree will be offered through the ICS School, beginning Fall Quarter 1972.

The primary objectives of the proposed undergraduate degree program are the following:

1. To provide quality education in response to the determined manpower requirements in the information processing professions in the State of Georgia and nationally:

2. To provide undergraduate education in an important new discipline of science and technology, in agreement with the role of the Georgia Institute of Technology within the University System of Georgia.

3. To strengthen and support educational programs of other academic departments of the Institute in a most cost-effective manner.

4. To improve the quality and level of existing graduate programs of the School of Information and Computer Science.

5. To complete the most comprehensive sequence of educational programs
and opportunities in information and computer science available in the
Southeast.

The B. S. program of the School of Information and Computer Science
will complete a rather unique, coordinated sequence of educational programs
in information and computer science in the Atlanta area, extending from
high school education through a doctoral program. The School of Information
and Computer Science of Georgia Tech was instrumental in developing this
sequence of programs, and assisting in its implementation particularly at
the high school level.

Table 1 provides the estimated enrollment of B. S. majors in information
and computer science at the Georgia Institute of Technology.

Table 1. Majors in Information/Computer Science
Estimated Enrollment, 1972-1976

<table>
<thead>
<tr>
<th>FISCAL YEAR</th>
<th>HEADCOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972/73</td>
<td>50</td>
</tr>
<tr>
<td>1973/74</td>
<td>150</td>
</tr>
<tr>
<td>1974/75</td>
<td>250</td>
</tr>
<tr>
<td>1975/76</td>
<td>400</td>
</tr>
</tbody>
</table>

New Courses. In association with the School's approved B.S. degree in Information
and Computer Science, the following new undergraduate courses were approved
during the 1971/72 fiscal year:

ICS 101 - Introduction to Algorithms and Computing
ICS 145 - Introduction to Semiotics
ICS 201 - Computer Programming
ICS 205 - Computer Organization and Programming
ICS 301 - Computer Systems I
ICS 302 - Computer Systems II
ICS 306 - Survey of Programming Languages

ICS 432 - Data Communications
ICS 433 - Basic ADP Systems Design
ICS 437 - Science Information Systems
ICS 438 - Health Information Processing
ICS 446 - Formal Semantics
ICS 447 - Theory of Computability
ICS 453 - Information Storage and Retrieval
ICS 456 - Introduction to Operating Systems
Summary of ICS Educational Activities and Programs. The following tables provide a statistical review and summary of the educational activities and programs of the School of Information and Computer Science since 1964.

Table 2. ICS Student Enrollment/Degrees Awarded, 1964-1972

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Total Enrollment</th>
<th>Total New</th>
<th>Degrees Awarded</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964/65</td>
<td>30</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>1965/66</td>
<td>38</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>1966/67</td>
<td>65</td>
<td>40</td>
<td>12</td>
</tr>
<tr>
<td>1967/68</td>
<td>108</td>
<td>46</td>
<td>34</td>
</tr>
<tr>
<td>1968/69</td>
<td>157</td>
<td>53</td>
<td>51</td>
</tr>
<tr>
<td>1969/70</td>
<td>155</td>
<td>84</td>
<td>40</td>
</tr>
<tr>
<td>1970/71</td>
<td>185</td>
<td>102</td>
<td>47</td>
</tr>
<tr>
<td>1971/72</td>
<td>252</td>
<td>138</td>
<td>68</td>
</tr>
</tbody>
</table>

Table 2a. Approved ICS Course Offerings, 1964-1972

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Undergraduate</th>
<th>Undergraduate/Graduate</th>
<th>Graduate</th>
<th>Total Number of Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964/65</td>
<td>-</td>
<td>4</td>
<td>13</td>
<td>17</td>
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<tr>
<td>1965/66</td>
<td>-</td>
<td>6</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>1966/67</td>
<td>1</td>
<td>11</td>
<td>21</td>
<td>33</td>
</tr>
<tr>
<td>1967/68</td>
<td>2</td>
<td>12</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>1968/69</td>
<td>3</td>
<td>12</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>1969/70</td>
<td>3</td>
<td>12</td>
<td>37</td>
<td>52</td>
</tr>
<tr>
<td>1970/71</td>
<td>9</td>
<td>13</td>
<td>41</td>
<td>63</td>
</tr>
<tr>
<td>1971/72</td>
<td>40</td>
<td>13</td>
<td>41</td>
<td>94</td>
</tr>
</tbody>
</table>
Table 3. ICS Academic Programs, 1964-1972

<table>
<thead>
<tr>
<th>Program</th>
<th>Degree</th>
<th>Year of Implementation</th>
<th>Enrollment Fall Quarter 1971</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information Systems Engineering</td>
<td>M.S.</td>
<td>1964</td>
<td>38</td>
</tr>
<tr>
<td>Computer Systems Engineering</td>
<td>M.S.</td>
<td>1966</td>
<td>85</td>
</tr>
<tr>
<td>Undergraduate Service Curriculum - 1966</td>
<td>-</td>
<td>1966</td>
<td>1100 (71/72)</td>
</tr>
<tr>
<td>Information and Computer Science</td>
<td>Ph.D.</td>
<td>1968</td>
<td>23</td>
</tr>
<tr>
<td>Off-Campus Program at Lockheed-Georgia Company</td>
<td>M.S.</td>
<td>1970</td>
<td>25 (Winter Quarter 1970)</td>
</tr>
<tr>
<td>Undergraduate Minor in Information and Computer Science</td>
<td>-</td>
<td>1970</td>
<td>30</td>
</tr>
<tr>
<td>Curriculum in Information Sciences for High School Teachers</td>
<td>-(a)</td>
<td>1970</td>
<td>17 (Summer Institute 1971)</td>
</tr>
<tr>
<td>Information/Computer Systems Engineering (evening program)</td>
<td>M.S.</td>
<td>1972</td>
<td>35 (Winter Quarter 1972)</td>
</tr>
<tr>
<td>Graduate Program in Biomedical Communication</td>
<td>M.S.(b)</td>
<td>1967</td>
<td>30 (total graduates)</td>
</tr>
<tr>
<td>Graduate Program in Biomedical Information Science</td>
<td>M.S.(c)</td>
<td>1971/72</td>
<td>20 (est. in 72/73)</td>
</tr>
<tr>
<td>Undergraduate Degree Program in Information/Computer Science</td>
<td>B.S.</td>
<td>1972</td>
<td>50 (est. in 72/73)</td>
</tr>
</tbody>
</table>

(a) Applicable to the M.A. degree in Education.
(b) Offered through a Consortium of universities, administered by Tulane University; ceased 1970.
(c) Jointly with Emory University, School of Medicine.
RESEARCH

The purpose of this section is to report on significant aspects of the School's research activities during the 1971/72 fiscal year, other than projects of the Science Information Research Center.*

March 16-18, 1972 State-of-the-Art Conference on the Use of Computers in Legal Research. A state-of-the-art national conference on contemporary uses of computers in retrieving material for legal research was held on the Georgia Tech campus on March 16-18, 1972. The conference, sponsored jointly by the American Bar Association and the School of Information and Computer Science, had an attendance of over 220. The participants represented commercial, governmental and academic organizations currently engaged in legal research programs using computer techniques. The following topics were covered by invited speakers:

Law Searching by Computer - An Introduction
An Interactive Full-Text Retrieval System (STAIRS)
Justice Retrieval and Inquiry System (JURIS)
Legal Information Thru Electronics (LITE)
Documentation Automatic Text -- University of Montreal (DATUM)
Queen's University Institute for Computing and Law (QUIC/LAW)

In addition the following workshop sessions were held:

Financial Considerations and Feasibility - Bar Associations
Financial Considerations and Feasibility - Private Firms
User Training and Acceptability
Systems Design and Research Techniques

* Attachment IV constitutes a substantive report on the School's research effort supported in part by the grant since July 1, 1971.
The conference, well received by its attendees, was the first national conference bringing together those active in the development of computerized legal research systems and the lawyers and governmental officials who have an interest in using such services. It is the intention of the American Bar Association to hold a second national conference on the Ga. Tech campus.

December 14-16, 1971 Computer Science Conference. A three day conference entitled, "Computer Science: Definition, Direction and Impact," was held on the Georgia Tech campus, December 14 through December 16, 1971. The conference was co-hosted by the School of Information and Computer Science and the Computer Network Committee of the University System of Georgia. The conference, under the direction of Dr. Vladimir Slamecka, Professor and Director, School of Information and Computer Science, was geared for non-computer science faculty members of the University System of Georgia who have been asked to develop, administer, and teach in Computer Science programs.

Faculty members of the School of Information and Computer Science participated in the conference as lecturers.

State of Georgia Government Reorganization Study. The State Government of Georgia called upon the School of Information and Computer Science to provide expertise to assist Governor Carter's state government reorganization team. Mr. Alton P. Jensen, Senior Research Engineer, School of Information and Computer Science, was subsequently appointed to direct the reorganization team's analysis of EDP facilities and operations in the Government and agencies of the State of Georgia. The appointment, without extra compensation, was made effective July 1, 1971. The reorganization study was completed in early October.

Regional Center for Information Science. On July 7, 11, and 12, 1971, Dr. Vladimir Slamecka, Professor and Director, School of Information and Computer Science, presented to the Governor and Community Leaders of Georgia the concept of a "Regional Center for Information Science." On the basis of
the presentation, a State task group was appointed to further investigate the desirability and feasibility of such a center. On August 18, 1971 the task group submitted a proposal to the Governor, highly endorsing the establishment of a "Regional Center for Information Science" in the State of Georgia.

State of Georgia Support for the School's Audiographic Learning Facility (ALF). The State Board of Education of the State of Georgia has authorized payments not to exceed $100,000 for the establishment of an experimental project utilizing the School's audiographic learning technology in secondary education in the State of Georgia. The project will be conducted by the School of Information and Computer Science, under the directorship of Mr. Alton P. Jensen, Senior Research Engineer, School of Information and Computer Science.

The experimental format will include four local school systems and one area vocational-technical school. The project is designed to:

1. Develop standard techniques and procedures for the preparation, recording, and management of learning materials in audiographic form;
2. Introduce audiographic instructions into the classrooms of the selected schools, and make a preliminary assessment of (a) its potential for improving the quality of instruction; (b) its acceptance by and effect on teachers and students;
3. Evaluate these specific technological devices under conditions of extended usage;
4. Assess the associated direct and indirect costs and benefits of audiographic instruction and self-instruction.

The products of the project will be detailed reports documenting the process, instruments and findings of the study.

The project is effective for the period extending from January 1, 1972 through December 31, 1972.
Information Processing Laboratory. No significant changes have been made with respect to the purpose, configuration and operating polices of the Laboratory as originally detailed in the School's published research memorandum, The Laboratory for Information and Computer Science (GITIS-68-01).

A complete list of current equipment, equipment maintenance contracts and equipment rentals associated with the School's Laboratory appears on pp. 25-28 of this report.

Negotiations for expansion of the Laboratory facilities continue, with acceptance of the bid by the Digital Equipment Corporation for a PDP 11/45 computer facility. In addition, the School of Information and Computer Science assumed responsibility for the operation and maintenance of the Georgia Institute of Technology B-5500 Computer System, effective July 1, 1972. The configuration of the system can be found on pp. 25-26 of this report.

Dissemination of Research Results. Table 4 shows the numbers of publications of various types which emanated from the research programs of the School of Information and Computer Science in the period of July 1967-1972. A complete list of references for the 1971/72 fiscal year is in the Bibliography. Publications prior to this time can be found in the Bibliography of the School's Biannual Summary Report (1967/69) and the Annual Summary Reports for fiscal years 1969/70 and 1970/71.

Table 4. Distribution of Research Publications

<table>
<thead>
<tr>
<th>Type of Publication</th>
<th>1967/69</th>
<th>1969/71</th>
<th>1971/72</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Publication in Open Literature</td>
<td>8</td>
<td>17</td>
<td>13</td>
<td>38</td>
</tr>
<tr>
<td>2. Books</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3. Research Reports</td>
<td>9</td>
<td>15</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>4. Internal Research Memorandums</td>
<td>6</td>
<td>6</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>5. Presentation of Papers</td>
<td>5</td>
<td>27</td>
<td>17</td>
<td>49</td>
</tr>
<tr>
<td>6. Thesis</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>7. Proposals</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>8. Administrative Reports</td>
<td>-</td>
<td>8</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>33</strong></td>
<td><strong>80</strong></td>
<td><strong>41</strong></td>
<td><strong>154</strong></td>
</tr>
<tr>
<td>Date</td>
<td>Lecturer</td>
<td>Title</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>August 25, 1971</td>
<td>Dr. Miroslav Valach</td>
<td>&quot;Cybernetics&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Professor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>School of Information and Computer Science</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>September 20, 1971</td>
<td>ICS Senior Faculty</td>
<td>&quot;Research in Information and Computer Science&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ph.D. Candidate</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>School of Information and Computer Science</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>October 14, 1971</td>
<td>ICS Senior Faculty</td>
<td>&quot;Selected Research Areas in Information and Computer Science&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>November 3-4, 1971</td>
<td>Dr. John M. Hoffman</td>
<td>&quot;Use of Monitors in Computer System Evaluation?&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EDP Equipment Office</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L. G. Hanscom Air Force Base</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>November 9, 1971</td>
<td>Dr. Andrew Schoene</td>
<td>&quot;Design of Interactive Systems for Applied Mathematics&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Burroughs Corporation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>November 16, 1971</td>
<td>Mr. Thomas H. Baumgartner</td>
<td>&quot;Exogeneous Scheduling of a Multi-Programmed Computer System&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ph.D. Student</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>School of Information and Computer Science</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>December 30, 1971</td>
<td>Dr. Fred Sias</td>
<td>&quot;Information Systems and Health Care&quot;</td>
<td></td>
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<tr>
<td></td>
<td>Assistant Professor</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Dept. of Physiology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>University of Mississippi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January 11, 1972</td>
<td>Mr. Richard A. DeMillo</td>
<td>&quot;Abstract Computers and the Semantics of Programming Languages&quot;</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Ph.D. Student</td>
<td></td>
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<td>School of Information and Computer Science</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January 13, 1972</td>
<td>Mr. Joseph R. Horgan</td>
<td>&quot;Abstract Computers and Degrees of Unsolvability&quot;</td>
<td></td>
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<td></td>
<td>Ph.D. Student</td>
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<tr>
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<td>Lecturer</td>
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<tr>
<td>February 4, 1972</td>
<td>Dr. Thomas G. Windeknecht</td>
<td>&quot;Mathematical Theory of General Systems&quot;</td>
<td></td>
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<tr>
<td></td>
<td>Professor of Electrical Engineering, Michigan</td>
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<td></td>
<td>Technological University</td>
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<tr>
<td>February 13, 1972</td>
<td>Dr. Vladimir Slamecka</td>
<td>&quot;Programs of the School of Information and Computer Science**</td>
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<tr>
<td></td>
<td>Professor and Director</td>
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<td>February 14, 1972</td>
<td>Dr. William Goffman</td>
<td>&quot;Quantitative Studies in the Development of Science Information&quot;</td>
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<tr>
<td></td>
<td>Dean, School of Library Science, Case Western</td>
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<tr>
<td>February 24, 1972</td>
<td>Mr. Alton P. Jensen</td>
<td>&quot;Audiographic Learning Facilities&quot;</td>
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<tr>
<td></td>
<td>Sr. Research Engineer</td>
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<tr>
<td>March 2, 1972</td>
<td>Mr. Morgan L. Stapleton</td>
<td>&quot;An Experimental Methodology Utilizing Semantic Measures of Informa-</td>
<td></td>
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<tr>
<td></td>
<td>Ph.D. Student</td>
<td>tion with Application to the Processing of Grammatical Transformations</td>
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<td>March 6, 1972</td>
<td>Dr. Chan Mo Park</td>
<td>&quot;Biomedical Information Processing Systems&quot;</td>
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<tr>
<td></td>
<td>Assistant Professor</td>
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<td>Computer Science Center</td>
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<td></td>
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<tr>
<td>March 28, 1972</td>
<td>Dr. Vladimir Slamecka</td>
<td>&quot;Manpower Assessment and the Professional Challenge&quot;***</td>
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<td>Professor and Director</td>
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<td>March 29, 1972</td>
<td>Dr. Miroslav Valach</td>
<td>&quot;A Method for the Determination of Isomorphic Structures&quot;</td>
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<tr>
<td></td>
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<td>School of Information and Computer Science</td>
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<td>March 31, 1972</td>
<td>Mr. Stephen R. Kennedy</td>
<td>&quot;The Interface Between Operations Research and Information Processing&quot;</td>
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<tr>
<td></td>
<td>Ph.D. Candidate</td>
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* Radio Broadcast, WGST, Atlanta, Georgia
**Panel Discussion, Atlanta ACM Section of the Mid-Southeast Chapter
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<tr>
<th>Date</th>
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<tr>
<td>April 12, 1972</td>
<td>Dr. Miroslav Valach Professor School of Information and Computer Science</td>
<td>&quot;Structural Properties of Boolean Expressions&quot;</td>
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<tr>
<td>April 24, 1972</td>
<td>Mr. Edgar M. Pass Ph.D. Student School of Information and Computer Science</td>
<td>&quot;An Adaptive Micro-scheduler for a Multi-programmed Computer System&quot;</td>
</tr>
<tr>
<td>May 9, 1972</td>
<td>Dr. James W. Sweeney Professor Information and Computer Science University of Oklahoma</td>
<td>&quot;Biomedical Information Systems&quot;</td>
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</table>
The research activities of the Science Information Research Center at the Georgia Institute of Technology, supported by NSF Grant GN-655, continue to be directed and administered by the School of Information and Computer Science.

As detailed in the previous annual reports, the Director of the School, Dr. Vladimir Slamecka, serves formally as head of the Research Center reporting directly to the Dean of the General College. Individual research topics and projects of the Center are under the immediate direction of respective principal investigators who report to Dr. Slamecka.

**Faculty and Staff**

Following is a list of faculty and staff members associated with the School of Information and Computer Science and supported in part by NSF Grant GN-655 during the 1971/72 fiscal year.

<table>
<thead>
<tr>
<th>Professor &amp; Director</th>
<th>Area of Research Interest</th>
<th>EFT*</th>
<th>GIT</th>
<th>NSF</th>
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<tr>
<td>Slamecka, Vladimir</td>
<td>Science information systems; educational technology</td>
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<tr>
<th>Professor</th>
<th>Area of Research Interest</th>
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<tbody>
<tr>
<td>Chiaraviglio, Lucio</td>
<td>Mathematical logic; theory of computing</td>
<td>.25</td>
<td>.52</td>
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<tr>
<td>Gough, James, Jr.</td>
<td>Semiotics; linguistics; models of grammar</td>
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<td>Valach, Miroslav</td>
<td>Cybernetics; computer architecture</td>
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<th>Associate Professor</th>
<th>Area of Research Interest</th>
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<th>GIT</th>
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<tr>
<td>Siegmann, Philip J.</td>
<td>Human learning; theory of information processes</td>
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<tr>
<td>Zunde, Pranas</td>
<td>Theory of information systems and processes; systems engineering</td>
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*1.00 EFT equals full-time for one fiscal year*
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<thead>
<tr>
<th>Assistant Professor</th>
<th>Area of Research Interest</th>
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<th>NSF</th>
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<tbody>
<tr>
<td>Goda, John, J., Jr.</td>
<td>Computer programming systems and languages; engineering applications of computing</td>
<td>-</td>
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<tr>
<td>Gwynn, John M., Jr.</td>
<td>Automata theory; theory of computer languages</td>
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<tr>
<td>Grosky, William I.</td>
<td>Automata theory; logic</td>
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<td>Kelly, Michael D.</td>
<td>Artificial intelligence; image processing</td>
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<td>.21</td>
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<td>Kraus, David H.</td>
<td>Linguistics; comparative structures of natural language</td>
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<td>.61</td>
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<tr>
<td>Rogers, David E.</td>
<td>Computational linguistics; programming languages; information storage and retrieval</td>
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<td>.33</td>
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</table>

<table>
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<tr>
<th>Senior Research Engineer</th>
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<tbody>
<tr>
<td>Jensen, Alton P.</td>
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</table>

<table>
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<th>Assistant Research Engineer</th>
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<tbody>
<tr>
<td>Hankamer, Philip C.</td>
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<td>Hooper, Charles H.</td>
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<table>
<thead>
<tr>
<th>Miscellaneous Professional</th>
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<tbody>
<tr>
<td>Gehl, John M.</td>
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<table>
<thead>
<tr>
<th>Administrative Specialist</th>
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<tbody>
<tr>
<td>Rumiano, Edmond F.</td>
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</table>

<table>
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<th>Graduate Research Assistant</th>
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<tbody>
<tr>
<td>Baird, Michael</td>
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<td>Basu, Saurinda M.</td>
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<tr>
<td>DeMillo, Richard A.</td>
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<td>Deimel, Lionel E.</td>
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<td>Dexter, Margaret E.</td>
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<td>Dunlavey, Michael R.</td>
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<td>Gayle, T. Vincent</td>
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<td>Norem, Julia A.</td>
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<td>Saulnier, Bruce M.</td>
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<td>Stapleton, Morgan L.</td>
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<td>VanWolkenten, R. V.</td>
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**Principal Secretary**

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<td>Champaign, Adele L.</td>
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**Secretary**

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<td>Childs, Judith K.</td>
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**Report Typist**

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<td>Pefley, Linda D.</td>
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**Student Assistant**

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**Miscellaneous Nonprofessional**

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<td>(Clerical, keypunching, etc.)</td>
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Senior Research Personnel

The following biographical sketches describe senior faculty members of the Georgia Institute of Technology who participated in the research effort in information science and engineering as funded under NSF Grant GN-655 for the period extending from July 1, 1971 through June 30, 1972. The alphabetically arranged list is incomplete with respect to the collaborating resident junior faculty and graduate students.

LUCIO CHIARAVIGLIO, Professor of Information and Computer Science. Dr. Chiaraviglio holds the M.A. degree (University of Chicago, 1956) and the Ph.D. degree (Emory University, 1961) in philosophy and mathematical logic. Dr. Chiaraviglio has been associated with the School of Information and Computer Science since 1967. His previous appointments include faculty positions at Emory University and the University of Delaware. His current research is in mathematical logic, semiotics, computer science, and metascience. In these areas, Dr. Chiaraviglio has published papers in English, Italian, Spanish, and French.

JAMES GOUGH, JR., Professor of Information and Computer Science. Dr. Gough received his A.M. and Ph.D. degrees in linguistics from Harvard University in 1953 and 1965, respectively. He has worked and taught in the field of linguistics since 1953. Previous appointments of Dr. Gough included that of Research Translator, American Meteorological Society; and Assistant Professor, Department of Modern Languages, Georgia Institute of Technology. His present interests are in the fields of semiotics and the structure of natural language, particularly that of the English noun phrase. Dr. Gough is the author of several publications in the area of linguistics.

WILLIAM I. GROSKY, Assistant Professor of Information and Computer Science. Dr. Grosky joined the staff of the School of Information and Computer Science on September 1, 1971, as a full-time Assistant Professor of Information and Computer Science. Dr. Grosky received his M.S. degree in applied mathematics from Brown University in 1968, and his Ph.D. in engineering and applied science from Yale University in 1971. His present interests are in the fields of computability theory, automata theory, and mathematical logic.

JOHN M. GWYNN, JR. Assistant Professor of Information and Computer Science and Mathematics

Dr. Gwynn received his M.A. and Ph.D. degrees in mathematics from the University of North Carolina in 1959 and 1968, respectively. He joined
John M. Gwynn, Jr. (cont'd.)
the faculty of the School of Information and Computer Science in 1964; previous appointments include teaching in the School of Mathematics, and a position of Research Scientist at the Rich Electronic Computer Center, Georgia Institute of Technology. Dr. Gwynn interests have moved from numerical computation to automata theory and the design of higher-level computer languages.

ALTON P. JENSEN, Senior Research Engineer, Information and Computer Science
Mr. Jensen holds a B.S. degree in mechanical engineering, awarded in 1956, and an M.S. degree (pending) in information and computer science, both from the Georgia Institute of Technology. He has been associated with the field of computing and computer applications since 1956; in his previous position, Mr. Jensen served as associate head of the Rich Electronic Computer Center at the Georgia Institute of Technology. Current interests of Mr. Jensen are research in advanced computing concepts and applications, and the design and management of information utilities. Mr. Jensen is consultant to numerous industrial, governmental and educational agencies in the Southeast and in South America. He has authored or co-authored various technical reports in the field of computing.

MICHAEL D. KELLY, Assistant Professor of Information and Computer Science
Dr. Kelly received his M.S. and Ph.D. degrees in computer science from Stanford University in 1967 and 1970, respectively, and has been associated with the field of computer science since 1960. Prior to entering Stanford University he served as a Systems Analyst/Programmer with Datafax Corporation, and IBM Corporation. His present interests are in the fields of artificial intelligence and computer picture processing.

DAVID H. Kraus, Assistant Professor of Information and Computer Science
Mr. Kraus received his M.A. degree in linguistics from Harvard University in 1946. He has been associated with the field of comparative linguistics since 1946; his more recent interests are with the intellectual processes of human translation and their algorithmization, and he was employed as Manager of Scientific Translation Services with the Meteorological Society. In the School of Information and Computer Science Professor Kraus is engaged in the synchronic study of the language of Russian science and technology, with the view toward an efficient design of such languages from the vernacular. He is fluent in the languages and scientific terminologies of the following: Polish, Czech, Hungarian, Serbo-Croatian, Bulgarian, Slovak, Ukrainian and Romanian.

DAVID E. ROGERS, Assistant Professor of Information and Computer Science
Dr. Rogers received his M.S. degree in Russian from Georgetown University in 1966, and his Ph.D. degree in linguistics from the University of Michigan.
David E. Rogers (cont'd.)
in 1969. Dr. Rogers has been associated with the fields of linguistics
and natural language processing systems since 1964. He served as
Senior Systems Service Representative with Honeywell EDP prior to
entering the University of Michigan in 1965 as a full-time Ph.D. stu-
dent. His present interests are in the fields of programming languages,
grammars of natural languages, and computer-based question and answer
type processing systems.

PHILIP J. SIEGMANN, Associate Professor of Information and Computer
Science.
Dr. Siegmann received his M.A. and Ph.D. degrees in psychology from
Ohio State University in 1951 and 1954, respectively. Prior to his
appointment in the School of Information and Computer Science, Dr.
Siegmann served as Executive Editor, Psychological Abstracts, American
Psychological Association. As Executive Editor, Dr. Siegmann contributed
significantly to the design and development of an information storage
and retrieval system for psychological abstracts. His current interest
is concerned with behavioral research in aspects of science information
systems and scientific communications. Dr. Siegmann has published
articles in the areas of psychological abstracts and information dis-
semination.

VLADIMIR SLAMECKA, Professor of Information and Computer
Science
Dr. Slamecka's education in chemical engineering at the University of
Technology (Brno, Czechoslovakia) was followed by postgraduate work
in mathematics and philosophy at the University of Sydney (Australia)
and University of Munich (Germany) in 1951-56. He also earned the
M.S. and D.L.S. degrees from Columbia University, New York, in 1958
and 1962, respectively. Dr. Slamecka serves as Director of the School
of Information and Computer Science, Georgia Institute of Technology.
Previous appointments included: Fulbright Professor, University of
Innsbruck; Manager, Cancer Chemotherapy National Service Center,
Bethesda, Md.; Manager, Special Studies Division, Documentation
Incorporated (Leasco Systems and Research), Bethesda, Md.; and lec-
turer, School of Engineering, Columbia University, New York. As
Director of the School of Information and Computer Science, Dr. Slamecka
has the over-all responsibility for the development and implementation
of academic and research programs of this graduate department. His own
research interests have been in the design and management of large
information systems; man-machine information processing techniques;
planning and management of science on the national level; and information
systems in education. Dr. Slamecka is a member of Sigma Xi, ACM, ASIS,
ACS; the author/editor of five monographs and over thirty-five papers,
and a holder of several patents; and listed in American Men of Science,
Who's Who in America, etc.

MIROSLAV VALACH, Professor of Information and Computer
Science
Dr. Valach received his M.S. degree from Engineering University in
Prague in 1951, and his Ph.D. in mathematics from Czechoslovak Academy
of Science in 1958. He has worked and taught in the field of computer
hardware and software since 1955. Previous appointments of Dr. Valach

-19-
Miroslav Valach (cont'd.)
include that of lecturer at the Engineering University in Prague,
Charles University in Prague and the School of Economics (Prague
and Bratislava). In addition, Dr. Valach served as Head of the
Peripheral Equipment Department of the Research Institute of Mathe-
matical Machines in Prague, and as consulting engineer in the Computer
Equipment Department of the General Electric Company in Phoenix,
Arizona from 1965 to 1969. Dr. Valach's current research is in
information processing machines, cybernetics, and artificial intelli-
genue. Dr. Valach is the author and co-author of two books and has
published over 16 technical papers.

PRANAS ZUNDE, Associate Professor of Information and Computer
Science and Industrial and Systems Engineering
Dr. Zunde holds a degree in mechanical engineering from the Uni-
versity of Hannover, West Germany (1947); an M.S. in applied science
and engineering from George Washington University in Washington, D. C.
(1965); and the Ph.D. in industrial engineering from Georgia Institute
of Technology (1968). Dr. Zunde has been associated with the School
of Information and Computer Science since 1965; his previous appointments
include: Senior Research Scientist, Engineering Experiment Station, Georgia
Institute of Technology; and Director of the Management Information Cen-
ter, Documentation Incorporated. Dr. Zunde's current research lies in
general systems theory, theory of information systems design, and in
mathematical studies of information processes and systems. He
has published over thirty-five papers.

Faculty/Staff Development

Table 5 provides a statistical overview of the development of the
School's faculty and staff since 1964.

Table 5. Faculty/Staff Development 1964-1972

<table>
<thead>
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<th>Fiscal Year</th>
<th>Equivalent Full-Time (1.00 equals Full-Time for 1 fiscal year)</th>
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<td>1972/73(est)</td>
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PROJECT SUPPORT/EXPENDITURES*

This section of the report summarizes the financial budget of NSF Grant GN-655, and it gives a detailed account of the manpower, equipment, and travel budgets and expenditures of the grant as of July 1, 1972. Expenditures for supplies and computer time are not detailed.

Financial

On May 15, 1972, the School of Information and Computer Science requested an approval for a minor modification of the Grant budget. The modifications are detailed in Table 6.


<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Total Award July 1967-June 1972</th>
<th>Requested Modifications Increase</th>
<th>Requested Modifications Decrease</th>
<th>Modified Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaries and Wages</td>
<td>$683,902</td>
<td>$29,773</td>
<td>$713,675</td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent Books</td>
<td>84,770</td>
<td></td>
<td>$44,798</td>
<td>39,972</td>
</tr>
<tr>
<td>Books</td>
<td>2,000</td>
<td>1,945</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Expendable Supplies**</td>
<td>86,302</td>
<td></td>
<td></td>
<td>86,302</td>
</tr>
<tr>
<td>Travel</td>
<td>13,000</td>
<td></td>
<td></td>
<td>13,000</td>
</tr>
<tr>
<td>Computer Time</td>
<td>19,326</td>
<td></td>
<td></td>
<td>19,326</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$889,300</td>
<td>$29,773</td>
<td>$46,743</td>
<td>$872,330</td>
</tr>
<tr>
<td>Overhead (57% of Salaries and Wages)</td>
<td>$389,824</td>
<td></td>
<td>$16,970</td>
<td>406,794</td>
</tr>
<tr>
<td>Retirement (7.75% of Applicable Salaries and Wages)</td>
<td>10,701</td>
<td></td>
<td></td>
<td>10,701</td>
</tr>
<tr>
<td>Total</td>
<td>$1,289,825</td>
<td>$46,743</td>
<td>$46,743</td>
<td>$1,289,825</td>
</tr>
</tbody>
</table>

* The data in this section is based on departmental records of the School, not on the official records of the Georgia Institute of Technology.
** Includes Publication Costs.
This shift of grant funds was approved by NSF on May 31, 1972. The modifications did not affect the total grant award or the total amount to be contributed by the Georgia Institute of Technology, and were required to permit the Science Information Research Center to obtain and utilize institutional, non-recurrent funds which the Institute is prepared to commit to this research program in FY 1973. Tables 7 and 8 incorporate the above modifications and show, respectively, the final NSF and GIT grant category allocations along with the expended and balance of funds in each of these categories as of July 1, 1972.

Table 7. GN-655 Financial Summary (NSF Funding) (July 1, 1967 - June 30, 1972)

<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Funding</th>
<th>Expenditures/Encumbrances</th>
<th>Balance as of July 1, 1972</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1967/69</td>
<td>1969/71</td>
<td>1971/72</td>
</tr>
<tr>
<td>Salaries &amp; Wages</td>
<td>$710,675</td>
<td>$155,077</td>
<td>$300,867</td>
</tr>
<tr>
<td></td>
<td>3,000*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent Equipment</td>
<td>39,972</td>
<td>14,264</td>
<td>25,708</td>
</tr>
<tr>
<td>Books</td>
<td>55</td>
<td>26</td>
<td>29</td>
</tr>
<tr>
<td>**Expendable Supplies</td>
<td>51,012</td>
<td>6,746</td>
<td>27,043</td>
</tr>
<tr>
<td></td>
<td>35,290*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel</td>
<td>13,000</td>
<td>4,150</td>
<td>3,282</td>
</tr>
<tr>
<td>Computer Time</td>
<td>19,326</td>
<td>4,514</td>
<td>5,906</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$872,330</td>
<td>$184,777</td>
<td>$362,835</td>
</tr>
<tr>
<td>Overhead (57% of Salaries and Wages)</td>
<td>405,084</td>
<td>88,394</td>
<td>171,463</td>
</tr>
<tr>
<td>Retirement (7.65% of Applicable Salaries &amp; Wages)</td>
<td>1,710*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research Planning Study</td>
<td>10,701</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>$1,289,825</td>
<td>$273,171</td>
<td>$534,298</td>
</tr>
</tbody>
</table>

* Includes publication costs.
<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Contribution</th>
<th>Actual Contribution</th>
<th>Total</th>
<th>Balance as of July 1, 1972</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1967/69</td>
<td>1969/71</td>
<td>1971/72</td>
<td></td>
</tr>
<tr>
<td>Salaries &amp; Wages</td>
<td>$413,315</td>
<td>$141,027</td>
<td>$180,288</td>
<td>$92,000</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent Books</td>
<td>81,780</td>
<td>81,780</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Expendable Supplies</td>
<td>17,787</td>
<td>1,939</td>
<td>10,848</td>
<td>5,000</td>
</tr>
<tr>
<td>Travel</td>
<td>5,522</td>
<td>-</td>
<td>3,522</td>
<td>1,000</td>
</tr>
<tr>
<td>Computer Time</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$518,404</td>
<td>$224,746</td>
<td>$194,658</td>
<td>$98,000</td>
</tr>
<tr>
<td>Overhead (57% of Salaries &amp; Wages)</td>
<td>235,590</td>
<td>80,386</td>
<td>102,764</td>
<td>52,440</td>
</tr>
<tr>
<td>Retirement (7.65% of Applicable Salaries &amp; Wages)</td>
<td>5,753</td>
<td>-</td>
<td>5,753</td>
<td>5,753</td>
</tr>
<tr>
<td>Grand Total</td>
<td>$759,747</td>
<td>$305,132</td>
<td>$297,422</td>
<td>$156,193</td>
</tr>
</tbody>
</table>

This analysis does not show the additional matching contribution by the Georgia Institute of Technology in the amount of $104,000 toward the purchase, through its library, of library materials related to information and computer science during the first four year period of the grant.

Includes publication costs.

As Table 7 shows, the unexpended NSF funds available as of July 1, 1972 amounts to $258,727. The School requested an extension of the Grant for the period of one year beginning July 1, 1972, without additional funding, to permit the Center to meet its remaining research commitments under the Grant and to provide for an even development of the Science Information Research Center. The request was subsequently approved by the National Science Foundation on May 31, 1972.
Manpower

Table 9 compares the planned 5-year manpower effort under NSF Grant GN-655 against the actual expended manpower as of July 1, 1972 (in terms of EFT*).

Table 9. Comparison of Planned and Expended Manpower (GN-655)
(July 1, 1967 - June 30, 1972)

<table>
<thead>
<tr>
<th>Manpower Category</th>
<th>GN-655 Budget EFT**</th>
<th>1967/69</th>
<th>1969/71</th>
<th>1971/72</th>
<th>Total</th>
<th>Balance as of July 1, 1972</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Investigator</td>
<td>2.80</td>
<td>1.13</td>
<td>1.75</td>
<td>.50</td>
<td>3.38</td>
<td>(.58)***</td>
</tr>
<tr>
<td>Faculty Associate</td>
<td>34.80</td>
<td>12.73</td>
<td>12.37</td>
<td>8.16</td>
<td>33.26</td>
<td>1.54</td>
</tr>
<tr>
<td>Non-Faculty Professionals (Other)</td>
<td>21.00</td>
<td>2.36</td>
<td>7.98</td>
<td>.63</td>
<td>10.97</td>
<td>10.03</td>
</tr>
<tr>
<td>Graduate Students</td>
<td>17.50</td>
<td>5.09</td>
<td>8.00</td>
<td>5.00</td>
<td>18.09</td>
<td>(.59)***</td>
</tr>
<tr>
<td>Pre-Baccalaureate Students</td>
<td>3.00</td>
<td>.07</td>
<td>1.03</td>
<td>.51</td>
<td>1.61</td>
<td>1.39</td>
</tr>
<tr>
<td>Technical</td>
<td>2.00</td>
<td>.29</td>
<td>1.94</td>
<td>-</td>
<td>2.23</td>
<td>(.23)***</td>
</tr>
<tr>
<td>Secretary/Clerical</td>
<td>12.50</td>
<td>3.65</td>
<td>5.37</td>
<td>2.36</td>
<td>11.38</td>
<td>1.12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>93.60</td>
<td>25.32</td>
<td>38.44</td>
<td>17.16</td>
<td>80.92</td>
<td>12.68</td>
</tr>
</tbody>
</table>

* 1.00 indicates Full-Time for one fiscal year.
** Includes Georgia Tech matching contribution, and the May 1972 approved transfer of Equipment monies into Personal Services ($29,773 @ 2.10 EFT). Does not include .50 EFT budgeted for the Research Planning Study.
*** Overexpenditure
Equipment

As of July 1, 1972, the equipment budget of the NSF portion of Grant GN-655 had a free balance of $.00. As its matching contribution to the Grant, the Georgia Institute of Technology has expended toward equipment $81,780.

Following is a detailed list of equipment and equipment maintenance and rental contracts associated with the School's Science Information Research Center as of July 1, 1972.

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Units</th>
<th>Description</th>
<th>Amount Expended/Encumbered</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>PDP-8/I Digital Computer with:</td>
<td>$70,739</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) MC8/I Memory Extension Control</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) KE8/I Automatic Multiply/Divide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) DM01 Data Channel Multiplexer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) RF08 Disk Control</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) RS08 Disk File</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) TC01 Dectape Control</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) TU55 Dectape Transports</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) KW8/IE Real Time Clock</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) VD8/I Display with 611 Scope</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) AF01A A/D Converter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) A121 Multiplexer Switch</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) AA01 D/A Converter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) PT08/C Dual Channel Serial</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) PT08/F Line Interface with EIA Adaptor</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) PC01I</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) DP01A Reader &amp; Punch</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) PT08X</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) ASR 33 Teletype Console Unit</td>
<td></td>
</tr>
</tbody>
</table>

2 1 Burroughs B-5500

(2) Central Processors
(8) Core Modules of 4,096 forty-eight bit words each (32,768 48 bit words)

Transferred
From Rich Electronic Computer Center
<table>
<thead>
<tr>
<th>Item No.</th>
<th>Units</th>
<th>Description</th>
<th>Amount Expended/Encumbered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grant GN-655</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NSF</td>
</tr>
<tr>
<td>(2)</td>
<td>Data communication telephone line adapters for Models 33 and 35 teletype remote terminals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3)</td>
<td>High Speed Disk Storage Modules (9.6 million characters each)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4)</td>
<td>I/O Channels (fully floating)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10)</td>
<td>Magnetic Tape Transports, 200 and 556 bits per inch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>High Speed Card Readers, 1400 cards per minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>High Speed Line Printers, 1040 lines per minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Card Punch, 300 cards per minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>PDP-11/45 CA (On Order)</td>
<td>-</td>
</tr>
<tr>
<td>(2)</td>
<td>Blocks &amp; K Words, Type MM11-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>MOS Memory Control MS11-8C plus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>KW11-P Real Time Clock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>KW11-L Line Frequency Clock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Read Only Memory-Type MR11-A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Teletypewriter Control Console</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Bulk Storage-Type RK11-CA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>General Purpose Interface Boards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>DC11-AB Dual Clock and System Unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>DC11-DA Full Duplex Serial Module Set</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Teletype (ASR 33) - Terminal System With ADC 260 Acoustic Data Coupler</td>
<td>2,037</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Teletype (Inktronic) Receive Only Printer</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Motorola (MDR-1000) Document Reader</td>
<td>4,985</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Bolt, Beranck &amp; Newman (800A) 17&quot; x-y Analog Recorder</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>Model GP-1 Grap/Pen (14&quot; x 14&quot;)</td>
<td>2,900</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>IBM (A-22-09) Keypunch</td>
<td>3,385</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>IBM 2741 Model 1-APL Terminal with Dial Up &amp; Interrupt</td>
<td>3,649</td>
</tr>
<tr>
<td>Item No.</td>
<td>Unit</td>
<td>Description</td>
<td>Amount Expended/Encumbered</td>
</tr>
<tr>
<td>---------</td>
<td>------</td>
<td>-------------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grant GN-655</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>4½ Digit 2400 Series Digital Multimeters (Model) 2440</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>Tektronic Storage Display Unit (611)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>DEC Advanced Logic Laboratory</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>Tektronic (422AC) Oscilloscope</td>
<td>1,460</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>Senior (FE 149) Volt Meter</td>
<td>123</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>10 Hz-80 MHz Frequency Counter</td>
<td>352</td>
</tr>
<tr>
<td>17</td>
<td>12</td>
<td>Model 501 Audiographic Tape Recorder/Player Unit</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>Wallensak Stereo Cassette Tape Recorder/Player</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>9</td>
<td>Sony (TC-666D) Tape Recorder</td>
<td>2,738</td>
</tr>
<tr>
<td>20</td>
<td>8</td>
<td>Revox Model 4 Tr (1104) Tape Recorder</td>
<td>4,120</td>
</tr>
<tr>
<td>21</td>
<td>17</td>
<td>Electrowriter Verb Receivers</td>
<td>5,080</td>
</tr>
<tr>
<td>22</td>
<td>16</td>
<td>Electrowriter Verb Projectors</td>
<td>2,440</td>
</tr>
<tr>
<td>23</td>
<td>14</td>
<td>Electrowriter Transmitters</td>
<td>2,200</td>
</tr>
<tr>
<td>24</td>
<td>1</td>
<td>Cartridge Deck Preamp (#15A7440U)</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>Allied Amplifier (#3246T)</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>Stereo Cassette Recorder/Player (Viking)</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>1</td>
<td>Setchell-Carlson Video/Audio 22&quot; Black/White Monitor</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>1</td>
<td>VCK 2100 Sony TV Camera Ensemble</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>1</td>
<td>Sony 1/2&quot; Video Tape Deck #AV 3600</td>
<td>601</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>Tactile Receptor for the Blind</td>
<td>1,594</td>
</tr>
<tr>
<td>31</td>
<td>1</td>
<td>Friden (132) Electronic Calculator</td>
<td>1,678</td>
</tr>
<tr>
<td>32</td>
<td>-</td>
<td>Books</td>
<td>55</td>
</tr>
<tr>
<td>33</td>
<td>-</td>
<td>Miscellaneous Equipment and Equipment Charges (Transportation, earphones, etc.)</td>
<td>630</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>40,027</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Expenditures/Encumbrances</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equipment Budget</td>
<td>40,027</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balance as of July 1, 1972</td>
<td>00</td>
</tr>
</tbody>
</table>
Table 11. Equipment Maintenance Contracts

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Units</th>
<th>Item Description</th>
<th>12 Month Maintenance Contract</th>
</tr>
</thead>
<tbody>
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Total Yearly Laboratory Equipment Maintenance $32,231

Table 12. Equipment Rental Contracts

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Total Yearly Laboratory Equipment Rental $2,516
Travel

As of July 1, 1972, the travel budget of the NSF portion of Grant GN-655 had a free balance of $3,943; the Georgia Institute of Technology matching contribution to the travel budget of the Grant had a free balance of $1,000. All travel charged against the NSF portion of the Grant was domestic. The purpose of the travel expenditures fell into the following categories: (1) appointments of the Project Director at the Foundation; (2) presentation of papers at national meetings of major associations; (3) attendance of regional meetings of professional associations; and (4) travel associated with activities of selected research and development projects.
BIBLIOGRAPHY
(July 1, 1971 - June 30, 1972)

Administrative Reports


2. "Quarterly Administrative Report No. 9, NSF Grant GN-655." Atlanta, Ga., Georgia Institute of Technology (School of Information and Computer Science), October 1, 1971. 10 p. (Administrative report to Dr. Edward C. Weiss, NSF).


Proposals

5. "Georgia Institute of Technology, Science Information Research Center." Atlanta, Ga., Georgia Institute of Technology (School of Information and Computer Science), May 1972. (Proposal to NSF requesting an extension of NSF Grant GN-655 for the period of one year beginning July 1, 1972, without additional funding).

Papers Presented


Published Papers


Books


Research Reports


Thesis


Patents

Invention Disclosure NSF-71-22-GN-655, "Phase-Lock Flutter Compensator."
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-5-
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QUARTERLY ADMINISTRATIVE REPORT
NO. 14
NSF GRANT GN-655

(October - December 1972)

School of Information and Computer Science
Georgia Institute of Technology
Atlanta Georgia 30332
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INTRODUCTION

The School of Information and Computer Science is pleased to submit its fourteenth quarterly administrative report under NSF Grant GN-655 covering the 3 month period extending from October 1 to December 31, 1972.

The report begins with a review of selected activities. Two subsequent sections of the report then review senior project personnel and project support and expenditures. A list of published reports and presentations supported in part by the Grant since October 1, 1972 concludes the report.
RESEARCH

The purpose of this section is to report on significant aspects of the School's research activities during the period October 1, 1972 thru December 31, 1972. Published reports for the period covered by the report and supported in part by NSF Grant GN-655 are listed on page 10.

Assignment of New Facilities to House the Research and Educational Activities of the School of ICS. The Institute has assigned to the School of Information and Computer Science new facilities in which to house its research and educational activities. The facilities (20,700 sq. ft.) are located in the recently completed new computer center and the immediately adjacent Hinman Building. They provide for:

1) A Centralized Computer Room (5,900 sq. ft.)
2) Administrative Offices (3,700 sq. ft.)
3) Faculty Offices, Lounge and Conference Room (11,100 sq. ft.)

Full occupancy is expected by July 1, 1973.

New Research Projects

General Dynamical Processes. The National Science Foundation has awarded the School of Information and Computer Science a grant of $14,000 to continue studies in the theory of general dynamical processes. This continuing research, previously funded by the National Science Foundation under grants GK-1394 and GK-13300 at Case Western Reserve University and GK-29023 at Michigan Technological University, is concerned with a mathematical approach to general systems theory using axiomatic set theory. The project will continue to develop the theory of general dynamical processes in two specific directions: 1) to unify and expand the existing theory of stereotype voting groups; and 2) to introduce within the established set-theoretic
formalism an axiomatic formulation of computing processes including the
elementary theory of recursive functions and sets, unsolvable problems, and
abstract computability.

The project is under the directorship of Dr. Thomas G. Windeknecht,
Professor of Information and Computer Science, Georgia Institute of
Technology, and is effective for the period from January 1, 1973 to June 30,
1974. Dr. Windeknecht previously served as Principal Investigator of this
research effort at Case Western Reserve University and Michigan Technological
University.

A Paradigm for Semantic Picture Recognition (Ph.D. Thesis Proposal). A "semantic" approach to picture processing by computer is proposed which is intended to overcome some of the limitations of current (syntactic, linguistic, grammar-based) approaches to picture processing. The dissertation research consists of (1) an analysis of the limitations of current picture recognition techniques, (2) the development of a new "semantic" paradigm which would conceptually overcome these limitations, and (3) an evaluation of the semantic paradigm through its application to several interesting and complex recognition problems. These problems involve (1) ambiguity of shape, (2) non-pictorial paraphrase, (3) non-ideal data, and (4) multistability in perception, each of which, it is found, cannot be adequately treated using current picture processing techniques. A solution to these problems based upon the general semantic paradigm will represent a significant contribution to the field. (M. L. Baird/M. D. Kelly).

Information Processing Laboratory

As described on page 2 of this report the School of Information and
Computer Science has been allocated 5,900 sq. ft. of floor space to house its computing laboratory. Occupancy of this space (located in Institute's new computer center) is scheduled for early Spring 1973.

The School has received shipment of its PDP 11/45 computer system. This system, as well as the School's Burroughs B-5500 and PDP 8/I, will
housed in the new computer facilities.

A complete list of current equipment, equipment maintenance contracts and equipment rentals associated with the School's Laboratory appears on pages 25 through 28 of the 1971/72 Annual Administrative Report, NSF Grant GN-655.

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<td>October 3, 1972</td>
<td>ICS Faculty</td>
<td>&quot;Selected Research Areas in Information and Computer Science&quot;</td>
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<tr>
<td>October 17, 1972</td>
<td>Dr. Laurent Siklosy Professor of Computer Science, University of Texas</td>
<td>&quot;Topics in Model Robotics&quot;</td>
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<tr>
<td>October 19, 1972</td>
<td>Dr. Donald R. Morrison Professor, University of New Mexico, National ACM Lecturer</td>
<td>&quot;Pattern Recognition&quot;</td>
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<td>October 27, 1972</td>
<td>Dr. Henry D'Angelo Professor of Electrical Engineering, Michigan Technological University</td>
<td>&quot;Modeling Real Decision Makers in an Evolving Society of Individuals&quot;</td>
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<td>November 14, 1972</td>
<td>Mr. Michael L. Baird Doctoral Student, School of Information and Computer Science, Georgia Institute of Technology</td>
<td>&quot;A Paradigm for Semantic Picture Recognition&quot;</td>
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<tr>
<td>November 17, 1972</td>
<td>Mr. Raymond V. VanWolkenten Doctoral Student, School of Information and Computer Science, Georgia Institute of Technology</td>
<td>&quot;Montague Grammars&quot;</td>
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## Seminars Cont.

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| December 14, 1972  | Dr. Samuel C. Lee  
                       Associate Professor of Electrical Engr. University of Houston | "On Completely and Incompletely Specified Diagnostic Machines" |
| December 27, 1972  | Mr. Albert N. Badre  
                       Doctoral Candidate, Educational and Cognitive Learning Psychology, University of Michigan | "Systems-Analytic Approach to Problem-Solving"       |
SENIOR PERSONNEL

Following is a list of senior personnel supported in part by NSF Grant GN-655 for the period extending from October 1, 1972 to December 31, 1972. The levels of involvement are not indicated, as a rule they depend on the research topics in question, and on other academic assignments.

Professors:  
Dr. Lucio Chiaraviglio  
Dr. James W. Sweeney  
Dr. Miroslav Valach  
Dr. Thomas G. Windeknecht

Associate Professors:  
Dr. Philip J. Siegmann  
Dr. Pranas Zunde

Assistant Professors:  
Dr. William I. Grosky  
Dr. John M. Gwynn Jr.  
Dr. Michael D. Kelly  
Dr. David E. Rogers

Senior Research Engineer:  
Mr. Alton P. Jensen

(Additions)  
NONE

(Deletions)  
NONE
PROJECT SUPPORT/EXPENDITURES*

This section of the report summarizes the financial budget of NSF Grant GN-655, and gives a detailed account of the manpower budget.

Financial

Tables 1 and 2 show, respectively, NSF and GIT category allocations under NSF Grant GN-655, along with the expended and balance of funds in each of these categories as of January 1, 1973.

Table 1. GN-655
Financial Summary (NSF Funding)
(July 1, 1967 - December 31, 1972)

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<th>1969/71</th>
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<td>35,290**</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>35,290**</td>
<td></td>
</tr>
<tr>
<td>Travel</td>
<td>13,000</td>
<td>4,150</td>
<td>3,282</td>
<td>1,625</td>
<td>1,641</td>
<td>10,698</td>
<td>2,302</td>
</tr>
<tr>
<td>Par Time</td>
<td>19,326</td>
<td>4,514</td>
<td>5,906</td>
<td>1,892</td>
<td>-</td>
<td>12,312</td>
<td>7,014</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$872,330</td>
<td>$184,777</td>
<td>$362,835</td>
<td>$145,566</td>
<td>$58,872</td>
<td>$752,050</td>
<td>$120,280</td>
</tr>
<tr>
<td>Head (57%)</td>
<td>405,084</td>
<td>88,394</td>
<td>171,463</td>
<td>75,215</td>
<td>28,557</td>
<td>363,629</td>
<td>41,455</td>
</tr>
<tr>
<td>Payroll &amp; Wages</td>
<td>1,710**</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1,710**</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>10,701</td>
<td>2,848</td>
<td>3,588</td>
<td>6,436</td>
<td>4,265</td>
<td>167,710</td>
<td></td>
</tr>
</tbody>
</table>

The data in this section is based on departmental records of the School, not on the official records of the Georgia Institute of Technology.

Search Planning Study
Includes Publication Costs
Table 2. GN-655 Financial Summary (Georgia Tech Matching Contribution)  
(July 1, 1967 - December 31, 1972)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1967/69</td>
<td>1969/71</td>
<td>1971/72</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Salaries and Wages</strong></td>
<td>$413,315</td>
<td>$141,027</td>
<td>$180,288</td>
<td>$92,000</td>
<td>$ -</td>
<td>$413,315</td>
</tr>
<tr>
<td><strong>Equipment</strong></td>
<td>129,180</td>
<td>81,780</td>
<td>-</td>
<td>-</td>
<td>47,400*</td>
<td>129,180</td>
</tr>
<tr>
<td><strong>Permanent Books</strong></td>
<td>****</td>
<td>****</td>
<td>****</td>
<td>****</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td><strong>Expendable Supplies</strong></td>
<td>17,787</td>
<td>1,939</td>
<td>10,848</td>
<td>5,000</td>
<td>-</td>
<td>17,787</td>
</tr>
<tr>
<td><strong>Travel</strong></td>
<td>5,522</td>
<td>-</td>
<td>3,522</td>
<td>1,000</td>
<td>-</td>
<td>4,522</td>
</tr>
<tr>
<td><strong>Computer Time</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>$565,804</td>
<td>$224,746</td>
<td>$194,658</td>
<td>$98,000</td>
<td>$47,400</td>
<td>$564,804</td>
</tr>
<tr>
<td><strong>Salaries and Wages (57% Applicable to Salaries and Wages)</strong></td>
<td>235,590</td>
<td>80,386</td>
<td>102,764</td>
<td>52,440</td>
<td>-</td>
<td>235,590</td>
</tr>
<tr>
<td><strong>Retirement (7.65% Applicable to Salaries and Wages)</strong></td>
<td>5,753</td>
<td>-</td>
<td>-</td>
<td>5,753</td>
<td>-</td>
<td>5,753</td>
</tr>
<tr>
<td><strong>and Total</strong></td>
<td>$807,147</td>
<td>$305,132</td>
<td>$297,422</td>
<td>$156,193</td>
<td>$47,400</td>
<td>$806,147</td>
</tr>
</tbody>
</table>

This analysis does not show the additional matching contribution by the Georgia Institute of Technology in the amount of $104,000 toward the purchase, through its library, of library materials related to information and computer science during the first four year period of the grant.

Includes Publication Costs.


## Table 3: Comparison of Planned and Expended Manpower (GN-655)

(July 1, 1967 - December 31, 1972)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Estimator</td>
<td>2.80</td>
<td>1.13</td>
<td>1.75</td>
<td>.50</td>
<td>-</td>
<td>3.38</td>
<td>(.58)***</td>
<td></td>
</tr>
<tr>
<td>Faculty Associate</td>
<td>34.80</td>
<td>12.73</td>
<td>12.37</td>
<td>8.16</td>
<td>2.33</td>
<td>35.59</td>
<td>(.79)***</td>
<td></td>
</tr>
<tr>
<td>Faculty Professionals (other)</td>
<td>21.00</td>
<td>2.36</td>
<td>7.98</td>
<td>.63</td>
<td>.50</td>
<td>11.47</td>
<td>9.53</td>
<td></td>
</tr>
<tr>
<td>Graduate Students</td>
<td>17.50</td>
<td>5.09</td>
<td>8.00</td>
<td>5.00</td>
<td>-</td>
<td>18.09</td>
<td>(.59)***</td>
<td></td>
</tr>
<tr>
<td>Baccalaureate Students</td>
<td>3.00</td>
<td>.07</td>
<td>1.03</td>
<td>.51</td>
<td>-</td>
<td>1.61</td>
<td>1.39</td>
<td></td>
</tr>
<tr>
<td>Technical</td>
<td>2.00</td>
<td>.29</td>
<td>1.94</td>
<td>-</td>
<td>-</td>
<td>2.23</td>
<td>(.23)***</td>
<td></td>
</tr>
<tr>
<td>Secretary/Typical</td>
<td>12.50</td>
<td>3.65</td>
<td>5.37</td>
<td>2.36</td>
<td>-</td>
<td>11.38</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>93.60</td>
<td>25.32</td>
<td>38.44</td>
<td>17.16</td>
<td>2.83</td>
<td>83.75</td>
<td>9.85</td>
<td></td>
</tr>
</tbody>
</table>

* 1.00 indicates Full-Time for one fiscal year.
** Does not include .50 EFT budgeted for the Research Planning Study
*** Overexpenditure
LIST OF PUBLICATIONS AND PRESENTATIONS
(October - December 1972)

Administrative Reports

1. "Quarterly Administrative Report No. 13, NSF Grant GN-655." Atlanta, Ga., Georgia Institute of Technology (School of Information and Computer Science), October 1, 1972, 12 p.

Papers Presented/Presentations


5. Sweeney, J.W. "What is An Information Scientist?" Presentation to the School of Biology, Georgia Institute of Technology, Atlanta, Ga., November 26, 1972.


Published Papers

8. Slamecka, V. "Nuevas Tendencias Educacionales en Ciencia de La Informacion." (Science and Information: Some Implications for the Education of Scientists), INFORMACIONES (Biblioteca de La Universidad Nacional de La Plata) 41:3-7; 42:3-6 (July 1972; August 1972).

-10-

1972/73
ANNUAL SUMMARY REPORT
(Quarterly Administrative Report No. 16)

NSF Grant GN-655

October 15, 1973

Science Information Research Center
School of Information and Computer Science
Georgia Institute of Technology
Atlanta, Georgia 30332
The School of Information and Computer Science, Georgia Institute of Technology, is pleased to submit the administrative portion of its Annual Report on NSF Grant GN-655 (Georgia Tech Science Information Research Center) for the one-year period extending from July 1, 1972 through June 30, 1973.

This report begins with a brief review of the present status of the School's academic programs. Three subsequent sections of the report then review, respectively, selected aspects of the School's research program, research personnel, and project support and expenditures. A bibliography listing administrative reports, proposals, papers presented, published papers, books, research reports and completed theses since July 1, 1972 concludes the report.

Appendix I provides a list of students enrolled in the graduate and undergraduate programs of the School of Information and Computer Science during the 1972/73 fiscal year.


The staff and administrator of the Georgia Tech Science Information Research Center wish to express their grateful appreciation to the Office of Science Information Service, NSF, for its support and interest in the School's research program.

Vladimir Slamecka
Project Director, Grant GN-655

October 15, 1973
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**APPENDIX I** STUDENT ENROLLMENT (1972/73)

**ATTACHMENT I** PROGRAMS AND COURSES

**ATTACHMENT II** REVIEW OF RESEARCH PROGRESS
ACADEMIC PROGRAMS*

The school year 1972/73 marks the tenth year of existence and operation of the School of Information and Computer Science.

Degree Programs and Enrollment. The 1972/73 part time and full time enrollment in the degree programs of the School of Information and Computer Science was 291, a 15 per cent increase over the enrollment for 1971/72. Of these students 197 were enrolled in the School's Master's degree program (4 as special students), 32 in the School's Ph.D. program, and 62 in the School's new undergraduate program.

The School awarded a total of 74 Master of Science degrees and 5 Doctor of Philosophy degrees during Fiscal Year 1973.

New B.S. Degree Program in Information and Computer Science. The School's proposal for a B.S. degree program in information and computer science was approved by the Board of Regents of the University System of Georgia in Summer 1972. The program, offered for the first time Fall Quarter 1972, has a projected enrollment of 400 students beginning Fall Quarter 1976.

New Graduate Program in Biomedical Information and Computer Science. The School's Graduate Program in Biomedical Information and Computer Science, offered for the first time in Fall 1972, currently has an enrollment of 16. Firm commitments indicate that the program will have no less than 10 full-time Ph.D. students beginning Fall 1973. The program, the first of its kind in the nation, is offered in association with Emory University Medical School, and is supported in part by a $434,365 training grant from the National Library of Medicine.

*Attachment I, Programs and Courses, provides a detailed description of the School's current programs of instruction.
Evening Graduate Program. In response to a large demand from the professional community a part-time evening program leading to the M.S. degree in Information and Computer Science was started in the Winter Quarter 1972. The requirements of the program are identical to the School's regular day-time program, and the program is designed to develop and extend professional competence in the engineering analysis, design and management of advanced information and computer systems. The program, scheduled to be completed Winter Quarter 1974, currently has an enrollment of 25 as compared to an initial enrollment of 35.

Summary of ICS Educational Activities and Programs. The following tables provide a statistical review and summary of the educational activities and programs of the School of Information and Computer Science.

Table 1. ICS Student Enrollment/Degrees Awarded, 1964-73

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Total Enrollment</th>
<th>Total New</th>
<th>Degrees Awarded</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964/65</td>
<td>30</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>1965/66</td>
<td>38</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>1966/67</td>
<td>65</td>
<td>40</td>
<td>12</td>
</tr>
<tr>
<td>1967/68</td>
<td>108</td>
<td>46</td>
<td>34</td>
</tr>
<tr>
<td>1968/69</td>
<td>137</td>
<td>53</td>
<td>51</td>
</tr>
<tr>
<td>1969/70</td>
<td>155</td>
<td>84</td>
<td>40</td>
</tr>
<tr>
<td>1970/71</td>
<td>185</td>
<td>102</td>
<td>47</td>
</tr>
<tr>
<td>1971/72</td>
<td>255</td>
<td>138</td>
<td>68</td>
</tr>
<tr>
<td>1972/73</td>
<td>291</td>
<td>145</td>
<td>79</td>
</tr>
</tbody>
</table>

Table 2. Approved ICS Course Offerings, 1964-73

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Undergraduate</th>
<th>Undergraduate/Graduate</th>
<th>Graduate</th>
<th>Total Number of Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964/65</td>
<td>--</td>
<td>4</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>1965/66</td>
<td>--</td>
<td>6</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>1966/67</td>
<td>1</td>
<td>11</td>
<td>21</td>
<td>33</td>
</tr>
<tr>
<td>1967/68</td>
<td>2</td>
<td>12</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>1968/69</td>
<td>3</td>
<td>12</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>1969/70</td>
<td>3</td>
<td>12</td>
<td>37</td>
<td>52</td>
</tr>
<tr>
<td>1970/71</td>
<td>9</td>
<td>13</td>
<td>41</td>
<td>63</td>
</tr>
<tr>
<td>1971/72</td>
<td>40</td>
<td>13</td>
<td>41</td>
<td>94</td>
</tr>
<tr>
<td>1972/73 (a)</td>
<td>--</td>
<td>50</td>
<td>41</td>
<td>91</td>
</tr>
</tbody>
</table>

(a) Numbers reflect new Institutional regulation permitting graduate students to apply credit for any undergraduate course toward a graduate degree, up to a maximum of 15 hours.
<table>
<thead>
<tr>
<th>Program</th>
<th>Degree</th>
<th>Year of Implementation</th>
<th>1972/73 Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information Systems Engineering</td>
<td>M.S.</td>
<td>1964</td>
<td>46</td>
</tr>
<tr>
<td>Computer Systems Engineering</td>
<td>M.S.</td>
<td>1966</td>
<td>115</td>
</tr>
<tr>
<td>Undergraduate Service Curriculum</td>
<td>-</td>
<td>1966</td>
<td>1024</td>
</tr>
<tr>
<td>Information and Computer Science</td>
<td>Ph.D.</td>
<td>1968</td>
<td>27</td>
</tr>
<tr>
<td>Off-Campus Program at Lockheed-Georgia Company</td>
<td>M.S.</td>
<td>1970</td>
<td>13 (Total (a) Graduates)</td>
</tr>
<tr>
<td>Undergraduate Minor in Information and Computer Science</td>
<td>-</td>
<td>1970</td>
<td>10</td>
</tr>
<tr>
<td>Curriculum in Information Sciences for High School Teachers</td>
<td>(b)</td>
<td>Summer 1970</td>
<td>41 (Total Graduates)</td>
</tr>
<tr>
<td>Information/Computer Systems Engineering (evening program)</td>
<td>M.S.</td>
<td>1972</td>
<td>25</td>
</tr>
<tr>
<td>Graduate Program in Biomedical Communication</td>
<td>M.S.</td>
<td>1967</td>
<td>30 (Total (c) Graduates)</td>
</tr>
<tr>
<td>Graduate Program in Biomedical Information and Computer Science</td>
<td>M.S. (d)</td>
<td>1972</td>
<td>11</td>
</tr>
<tr>
<td>Undergraduate Degree Program in Information/Computer Science</td>
<td>B.S.</td>
<td>1972</td>
<td>62</td>
</tr>
</tbody>
</table>

(a) Ceased 1972
(b) Applicable to the M.A. degree in Education
(c) Offered through a Consortium of universities, administered by Tulane University; ceased 1970
(d) Jointly with Emory University, School of Medicine
The purpose of this section is to report on significant aspects of the School's research activities during the 1972/73 fiscal year, other than projects of the Science Information Research Center.*

New Research and Education Facilities

The Institute has assigned to the School of Information and Computer Science new facilities in which to house its research and educational activities. The facilities (20,700 sq. ft.) are located in the recently completed new computer center and the immediately adjacent Calculator Building. They provide for:

1) A Centralized Computer Room (5,900 sq ft.)
2) Administrative Offices (3,700 sq. ft.)
3) Faculty Offices, Lounge and Conference Room (11,100 sq. ft.)

Occupancy of the computer room and administrative offices was effected July 1, 1973. Full occupancy of the remaining facilities is expected by July 1, 1974, upon completion of necessary renovations.

New Research Grants

Evaluation of Audiographic Technology in Continuing Graduate Science Education. As part of its program to explore the potential of educational technology for improving continuing education in science, the National Science Foundation has awarded the School of Information and Computer Science a grant of $170,000 to implement and evaluate operationally an ALF system for continuing education of professional employees of the State of Georgia. The funded project is a cooperative effort between the School of Information and Computer Science and the Department of Administrative Services of the State Government of Georgia. In the two-year experiment professional employees of the Georgia Department of Administrative Services will be able

*Attachment II constitutes a substantive report on the School's research effort supported in part by NSF Grant GN-655 since July 1, 1972.
to call, at any hour of the day or evening, for delivery by telephone of audiovisual lectures from the Georgia Tech campus to the State Capitol. The project responds to a suggestion by Governor Jimmy Carter of the State of Georgia that the University System of Georgia develop new approaches whereby professional State employees can avail themselves of on-the-job educational opportunities.

The self-instruction system ALF, developed at this School over the past two years, allows for inexpensive preparation, storage, telephone transmission, and synchronous replay of voice and blackboard graphics presentations at remote locations. From these locations, individual students or small groups of learners can call up the computer-controlled system to have automatically transmitted to them, by telephone, blackboard lectures in narrative and motion graphic form on the subjects of their choice. Using the self-testing and other aids of ALF, students can effectively control their choice of subjects and their pace of study. The system is already under demonstration in selected Georgia high schools.

The project is under the directorship of Dr. Vladimir Slamecka, Professor and Director, School of Information and Computer Science, and is effective for the period from September 1, 1972 to November 30, 1974.

Towards a Symbiosis of Science Information and Learning Systems. The National Science Foundation has awarded the School of Information and Computer Science a grant of $181,000 to study, design and experimentally evaluate man-machine mechanisms for enhancing the transfer of science information from its present repositories into science learning systems.

With the general objective of investigating the mechanism of science information transfer into science education, the funded project has the following specific goals:

1. To describe operationally the human process of transformation of science information system outputs for the purpose of integrating them into the content of ALF-type learning systems;

2. To investigate comparitively the design and operating characteristics of science information systems and ALF-type science learning systems, particularly from the viewpoint of requirements for transferring information between them via a man-machine interface;
3. To implement an experimental design of limited transfer mechanism from appropriate existing science information systems into an ALF-type science learning system, and to evaluate selected aspects of the mechanism.

The findings of the proposed research should result in conclusions concerning the minimum design requirements for the compatibility of science information systems and science learning systems, and in an evaluation of an operational method for a rapid integration of up-to-date science information into the content of modular facilities for self-instruction in science.

The project is under the directorship of Dr. Pranas Zunde, Professor, School of Information and Computer Science, and is effective for the period from November 1, 1972 to April 30, 1975.

**Evaluation of Remote Bibliographic and Physical access to a Research Library by Microfiche Catalogs, Computer Services and Delivery Service.** The School of Information and Computer Science jointly with the Georgia Tech library has been awarded by NSF a grant of $37,000 to develop and execute procedures to evaluate the operation of an extended bibliographic and physical access system for the use of the faculty of the Institute. The evaluation will study the effects of the system on (1) faculty use and information gathering habits; (2) library operation and service policy; and (3) costs of operating the system.

The system to be evaluated provides bibliographic access by (a) placement in each academic and research department of microfiche copy of the card catalog updated with a cumulative monthly supplement and (b) computer search services to the published technical journal literature via the Georgia Information Dissemination Center. Physical access is provided by a physical document delivery service of requested books and photo copies of journal articles, reports, bibliographies, etc.

The project is under the directorship of Dr. Philip J. Siegmann, Associate Professor, School of Information and Computer Science, and is effective for the period from October 1, 1972 to March 31, 1974.
General Dynamical Processes. The National Science Foundation has awarded the School of Information and Computer Science a grant of $14,000 to continue studies in the theory of general dynamical processes. This continuing research, previously funded by the National Science Foundation under grants GK-1394 and GK-13300 at Case Western Reserve University and GK-29023 at Michigan Technological University, is concerned with a mathematical approach to general systems theory using axiomatic set theory. The project will continue to develop the theory of general dynamical processes in two specific directions: 1) to unify and expand the existing theory of stereotype voting groups; and 2) to introduce within the established set-theoretic formalism an axiomatic formulation of computing processes including the elementary theory of recursive function and sets, unsolvable problems, and abstract computability.

The project is under the directorship of Dr. Thomas G. Windeknecht, Professor of Information and Computer Science, Georgia Institute of Technology, and is effective for the period from January 1, 1973 to June 30, 1974. Dr. Windeknecht previously served as Principal Investigator of this research effort at Case Western Reserve University and Michigan Technological University.

Travel Grant. The National Science Foundation awarded to Dr. Robert B. Cooper, Associate Professor of Information and Computer Science, a travel grant in the amount of $894 to assist in defraying transportation expenses to attend and present an invited paper at the Twentieth International Meeting of the Institute of Management Sciences, held in Tel Aviv, Isreal during the period June 24, 1973 through June 29, 1973. The title of Dr. Cooper's presentation was "Queues with Ordered Servers that Work at Different Rates."

Study of Soviet Science Information Systems

Dr. Vladimir Slamecka, Director and Professor of the School of Information and Computer Science, served on an eight-member delegation which visited the Soviet Union in June as part of the U.S. - U.S.S.R. Scientific and Technical Cooperation Agreement. The delegation, which also included senior executives from government and industry, studied Soviet programs of scientific
information and computation, and identified areas in which U.S. - U.S.S.R. cooperation may be possible. The U.S. delegation spent one week in Moscow as guests of the U.S.S.R. Central Committee for Science and Technology. Subsequent itinerary included visits to Novosibirsk, the "science city" in Central Siberia; Yerevan, the capital of the Armenian Republic; and the Research Institute for Cybernetics in Kiev, the Ukraine. The group returned to Moscow for final discussions in early July. The U.S. - U.S.S.R. Scientific and Technical Cooperation Agreement was negotiated by President Nixon during his visit to the Soviet Union in June 1972. The agreement seeks to expand cooperative programs between the two countries in several areas of science, notably in space and environmental research, the exchange of scientific data, and in systems analysis and non-military computer applications.

Visiting Professor

Dr. Gordon Pask, Brunel University, U.K., an authority on learning systems, was appointed as a Visiting Professor in the School of Information and Computer Science for the 1973 Spring Quarter.

Information Processing Laboratory

A complete list of current equipment, equipment maintenance contracts and equipment rentals associated with the School's Laboratory appears on pp. 28 - 31 of this report.

As reported in a previous section of this Annual Summary Report, the School has been allocated 5,900 sq. ft. of floor space in the Institute's New Computer Center to house its computing laboratory. Full occupancy of these facilities was accomplished during the period June 11 - June 22, 1973. The new facilities permit a centralized location for the School's computing equipment, including the Burroughs B-5500*, PDP 11/45 (purchased new in 1972), and PDP 8/1.

* The School of ICS assumed responsibility for the operation and maintenance of the Georgia Institute of Technology B-5500 Computer System, effective July 1, 1972.
Dissemination of Research Results

Table 4 shows the number of publications of various types which emanated from the research programs of the School of Information and Computer Science in the period of July 1967-1973. A complete list of references for the 1972-73 fiscal year is in the Bibliography. Publications prior to this time can be found in the Bibliography of the School's Biannual Summary Report (1967/69) and the Annual Summary Reports for fiscal years 1969/70, 1970/71 and 1971/72.

Table 4. Distribution of Research Publications

<table>
<thead>
<tr>
<th>Type of Publication</th>
<th>1967/69</th>
<th>1969/71</th>
<th>1971/73</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Publications in Open Literature</td>
<td>8</td>
<td>17</td>
<td>21</td>
<td>46</td>
</tr>
<tr>
<td>2. Books</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3. Research Reports</td>
<td>9</td>
<td>15</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>4. Internal Research Memorandums</td>
<td>6</td>
<td>6</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>5. Presentation of Papers</td>
<td>5</td>
<td>27</td>
<td>49</td>
<td>81</td>
</tr>
<tr>
<td>6. Theses</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>7. Proposals</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>8. Administrative Reports</td>
<td>-</td>
<td>8</td>
<td>8</td>
<td>16</td>
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<tr>
<td>Total</td>
<td>33</td>
<td>80</td>
<td>93</td>
<td>206</td>
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Seminars

<table>
<thead>
<tr>
<th>Date</th>
<th>Lecturer</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 31, 1972</td>
<td>Mr. Richard A. DeMillo</td>
<td>&quot;Formal Semantics and Logical Structure of Programming Languages&quot;</td>
</tr>
<tr>
<td></td>
<td>Ph.D. Candidate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>School of Information</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and Computer Science</td>
<td></td>
</tr>
</tbody>
</table>

-9-
<table>
<thead>
<tr>
<th>Date</th>
<th>Lecturer</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>August 16, 1972</td>
<td>Miss Margaret E. Dexter Ph.D. Candidate</td>
<td>&quot;Some Effects of Locus Of Control on Computer-Aided Instruction (CAI)&quot;</td>
</tr>
<tr>
<td>August 17, 1972</td>
<td>Dr. Gordon Pask Professor of Cybernetics</td>
<td>&quot;A Theory of Cognition&quot;</td>
</tr>
<tr>
<td>September 19, 1972</td>
<td>Mr. Joseph R. Hogan Ph.D. Candidate</td>
<td>&quot;Abstract Computer and Degrees of Unsolvability&quot;</td>
</tr>
<tr>
<td>October 3, 1972</td>
<td>ICS Faculty</td>
<td>&quot;Selected Research Areas in Information and Computer Science&quot;</td>
</tr>
<tr>
<td>October 17, 1972</td>
<td>Dr. Laurent Siklossy Professor of Computer Science, University of Texas</td>
<td>&quot;Topics in Model Robotics&quot;</td>
</tr>
<tr>
<td>October 19, 1972</td>
<td>Dr. Donald R. Morrison Professor, University of New Mexico, National ACM Lecturer</td>
<td>&quot;Pattern Recognition&quot;</td>
</tr>
<tr>
<td>October 27, 1972</td>
<td>Dr. Henry D'Angelo Professor of Electrical Engineering, Michigan Technological University</td>
<td>&quot;Modeling Real Decision Makers in an Evolving Society of Individuals&quot;</td>
</tr>
<tr>
<td>Date</td>
<td>Lecturer</td>
<td>Title</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------------------------------------------</td>
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</tr>
<tr>
<td>November 14, 1972</td>
<td>Mr. Michael L. Baird</td>
<td>&quot;A Paradigm for Semantic Picture Recognition&quot;</td>
</tr>
<tr>
<td></td>
<td>Doctoral Student, School of Information and Computer Science, Georgia Institute of Technology</td>
<td></td>
</tr>
<tr>
<td>November 17, 1972</td>
<td>Mr. Raymond V. VanWolkenten</td>
<td>&quot;Montague Grammars&quot;</td>
</tr>
<tr>
<td></td>
<td>Doctoral Student, School of Information and Computer Science, Georgia Institute of Technology</td>
<td></td>
</tr>
<tr>
<td>December 5, 1972</td>
<td>Dr. H. S. Valk, Dean</td>
<td>&quot;Functions of Faculty Advisors&quot;</td>
</tr>
<tr>
<td></td>
<td>General College, Georgia Institute of Technology</td>
<td></td>
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<tr>
<td>December 14, 1972</td>
<td>Dr. Samuel C. Lee</td>
<td>&quot;On Multivalued Symmetric Functions&quot;</td>
</tr>
<tr>
<td></td>
<td>Associate Professor, School of Computer Science, University of Houston</td>
<td></td>
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<tr>
<td>December 27, 1972</td>
<td>Dr. Albert N. Badre</td>
<td>&quot;Systems-Analytic Approach to Problem-Solving&quot;</td>
</tr>
<tr>
<td></td>
<td>Doctoral Candidate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Educational and Cognitive Learning Psychology, University of Michigan</td>
<td></td>
</tr>
<tr>
<td>February 13, 1973</td>
<td>Mr. Warren T. Jones</td>
<td>&quot;A Phenomenalistic Theory for the Development of Science&quot;</td>
</tr>
<tr>
<td></td>
<td>Doctoral Student, School of Information and Computer Science, Georgia Institute of Technology</td>
<td></td>
</tr>
<tr>
<td>March 2, 1973</td>
<td>Mr. Lou Gomez</td>
<td>&quot;Business Information Processing&quot;</td>
</tr>
<tr>
<td></td>
<td>Vice President of Data Processing, National Data Corp., Atlanta, Georgia</td>
<td></td>
</tr>
<tr>
<td>March 23, 1973</td>
<td>Dr. William Howden</td>
<td>&quot;Uniform Formal Approach to Problem Solving&quot;</td>
</tr>
<tr>
<td></td>
<td>Department of Information and Computer Science, University of California at Irvine</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Lecturer</td>
<td>Title</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
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</tbody>
</table>
| April 5, 1973 | Mr. Charls R. Pearson  
Doctoral Student  
School of Information 
and Computer Science, 
Georgia Institute of Technology | "The Concept of Meaning in Natural Language" |
| April 16, 1973 | Mr. Yun Chung Cho  
Ph.D. Candidate,  
School of Electrical 
Engineering & Computer Science, University of California at Berkeley | "Application of Syntactic Methods to Picture Processing" |
| April 27, 1973 | Dr. Laurent Siklossy  
Assistant Professor,  
Department of Computer Science, University of Texas at Austin | "Modelled Exploration by Robot" |
| May 8, 1973 | Dr. Matias Eduardo Fernandez  
Acting Assistant Professor  
Dept of Computer Science  
University of California at Los Angeles | "An Evaluation of Tree Generation Methods" |
| May 10, 1973 | Dr. Edgar M. Pass  
Doctoral Student  
School of Information 
and Computer Science, 
Georgia Institute of Technology | "An Adaptive Microscheduler for a Multiprogrammed Computer Systems" |
| May 15, 1973 | Mr. Michael L. Baird  
Doctoral Student  
School of Information 
and Computer Science, 
Georgia Institute of Technology | "A Paradigm for Semantic Picture Recognition" |
| May 30, 1973 | Dr. Paul Ernest Weston  
Electrical Engineering and Coordinated Science Laboratory, Research Associate, University of Illinois | "Natural Languages Interaction with Machines" |
<table>
<thead>
<tr>
<th>Date</th>
<th>Lecturer</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 1, 1973</td>
<td>Jorge Baralt-Torrijos</td>
<td>&quot;A Programmatic Interpretation of Combinatory Logics&quot;</td>
</tr>
<tr>
<td></td>
<td>Doctoral Candidate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&quot;School of Information and Computer Science, Georgia Institute of Technology</td>
<td></td>
</tr>
</tbody>
</table>
PERSONNEL

Management

The research activities of the Science Information Research Center at the Georgia Institute of Technology, supported by NSF Grant GN-655, continue to be directed and administered by the School of Information and Computer Science.

As detailed in the previous annual reports, the Director of the School, Dr. Vladimir Slamecka, serves formally as head of the Research Center reporting directly to the Dean of the General College. Individual research topics and projects of the Center are under the immediate direction of respective principal investigators who report to Dr. Slamecka.

Faculty and Staff

Following is a list of faculty and staff members associated with the School of Information and Computer Science and supported in part by NSF Grant GN-655 during the 1972/73 fiscal year.

<table>
<thead>
<tr>
<th>Area of Research Interest</th>
<th>EFT*</th>
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</thead>
<tbody>
<tr>
<td>Information systems; educational technology</td>
<td>.25</td>
</tr>
<tr>
<td>Mathematical logic; theory of computing</td>
<td>.47</td>
</tr>
<tr>
<td>Semiotics; linguistics; models of grammar</td>
<td>.21</td>
</tr>
</tbody>
</table>

* 1.00 EFT equals full-time for one fiscal year
<table>
<thead>
<tr>
<th>Area of Research Interest</th>
<th>EFT*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomedical information systems; large-scale data banks</td>
<td>.40</td>
</tr>
<tr>
<td>Cybernetics; computer architecture</td>
<td>.27</td>
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<tr>
<td>Mathematical theory of general systems; general dynamical processes</td>
<td>.46</td>
</tr>
<tr>
<td>Telecommunications; operations research</td>
<td>.08</td>
</tr>
<tr>
<td>Human learning; theory of information processes</td>
<td>.17</td>
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<tr>
<td>Theory of information systems and processes; systems engineering</td>
<td>.52</td>
</tr>
<tr>
<td>Computer programming systems and languages; engineering applications of computing</td>
<td>.09</td>
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<tr>
<td>Automata theory; theory of computer languages</td>
<td>.08</td>
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<tr>
<td>Automata theory; logic</td>
<td>.55</td>
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<tr>
<td>Artificial intelligence; image processing</td>
<td>.52</td>
</tr>
<tr>
<td>Linguistics; comparative structures of natural language</td>
<td>.08</td>
</tr>
<tr>
<td>Computational linguistics; programming languages; information storage and retrieval</td>
<td>.29</td>
</tr>
<tr>
<td>Management of information industry</td>
<td>.33</td>
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<tr>
<td>Computer hardware systems</td>
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*1.00 EFT equals full-time for one fiscal year
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<thead>
<tr>
<th>Area of Research Interest</th>
<th>EFT*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gallaher, Lawrence J.</td>
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<tr>
<td>Programming Languages</td>
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<table>
<thead>
<tr>
<th>Graduate Research Assistant</th>
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<tbody>
<tr>
<td>Baird, Michael</td>
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<tr>
<td>Basu, Saurinda M.</td>
<td>.08</td>
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<tr>
<td>Bedingfield, James C.</td>
<td>.11</td>
<td></td>
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<tr>
<td>Chu, Fa Shan F.</td>
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<tr>
<td>Hafiz, Khalid</td>
<td>.02</td>
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<tr>
<td>Jones, Warren T.</td>
<td>.05</td>
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<td>Raynor, Randall J.</td>
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<td>Subramanian, N. V.</td>
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<td>Tsui, Frank</td>
<td>.08</td>
<td></td>
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<td>Wang, Shen Pei</td>
<td>.08</td>
<td></td>
</tr>
<tr>
<td>VanWolkenten, R. V.</td>
<td>.08</td>
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<table>
<thead>
<tr>
<th>Secretary III</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Rub, Margrit</td>
<td>.04</td>
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</table>

<table>
<thead>
<tr>
<th>Student Assistant</th>
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<th></th>
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<tbody>
<tr>
<td>Dillard, William K.</td>
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<td>Kerzel, David F.</td>
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<td>Smith, Philip C.</td>
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<tr>
<td>Yoo, Jakyang</td>
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<td>Zayas, Fernando F.</td>
<td>.06</td>
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<table>
<thead>
<tr>
<th>Miscellaneous Non-professional</th>
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<tbody>
<tr>
<td>Kerzel, David F.</td>
<td>.05</td>
<td></td>
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</tbody>
</table>

*1.00 EFT equals full-time for one fiscal year
The following biographical sketches describe senior faculty members of the Georgia Institute of Technology who participated in the research effort in information science and engineering as funded under NSF Grant GN-655 for the period extending from July 1, 1972 through June 30, 1973. The alphabetically arranged list is incomplete with respect to the collaborating resident junior faculty and graduate students.

LUCIO CHIARAVIGLIO, Professor of Information and Computer Science. Dr. Chiaraviglio holds the M.A. degree (University of Chicago, 1956) and the Ph.D. degree (Emory University, 1961) in philosophy and mathematical logic. Dr. Chiaraviglio has been associated with the School of Information and Computer Science since 1967. His previous appointments include faculty positions at Emory University and the University of Delaware. His current research is in mathematical logic, semiotics, computer science, and meta-science. In these areas, Dr. Chiaraviglio has published papers in English, Italian, Spanish and French.

ROBERT B. COOPER, Associate Professor of Information and Computer Science/Industrial and Systems Engineering. Dr. Cooper joined the School of Information and Computer Science on September 15, as a part-time Associate Professor of Information and Computer Science. Previously, Dr. Cooper served as a full-time Associate Professor of Industrial and Systems Engineering, Georgia Institute of Technology. He received his B.S. degree from Stevens Institute of Technology in 1961, and his M.S. and Ph.D. degrees from the University of Pennsylvania in 1962 and 1968, respectively. His present interests are in the fields of telecommunications and operations research. Dr. Cooper is the author of several technical publications, and a textbook entitled Introduction to Queueing Theory.

JAMES GOUGH, JR., Professor of Information and Computer Science. Dr. Gough received his M.A. and Ph.D. degrees in linguistics from Harvard University in 1953 and 1965, respectively. He has worked and taught in the field of linguistics since 1953. Previous appointments of Dr. Gough included that of Research Translator, American Meteorological Society; and Assistant Professor, Department of Modern Languages, Georgia Institute of Technology. His present interests are in the fields of semiotics and the structure of natural language, particularly that of the English noun phrase. Dr. Gough is the author of several publications in the area of linguistics.
WILLIAM I. GROSKY, Assistant Professor of Information and Computer Science.
Dr. Grosky joined the staff of the School of Information and Computer Science on September 1, 1971, as a full-time Assistant Professor of Information and Computer Science. Dr. Grosky received his M.S. degree in applied mathematics from Brown University in 1968, and his Ph.D. in engineering and applied science from Yale University in 1971. His present interests are in fields of computability theory, automata theory, and mathematical logic.

JOHN W. GWYNN, JR., Assistant Professor of Information and Computer Science.
Dr. Gwynn received his M.A. and Ph.D. degrees in mathematics from the University of North Carolina in 1959 and 1968, respectively. He joined the faculty of the School of Information and Computer Science in 1964; previous appointments include teaching in the School of Mathematics, and a position of Research Scientist at the Rich Electronic Computer Center, Georgia Institute of Technology. Dr. Gwynn's interests have moved from numerical computation to automata theory and the design of higher-level computer languages.

ALTON P. JENSEN, Senior Research Engineer, Information and Computer Science.
Mr. Jensen holds a B.S. degree in mechanical engineering, awarded in 1956, and an M.S. degree (pending) in information and computer science, both from the Georgia Institute of Technology. He has been associated with the field of computing and computer applications since 1956; in his previous position, Mr. Jensen served as associate head of the Rich Electronic Computer Center at the Georgia Institute of Technology. Current interests of Mr. Jensen are research in advanced computing concepts and applications, and the design of management of information utilities. Mr. Jensen is consultant to numerous industrial, governmental and educational agencies in the Southeast and in South America. He has authored or co-authored various technical reports in the field of computing.

MICHAEL D. KELLY, Assistant Professor of Information and Computer Science.
Dr. Kelly received his M.S. and Ph.D. degrees in computer science from Stanford University in 1967 and 1970, respectively, and has been associated with the field of computer science since 1960. Prior to entering Stanford University he served as a Systems Analyst/Programmer with Datafax Corporation, and IBM Corporation. His present interests are in the fields of artificial intelligence and computer picture processing.

DAVID H. KRAUS*, Assistant Professor of Information and Computer Science.
Mr. Kraus received his M.A. degree in linguistics from Harvard University in 1946. He has been associated with the field of comparative linguistics since 1946; his more recent interests are with the intellectual processes of human translation and their algorithmization, and he was employed as Manager of Scientific Translation Services with the Meteorological Society.

*Resigned, effective Fall Quarter 1973.
In the School of Information and Computer Science Professor Kraus was engaged in the synchronic study of the language of Russian science and technology, with the view toward an efficient design of such languages from the vernacular. He is fluent in the languages and scientific terminologies of the following: Polish, Czech, Hungarian, Serbo-Croatian, Bulgarian, Slovak, Ukranian and Romanian.

DAVID E. ROGERS, Assistant Professor of Information and Computer Science. Dr. Rogers received his M.S. degree in Russian from Georgetown University in 1966, and his Ph.D. degree in linguistics from the University of Michigan in 1969. Dr. Rogers has been associated with the fields of linguistics and natural language processing systems since 1964. He served as Senior Systems Service Representative with Honeywell EDP prior to entering the University of Michigan in 1965 as a full-time Ph.D. student. His present interests are in the fields of programming languages, grammars of natural languages, and computer-based question and answer type processing systems.

PHILIP J. SIEGMANN, Associate Professor of Information and Computer Science. Dr. Siegmann received his M.A. and Ph.D. degrees in psychology from Ohio State University in 1951 and 1954, respectively. Prior to his appointment in the School of Information and Computer Science, Dr. Siegmann served as Executive Editor, Psychological Abstracts, American Psychological Association. As Executive Editor, Dr. Siegmann contributed significantly to the design and development of an information storage and retrieval system for psychological abstracts. His current interest is concerned with behavioral research in aspects of science information systems and scientific communications. Dr. Siegmann has published articles in the areas of psychological abstracts and information dissemination.

VLADIMIR SLAMECKA, Professor of Information and Computer Science. Dr. Slamecka's education in chemical engineering at the University of Technology (Brno, Czechoslovakia) was followed by postgraduate work in mathematics and philosophy at the University of Sydney (Australia) and University of Munich (Germany) in 1951-56. He also earned the M.S. and D.L.S. degrees from Columbia University, New York, in 1958 and 1962, respectively. Dr. Slamecka serves as Director of the School of Information and Computer Science, Georgia Institute of Technology. Previous appointments included: Fulbright Professor, University of Innsbruck; Manager, Cancer Chemotherapy National Service Center, Bethesda, Md.; Manager, Special Studies Division, Documentation Incorporated (Leasco Systems and Research), Bethesda, Md.; and lecturer, School of Engineering, Columbia University, New York. As Director of the School of Information and Computer Science, Dr. Slamecka has the over-all responsibility for the development and implementation of academic and research programs of this department. His own research interests have been in the design and management of large information systems; man-machine information processing techniques; planning and management of science on the national level; and information systems in education. Dr. Slamecka is a member of Sigma Xi, ACM, ASIS, ACS; the author/editor of five monographs and over thirty-five papers, and a holder of several patents; and listed in American Men of Science, Who's Who in America, etc.
JAMES W. SWEENEY, Visiting Professor* of Information and Computer Science. Dr. Sweeney joined the staff of the School of Information and Computer Science on August 1, 1972 as a full-time visiting Professor of Information and Computer Science. He received his B.S. and M.S. degrees from the Georgia Institute of Technology in 1948 (Dual-Degree), and his Ph.D. from the Massachusetts Institute of Technology in 1954. Previous appointments include Professor, Tulane University, and Professor, University of Oklahoma. Dr. Sweeney has extensive experience in the application of digital computers in the field of medicine and currently serves as coordinator of the academic and research aspects of the School's new graduate degree program in biomedical information and computer science. He has published over 20 technical reports in the area of clinical applications of digital computers and is a holder of patent number 3,614,744, entitled "Generalized Information Processing." Dr. Sweeney is a member of numerous professional and honorary societies and serves as consultant to several governmental health agencies and hospitals.

MIROSLAV VALACH, Professor of Information and Computer Science. Dr. Valach received his M.S. degree from Engineering University in Prague in 1951, and his Ph.D. in mathematics from Czechoslovak Academy of Science in 1958. He has worked and taught in the field of computer hardware and software since 1955. Previous appointments of Dr. Valach include that of lecturer at the Engineering University in Prague, Charles University in Prague and the School of Economics (Prague and Bratislava). In addition, Dr. Valach served as Head of the Peripheral Equipment Department of the Research Institute of Mathematical Machines in Prague, and as consulting engineer in the Computer Equipment Department of the General Electric Company in Phoenix, Arizona from 1965 to 1969. Dr. Valach's current research is in information processing machines, cybernetics, and artificial intelligence. Dr. Valach is the author and co-author of two books and has published over 16 technical papers.

THOMAS G. WINDEKENCHT**, Professor of Information and Computer Science. Dr. Windeknecht joined the staff of the School of Information and Computer Science on September 15, 1972, as a full-time Professor of Information and Computer Science. He received his BSE and MSE degrees from the University of Michigan in 1958 and 1959, respectively, and his Ph.D. from Case Institute of Technology in 1964. Previous appointments include Associate Professor, Case Western Reserve University, and Professor, Michigan Technological University. His current research interests are in the fields of mathematical theory of general systems and general dynamical processes. Dr. Windeknecht is the author of two books, General Dynamical Processes: A Mathematical Introduction and General Dynamical Processes II: The State Space Approach (In print), and the author or co-author of over 20 technical papers.

*Professor, effective Fall Quarter 1973
**Resigned, effective Fall Quarter 1973
PRANAS ZUNDE, Associate Professor of Information and Computer Science and Industrial and Systems Engineering. Dr. Zunde holds a degree in mechanical engineering from the University of Hannover, West Germany (1947); an M.S. in applied science and engineering from George Washington University in Washington, D.C. (1965); and the Ph.D. in industrial engineering from Georgia Institute of Technology (1968). Dr. Zunde has been associated with the School of Information and Computer Science since 1965; his previous appointments include: Senior Research Scientist, Engineering Experiment Station, Georgia Institute of Technology; and Director of the Management Information Center, Documentation Incorporated. Dr. Zunde's current research lies in general systems theory, theory of information systems design, and in mathematical studies of information processes and systems. He has published over thirty-five papers.

**Faculty/Staff Development**

Table 5 provides a statistical overview of the development of the School's faculty and staff since 1964.

**Table 5. Faculty/Staff Development 1964-1973**

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Faculty Equivalents (1.00 equals Full-Time for 1 fiscal year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equivalent Full-Time</td>
</tr>
<tr>
<td></td>
<td>Faculty Professors</td>
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<tr>
<td>1964/65</td>
<td>3.44</td>
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<tr>
<td>1965/66</td>
<td>2.72</td>
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<td>1966/67</td>
<td>4.60</td>
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<td>1967/68</td>
<td>6.44</td>
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<tr>
<td>1968/69</td>
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</tr>
<tr>
<td>1969/70</td>
<td>9.34</td>
</tr>
<tr>
<td>1970/71</td>
<td>10.80</td>
</tr>
<tr>
<td>1971/72</td>
<td>11.60</td>
</tr>
<tr>
<td>1972/73</td>
<td>17.61</td>
</tr>
<tr>
<td>1973/74(est.)</td>
<td>20.14</td>
</tr>
</tbody>
</table>

*Professor, effective Fall Quarter 1973
This section of the report summarizes the financial budget of NSF Grant GN-655, and it gives a detailed account of the manpower, equipment, and travel budgets and expenditures of the grant as of July 1, 1973. Expenditures for supplies and computer time are not detailed.

Financial

On April 24, 1973, May 16, 1973, and June 1, 1973, the School of Information and Computer Science received Foundation approval for the following modifications to the Grant budget.

April 24, 1973. Approval to (1) decrease the line items "Other (Computer Rental)" and "Travel" by $7,014 and $1,500, respectively, and (2) increase in a corresponding amount ($8,514) the line item "Expendable Supplies and Equipment." The following reasons justified the modifications. Up to July 1, 1972, major computer time requirements of the grant were met through the use of the Georgia Tech Rich Electronic Computer Center B-5500 Computer System. Payments for use of the system were based on an hourly rental rate (as approved by the Defense Contract Audit Agency), and were budgeted for under the grant line item, "Other (Computer Rental)." On July 1, 1972, the School of Information and Computer Science assumed full responsibility for the B-5500 and began supporting it from the budget line item "Expendable Supplies and Equipment." The grant budget modification shifted the monies for computer time into this category.

Similarly, the requested shift of $1,500 of budgeted funds from line items "Travel" to line item "Expendable Supplies and Equipment" did not affect the intended use of these funds. The Institute requires that travel expenses incurred by visiting scholars be budgeted under Per Diem and Fees, a sub-account of "Expendable Supplies and Equipment."

*The data in this section is based on departmental records of the School, not on the official records of the Georgia Institute of Technology.*
May 16, 1973. Approval to use available Grant funds to pay for travel expenses ($1,508) of Dr. Vladimir Slamecka to the U.S.S.R., as one of eight U.S. representatives to the U.S. - U.S.S.R. symposium on national scientific and technical information programs. The symposium was held in Moscow as part of the U.S. - U.S.S.R. Agreement on Cooperation in Science and Technology.

June 1, 1973. Approval to (1) extend the expiration date of the Grant to December 31, 1974, and (2) amend Grant funds specifically earmarked for the Research Planning Study as follows:

<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Funding</th>
<th>Requested Modification</th>
<th>Modified Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaries &amp; Wages</td>
<td>3,000</td>
<td>15,828</td>
<td>18,828</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent Books</td>
<td>840</td>
<td></td>
<td>840</td>
</tr>
<tr>
<td>Expendable Supplies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment*</td>
<td>35,290</td>
<td>400</td>
<td>27,440</td>
</tr>
<tr>
<td>Travel</td>
<td>1,350</td>
<td></td>
<td>1,350</td>
</tr>
<tr>
<td>Total Direct Costs</td>
<td>38,290</td>
<td>18,418</td>
<td>29,268</td>
</tr>
<tr>
<td>Indirect Costs (57% of Salaries &amp; Wages)</td>
<td>1,710</td>
<td>9,022</td>
<td>10,732</td>
</tr>
<tr>
<td>Total Costs</td>
<td>40,000</td>
<td>27,440</td>
<td>40,000</td>
</tr>
</tbody>
</table>

Not shown, but also included in this modification, was a matching contribution to the Research Planning Study by the Georgia Institute of Technology in the amount of $32,764.

* Includes Publication Costs
These modifications are detailed in Table 6.

<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Finding</th>
<th>Requested Modifications</th>
<th>Modified Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaries &amp; Wages</td>
<td>710,675</td>
<td>15,828****</td>
<td>710,675</td>
</tr>
<tr>
<td></td>
<td>3,000*</td>
<td></td>
<td>18,828*</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent Books</td>
<td>39,972</td>
<td>840****</td>
<td>39,972</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td></td>
<td>840*</td>
</tr>
<tr>
<td>Expendable Supplies</td>
<td>51,012</td>
<td>8,514**</td>
<td>59,526</td>
</tr>
<tr>
<td>(Includes Publication Costs)</td>
<td>35,290*</td>
<td>400**** 27,440****</td>
<td>8,250*</td>
</tr>
<tr>
<td>Travel</td>
<td>13,000</td>
<td>1,508*** 1,500**</td>
<td>13,008</td>
</tr>
<tr>
<td></td>
<td>1,350****</td>
<td></td>
<td>1,350*</td>
</tr>
<tr>
<td>Computer Time</td>
<td>19,326</td>
<td>7,014**</td>
<td>12,312</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$872,330</td>
<td>$28,440 $35,954</td>
<td>$864,816</td>
</tr>
<tr>
<td>Overhead (57% of Applicable Salaries &amp; Wages)</td>
<td>405,084</td>
<td>9,022****</td>
<td>405,084</td>
</tr>
<tr>
<td></td>
<td>1,710*</td>
<td></td>
<td>10,732*</td>
</tr>
<tr>
<td>Retirement (7.65% of Applicable Salaries &amp; Wages)</td>
<td>10,701</td>
<td>1,508***</td>
<td>9,193</td>
</tr>
<tr>
<td>Grand Total</td>
<td>$1,289,825</td>
<td>$37,462 $37,462</td>
<td>$1,289,825</td>
</tr>
</tbody>
</table>

* Research Planning Study
** April 24, 1973 Modifications
*** May 16, 1973 Modifications
**** June 1, 1973 Modifications
Tables 7 and 8 incorporate the above modifications and show, respectively, the final NSF and GIT grant category allocations along with the expanded and balance of funds in each of these categories as of July 1, 1973.

**Table 7. GN-655 Financial Summary (NSF Funding)**
(July 1, 1967 - June 30, 1973)

<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Funding</th>
<th>Expenditures/Encumbrances</th>
<th>Balance as of July 1, 1973</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1967/69</td>
<td>1969/71</td>
<td>1971/73</td>
</tr>
<tr>
<td>Salaries &amp; Wages</td>
<td>$710,675</td>
<td>155,077</td>
<td>300,867</td>
</tr>
<tr>
<td></td>
<td>18,828*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent</td>
<td>39,972</td>
<td>14,264</td>
<td>25,708</td>
</tr>
<tr>
<td>Books</td>
<td>55</td>
<td>26</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>840*</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Expendable</strong></td>
<td>59,526</td>
<td>6,746</td>
<td>27,043</td>
</tr>
<tr>
<td>Supplies</td>
<td>8,250*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Travel</td>
<td>13,008</td>
<td>4,150</td>
<td>3,282</td>
</tr>
<tr>
<td></td>
<td>1,350*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Computer Time</td>
<td>12,312</td>
<td>4,514</td>
<td>5,906</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>$864,816</td>
<td>$184,777</td>
<td>$362,835</td>
</tr>
<tr>
<td>Overhead (57% of Salaries &amp; Wages)</td>
<td>405,084</td>
<td>88,394</td>
<td>171,463</td>
</tr>
<tr>
<td></td>
<td>10,732*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Retirement (7.65 % of Applicable Salaries &amp; Wages)</td>
<td>9,193</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grand Total</td>
<td>$1,289,825</td>
<td>$273,171</td>
<td>$534,298</td>
</tr>
</tbody>
</table>

*Research Planning Study
**Includes Publication Costs
<table>
<thead>
<tr>
<th>Budget Category</th>
<th>Approved Contribution</th>
<th>1967/69</th>
<th>1969/71</th>
<th>1971/73</th>
<th>Total</th>
<th>Balance as of July 1, 1973</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaries &amp; Wages</td>
<td>434,184</td>
<td>141,027</td>
<td>180,288</td>
<td>92,000</td>
<td>413,315</td>
<td>20,869</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent</td>
<td>111,553</td>
<td>81,780</td>
<td></td>
<td>29,773</td>
<td>111,553</td>
<td></td>
</tr>
<tr>
<td>Books * * * * *</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Expendable Supplies**</td>
<td>17,787</td>
<td>1,939</td>
<td>10,848</td>
<td>5,000</td>
<td>17,787</td>
<td></td>
</tr>
<tr>
<td>Travel</td>
<td>5,522</td>
<td>-</td>
<td>3,522</td>
<td>2,000</td>
<td>5,522</td>
<td></td>
</tr>
<tr>
<td>Computer Time</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>$569,046</td>
<td>$224,746</td>
<td>$194,658</td>
<td>$128,773</td>
<td>548,177</td>
<td>20,869</td>
</tr>
<tr>
<td>Overhead (57% of Salaries &amp; Wages)</td>
<td>247,485</td>
<td>80,386</td>
<td>102,764</td>
<td>52,440</td>
<td>235,590</td>
<td>11,895</td>
</tr>
<tr>
<td>Retirement (7.65% of Applicable Salaries &amp; Wages)</td>
<td>5,753</td>
<td>-</td>
<td>-</td>
<td>5,753</td>
<td>5,753</td>
<td>--</td>
</tr>
<tr>
<td>Grand Total</td>
<td>$822,284</td>
<td>$305,132</td>
<td>$297,422</td>
<td>$186,966</td>
<td>$789,520</td>
<td>$32,764</td>
</tr>
</tbody>
</table>

*This analysis does not show the additional matching contribution by the Georgia Institute of Technology in the amount of $104,000 toward the purchase, through its library, of library materials related to information and computer science during the first four year period of the grant.

** Includes Publication Costs
Manpower

Table 9 compares the planned manpower effort under NSF Grant GN-655 against the actual expended manpower as of July 1, 1973 (in terms of EFT*).

Table 9. Comparison of Planned and Expended Manpower (GN-655)
(July 1, 1967 - June 30, 1973)

<table>
<thead>
<tr>
<th>Manpower Category</th>
<th>GN-655 Budget</th>
<th>1967/69</th>
<th>1969/71</th>
<th>1971/73</th>
<th>Total</th>
<th>Balance as of July 1, 1973</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Investigator</td>
<td>3.18</td>
<td>1.13</td>
<td>1.75</td>
<td>.75</td>
<td>3.63</td>
<td>(.45)**</td>
</tr>
<tr>
<td>Faculty Associate</td>
<td>35.68</td>
<td>12.73</td>
<td>12.37</td>
<td>13.69</td>
<td>38.79</td>
<td>(3.11)**</td>
</tr>
<tr>
<td>Non-Faculty Professionals (Other)</td>
<td>21.00</td>
<td>2.36</td>
<td>7.98</td>
<td>.63</td>
<td>10.97</td>
<td>10.03</td>
</tr>
<tr>
<td>Graduate Students</td>
<td>18.00</td>
<td>5.09</td>
<td>8.00</td>
<td>5.86</td>
<td>18.95</td>
<td>(.95)**</td>
</tr>
<tr>
<td>Pre-Baccalaureate Students</td>
<td>3.00</td>
<td>.07</td>
<td>1.03</td>
<td>.83</td>
<td>1.93</td>
<td>1.07</td>
</tr>
<tr>
<td>Technical</td>
<td>2.00</td>
<td>.29</td>
<td>1.94</td>
<td>.05</td>
<td>2.28</td>
<td>(.28)**</td>
</tr>
<tr>
<td>Secretary/Clerical</td>
<td>12.90</td>
<td>3.65</td>
<td>5.37</td>
<td>2.40</td>
<td>11.42</td>
<td>1.48</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>95.76</td>
<td>25.32</td>
<td>38.44</td>
<td>24.21</td>
<td>87.97</td>
<td>7.79</td>
</tr>
</tbody>
</table>

* 1.00 indicates Full-Time for one fiscal year
** Overexpenditure
Equipment

As of July 1, 1973, the equipment budget of the NSF portion of Grant GN-655 had a free balance of $.00. As its matching contribution to the Grant, the Georgia Institute of Technology has expended $111,553 for equipment.

Following is a detailed list of equipment and equipment maintenance and rental contracts associated with the School's Science Information Research Center as of July 1, 1973.

Table 10. Equipment Expenditures/Encumberances

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Units</th>
<th>Description</th>
<th>Amount Expended/Encumbered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>NSF</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>PDP-8/I Digital Computer with:</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) MC8/I Memory Extension Control</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) KE8/I Automatic Multiply/Divide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) DM01 Data Channel Multiplexer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) RF08 Disk Control</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) RS08 Disk File</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) TC01 Dectape Control</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) TU55 Dectape Transports</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) KW8/IE Real Time Clock</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) VD8/I Display with 611 Scope</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) AF01A A/D Converter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) A121 Multiplexer Switch</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) AA01 D/A Converter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) PT08/C Dual Channel Serial</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) PT08/F Line Interface with EIA Adaptor</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) PC8/I</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) DP01A Reader &amp; Punch</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) PT08X</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) ASR 33 Teletype Console Unit</td>
<td></td>
</tr>
</tbody>
</table>

2 1 Burroughs B-5500 - - Transferred
(2) Central Processors
(8) Core Modules of 4,096 forty-eight bit words each (32,768 48 bit words)

-28-
<table>
<thead>
<tr>
<th>Item No.</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2)</td>
<td>Data communication telephone line adapters for Models 33 and 35 teletype remote terminals</td>
<td></td>
</tr>
<tr>
<td>(3)</td>
<td>High Speed Disk Storage Modules (9.6 million characters each)</td>
<td></td>
</tr>
<tr>
<td>(4)</td>
<td>I/O Channels (fully floating)</td>
<td></td>
</tr>
<tr>
<td>(10)</td>
<td>Magnetic Tape Transports, 200 and 556 bits per inch</td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>High Speed Card Readers, 1400 cards per minute</td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>High Speed Line Printers, 1040 lines per minute</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Card Punch, 300 cards per minute</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>PDP-11/45 CA</td>
</tr>
<tr>
<td>(2)</td>
<td>Blocks &amp; K Words, Type MM11-5</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>MOS Memory Control MS-11-8C plus</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>KW11-P Real Time Clock</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>KW11-L Line Frequency Clock</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Read Only Memory-Type MR11-A</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Teletypewriter Control Console</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Bulk Storage-Type RK11-CA</td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>General Purpose Interface Boards</td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>DC11-AB Dual Clock &amp; System Unit</td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>DC11-DA Full Duplex Serial Module Set</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Teletype (ASR 33) - Terminal System With ADC 260 Acoustic Data Coupler</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Teletype (Inktronic) Receive Only Printer</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Motorola (MDS-1000) Document Reader</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Bolt, Beranck &amp; Newman (800A) 17&quot; x-y Analog Recorder</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>Model GP-1 Graf/Pen (14&quot; X 14&quot;)</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>IBM (A-22-09) Keypunch</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>IBM 2741 Model 1-APL Terminal with Dial Up &amp; Interrupt</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>4 1/2 Digit 2400 Series Digital Multimeters (Model) 2440</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>Tektronic Storage Display Unit (611)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Amount Expended/Encumbered</th>
<th>Grant GN-655</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSF</td>
<td>29,773</td>
<td>17,627</td>
</tr>
<tr>
<td>GIT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

-29-
<table>
<thead>
<tr>
<th>Item No.</th>
<th>Units</th>
<th>Description</th>
<th>Amount Expended/Encumbered</th>
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Table 11. Equipment Maintenance Contracts

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Total Yearly Laboratory Equipment Maintenance $32,231

Table 12. Equipment Rental Contracts

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<td>Special Service Arrangement.......($45.00/Mo.)</td>
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Total Yearly Laboratory Equipment Rental $1,967
Travel

As of July 1, 1973, the travel budget of the NSF portion of Grant GN-655 had a free balance $1,505, the Georgia Institute of Technology matching contribution to the travel budget of the Grant had a free balance of $.00. All travel charged against the NSF portion of the Grant (with the exception of $1,508 used to support Dr. Vladimir Slamecka's travel to U.S.S.R. as part of the U.S. - U.S.S.R. Scientific and Technical Cooperation Agreement -- for details see pages 7 and 23 of this report) was domestic. The purpose of the travel expenditures fell into the following categories: (1) appointments of the Projector Director at the Foundation; (2) presentation of papers at national meetings of major associations; (3) attendance of regional meetings of professional associations; and (4) travel associated with activities of selected research and development projects.
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(July 1, 1972 - June 30, 1973)

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1. "1971/72 Annual Summary Report, NSF Grant GN-655." Atlanta, Georgia, Georgia Institute of Technology (School of Information and Computer Science), September 25, 1972. 33p. (Annual report to Dr. Edward C. Weiss, NSF).


Proposals

5. "Georgia Institute of Technology, Science Information Research Center." Atlanta, Georgia, Georgia Institute of Technology (School of Information and Computer Science), May, 1973. (Proposal to NSF requesting an extension of NSF Grant GN-655 for the period of 18 months beginning July 1, 1973, without additional funding).

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23. Rogers, D. E. "A Comparative Evaluation of Several High-Level Programming Languages." Presentation to the ACM Student Chapter, Georgia Institute of Technology, Atlanta, Georgia, June 1, 1973.


30. Sweeney, J. W. "What is An Information Scientist?" Presentation to the School of Biology, Georgia Institute of Technology, Atlanta, Georgia, November 26, 1972.


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42. Slamecka, V. "Nuevas Tendencias Educacionales en Ciencia de La Informacion." (New Trends in Education in Information Science), INFORMACIONES (Biblioteca de La Universidad Nacional de La Plata) 41:3-7; 42:3-6 (July 1972; August 1972).


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Theses


Papers Accepted for Publication


70. Slamecka, V. Use of Audiographic Technology in Continuing Graduate-Level Science Information. Atlanta, Georgia, Georgia Institute of Technology (School of Information and Computer Science), 1973 (in press).


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<td>- x     x x x</td>
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<td>Keen, David Earl</td>
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<td>3</td>
<td>Tennessee</td>
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<td>- - - x</td>
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<td>27.</td>
<td>Dendall, John S. Jr.</td>
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<td>2</td>
<td>Missouri</td>
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<td>28.</td>
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<td>30.</td>
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<td>34.</td>
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<td>35.</td>
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<td>Peek, Thomas A.</td>
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<td>Peplow, Kenneth Wm.</td>
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<td>38.</td>
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<td>39.</td>
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<td>40.</td>
<td>Raymo, Randall David</td>
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<td>49.</td>
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<td>Georgia</td>
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<td>- x x</td>
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<td>50.</td>
<td>Smith, Martin Paul</td>
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<td>Georgia</td>
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<td>- - x</td>
</tr>
<tr>
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<td>NAME</td>
<td>SEX</td>
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<td>LEGAL RESIDENCE</td>
<td>BIRTH YEAR</td>
<td>QUARTERS ENROLLED</td>
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<td>Stegner, Conrad G.</td>
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<td>Georgia</td>
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<td>- x x x x</td>
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<td>54.</td>
<td>Strode, Margaret S.</td>
<td>F</td>
<td>3</td>
<td>Virginia</td>
<td>52</td>
<td>- - x x x</td>
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<td>55.</td>
<td>Terrell, Vicki Lynn</td>
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<td>Georgia</td>
<td>45</td>
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<td>56.</td>
<td>Trimmer, Gary P.</td>
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<td>53</td>
<td>- - x x x</td>
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<td>57.</td>
<td>Tyson, Jeanette A.</td>
<td>F</td>
<td>3</td>
<td>Georgia</td>
<td>53</td>
<td>- x x x x</td>
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<td>58.</td>
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<td>Georgia</td>
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<td>Georgia</td>
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<td>- - - x</td>
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<td>60.</td>
<td>Wolf, Karl R.</td>
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<td>Connecticut</td>
<td>54</td>
<td>- - x x</td>
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<tr>
<td>61.</td>
<td>Zayas, Fernandez A.</td>
<td>M</td>
<td>1</td>
<td>Florida</td>
<td>54</td>
<td>- x x x x</td>
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<tr>
<td>62.</td>
<td>Zunz, Wilson R.</td>
<td>M</td>
<td>2</td>
<td>Georgia</td>
<td>54</td>
<td>- - - x</td>
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**TOTALS** 0 28 47 60
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Preliminary Announcement

GRADUATE PROGRAMS IN
BIOMEDICAL INFORMATION/COMPUTER SCIENCE

Beginning Fall Quarter of 1972, the School of Information and Computer Science of the Georgia Institute of Technology, in association with the Emory University School of Medicine, will offer graduate programs in biomedical information and computer science, leading to the degrees of Master of Science and Doctor of Philosophy. The professionally-oriented Master of Science program emphasizes the design of advanced information processing systems and networks for health care and biomedicine. The Ph.D. program is research-oriented and seeks to advance the understanding and theory of biomedical information/computer science.

Curriculum. The Master of Science program comprises two options. Biomedical Information Systems and Biomedical Computer Systems, each of which offers four to five academic quarters of carefully structured courses, offered jointly by the School of Information and Computer Science (Georgia Tech) and the School of Medicine (Emory University). The doctoral program is similar in format to the present Ph.D. program of the School of Information and Computer Science, with emphasis on coursework and dissertation research in biomedical information/computer science. The degree requirements and standards of these programs are identical to those of the regular degree programs offered by the School of Information and Computer Science. The degrees are awarded by the Georgia Institute of Technology.

Admission Requirements. The graduate programs should prove particularly attractive for persons holding advanced degrees in medicine or the natural sciences and seeking interdisciplinary professional or research careers in biomedical information processing. Other students applying for admission must have earned a Bachelor's degree from an accredited institution, and should show evidence of their ability and motivation to pursue advanced work. The undergraduate major field of study is not specified; background in the pre-medical or biological sciences is appropriate. In all cases, the prospective students' preparation should include substantial work in mathematics. For detailed description of admission requirements please see p. 12.

Stipends. A limited number of stipends ($2400–$2600/year), and dependent allowances ($500/year) are available to qualified M.S. and Ph.D. students who demonstrate the intention to pursue careers in biomedical information/computer science.
UNDERGRADUATE PROGRAMS

The School of Information and Computer Science is a graduate department of instruction and research in the General College of the Georgia Institute of Technology. In an endeavor to provide comprehensive and flexible education at all levels of the discipline, the School also offers two types of undergraduate programs. Their intent is to provide the equivalents of, respectively, a "minor" and a "major" in these fields.

Either undergraduate program is open to baccalaureate degree students registered in any degree-granting department of the Institute who have completed ICS 151 - DIGITAL COMPUTER ORGANIZATION AND PROGRAMMING (or an equivalent course), and have secured the approval of their departmental advisors to take elective coursework in the information sciences. While neither of these undergraduate programs is intended to be a prerequisite for admission to graduate study in information and computer science, students successfully completing either of the two options may consider themselves well prepared for pursuing graduate work in this discipline.

Elective "Minor" in Information and Computer Science

This program is designed flexibly to serve two categories of students: those interested in information/computer science as a formal discipline of study; and those interested in information processing and computing techniques and their application to other fields of knowledge or professions.

The academic program recommended for the first type of student is shown in Table 1; it consists, in addition to ICS 151, of eight 3-hour courses providing a balanced treatment of the formal core of this science.

The second category of students, interested in techniques and applications of information processing and computing to their disciplines and professions, should substitute four courses in Table 1 (ICS 325, 342, 406 and 410) with 12 hours of electives appropriate to their objectives. These electives may be in areas such as: systems analysis; computer programming; numerical analysis; computing applications in management, engineering process control, or automation; switching theory, logic design and hardware architecture; or others. The School of Information and Computer Science offers courses in several of these areas; students are also encouraged to pursue relevant elective courses offered by their departments.
Table 1.
Elective Undergraduate "Minor" in Information and Computer Science

<table>
<thead>
<tr>
<th>Year</th>
<th>Quarter</th>
<th>Course</th>
<th>Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshman</td>
<td>Fall</td>
<td>ICS 151-Digital Computer Organization and Programming (or equivalent)</td>
<td>2-3-3</td>
</tr>
<tr>
<td></td>
<td>or Winter</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>or Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sophomore</td>
<td>Fall</td>
<td>ICS 256-Computer and Programming Systems</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td>or Winter</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>Math 239-Introduction to Set-Theoretic Concepts</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Junior</td>
<td>Fall</td>
<td>ICS 325-Introduction to Cybernetics</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>ICS 310-Computer-Oriented Numerical Methods</td>
<td>2-3-3</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>ICS 355-Information Structures and Processes</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Senior</td>
<td>Fall</td>
<td>ICS 342-Introduction to Semiotics</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>ICS 406-Computing Languages</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>ICS 410-Problem Solving</td>
<td>3-0-3</td>
</tr>
</tbody>
</table>

Undesignated B.S. "Major" in Information and Computer Science

The Institute offers experimentally an undesignated baccalaureate degree, the mechanism of which permits certain students to major in information/computer science. Interested and qualified students should arrange an interview with the Director of the School of Information and Computer Science prior to seeking a formal approval of such a program by the Curriculum Committee.

Inquiries concerning these programs should be addressed to Prof. J. J. Goda, Jr., ICS Undergraduate Advisor (Room 301, D. M. Smith Building, Telephone: (404) 894-3156 — or to Director, School of Information and Computer Science, Georgia Institute of Technology, Atlanta, Ga. 30332.
GRADUATE DEGREE PROGRAMS

The School offers two types of advanced degree programs, each having a distinct objective and content: a professional program in information and computer systems design terminating with the designated Master of Science degree; and a research-oriented program emphasizing theory and leading to the degree of Doctor of Philosophy.

The options open to the entering students are illustrated in the schema below. Students seeking education for professional careers in the information and computer industries should select one of the two options of study offered in the applied Master's program. Students interested in academic or research careers may, with the prior approval of the School, immediately begin preparing themselves for the Preliminary Examination in the Ph.D. program (formal admission to the doctoral program is contingent, however, on the passing of this Examination). The academic effort involved in preparing for the Preliminary Examination is approximately equivalent to that of the Master's degree programs; thus students unable to complete their doctoral program are eligible to receive the M.S. degree providing they have met the requirements for that degree.
THE DEGREE OF MASTER OF SCIENCE

The M.S. degree program extends over a minimum of four academic quarters, beginning the Fall Quarter. Full-time students should normally allow for five or six quarters to complete their degree requirements, and to take advantage of the broad course offerings of the School and the Institute.

Entering students seeking professionally-oriented education will select one of the two options of study offered by the School at the M.S. degree level: OPTION II - INFORMATION SYSTEMS DESIGN, emphasizing the analysis and design of advanced information systems and networks; or OPTION III - COMPUTER SYSTEMS DESIGN, concerned with the design, operations and management of computer systems (as complexes of objectives, people, hardware and software). Two new degree programs of study, representing a specialized orientation in information and computer systems design careers in biomedicine and health care, will be introduced in Fall 1972 through cooperation with the School of Medicine, Emory University.

In consultation with the faculty advisor of the program selected, each student outlines his individual program of study leading to the M.S. degree; examples of curricula in Options II and III are shown in Table 2. Considerable freedom is available to students and their faculty advisors to structure course programs which meet a wide variety of educational objectives. In addition to the broad course offering by the School, numerous relevant subjects may be elected by students from other departments of instruction. The student's plan of study must be approved by his faculty advisor and the Director of the School.

To fulfill the requirements for the Master's degree, students must successfully complete at least 50 quarter hours (of which a minimum of 35 must be in courses at the 600-700 level), and attain at least a 2.7/4.0 grade average. A Master's thesis is not required; however, exceptionally qualified students may request to write a thesis in lieu of 17 credit hours of graduate coursework.

Admission requirements for the M.S. degree programs are described in detail on pp. 12-14, and should be studied carefully by prospective applicants.

The Georgia Institute of Technology operates a highly professional, nationwide placement service, with regularly scheduled personnel interviews by several hundred industrial and research organizations. Students are encouraged to avail themselves of the services of the Georgia Tech Placement Center early during their campus residency.
# Table 2
Typical Professional Programs Leading to a Master of Science Degree

<table>
<thead>
<tr>
<th>Quarter</th>
<th>OPTION II</th>
<th>OPTION III</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUMMER</td>
<td>Preparatory coursework needed to satisfy admission requirement for full graduate standing</td>
<td></td>
</tr>
<tr>
<td>FALL</td>
<td>*ICS 436-Information Systems</td>
<td>*ICS 445-Logistic Systems</td>
</tr>
<tr>
<td></td>
<td>*ICS 445-Logistic Systems</td>
<td>*ICS 458-Computer Systems</td>
</tr>
<tr>
<td></td>
<td>*ICS 458-Computer Systems</td>
<td>ICS 612-Graph Theory</td>
</tr>
<tr>
<td>WINTER</td>
<td>ICS 607-Communication and Control of Information</td>
<td>*ICS 452-Logic Design and Switching Theory</td>
</tr>
<tr>
<td></td>
<td>Mgt.620-The Theory of Industrial Organization</td>
<td>*ICS 656-Computer Operating Systems</td>
</tr>
<tr>
<td></td>
<td>*ISyE 634-Operations Research</td>
<td>*ICS 661-Computer Language Design</td>
</tr>
<tr>
<td>SPRING</td>
<td>ICS 621-Theory of Communication</td>
<td>ICS 705-Theory of Programming Languages</td>
</tr>
<tr>
<td></td>
<td>ICS 632-Equipment of Information Systems</td>
<td>*ISyE 634-Methods of Operations Research</td>
</tr>
<tr>
<td></td>
<td>*ICS 636-Information Systems Design</td>
<td>*ICS 658-Evaluation of Computer Systems</td>
</tr>
<tr>
<td></td>
<td>ICS 653-Computer Techniques for Information/Storage and Retrieval</td>
<td>ICS 761-Syntax-Directed Compilation</td>
</tr>
<tr>
<td>SUMMER</td>
<td>*ICS 616-Information Control Methods</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*ICS 629-Information Measures</td>
<td>ICS 632-Equipment of Information Systems</td>
</tr>
<tr>
<td></td>
<td>ICS 673-Organization and Management of Information Industry</td>
<td>ICS 652-Advanced Computer Organization</td>
</tr>
<tr>
<td></td>
<td>ICS 706-Special Problems</td>
<td>ICS 673-Organization and Management of Information Industry</td>
</tr>
<tr>
<td>FALL</td>
<td>Additional coursework needed or desired</td>
<td>ICS 706-Special Problems</td>
</tr>
</tbody>
</table>

* Required Courses
THE DEGREE OF DOCTOR OF PHILOSOPHY

For full-time students, the program of study and research leading to the doctorate in information and computer science extends over a minimum period of three calendar years, roughly divided as follows: preparation for the Preliminary Examination (first year); preparation for the Comprehensive Examination and for admission to candidacy (second year); dissertation research and thesis defense (third year). While the initial period is dominated by coursework, the student will commit an increasing effort to research activities very early in his residency.

Preparatory Study and Preliminary Examination

The objective of the Preliminary Examination, which serves to admit students to the doctoral program of the School, is to give each student an opportunity to demonstrate his scholarship and maturity in the subjects of the discipline, and to define his research interests and commitment.

The Preliminary Examination consists of two parts: a written examination, and a research essay. The contents of the written portion is based on the substance of a theory-oriented curriculum which the School offers as a preparation for doctoral study and the Preliminary Examination. The plan of study for this curriculum, shown in Table 3, extends over four academic quarters, beginning with the Fall Quarter.

The research essay is an analytical paper dealing in a scholarly manner with a research area of the student's choice and commitment. Its purpose is to assure the student's early commitment to a significant research activity which the faculty is qualified to guide and which harbors doctoral thesis topics. The development of such research interests is the early responsibility of each student aspiring to enter the doctoral program, and a matter of his initiative; the School's faculty will assist his inquiry into existing and potential research areas in several ways, by seminars, projects, guided study, and research assistantship appointments.

The subject scope of the research essay should be considerably broader than that of a dissertation topic or a similarly narrow problem statement. Its depth, however, must be substantial enough to demonstrate (1) the student's knowledge of the state of the art of that area, (2) his maturity in discerning significant research issues in that area, and (3) a good grasp of strategies, methods and techniques which are relevant and promising in such research. The time allowed for preparing the research essay is not restricted; the paper should, however, be submitted at the time of the Preliminary Examination (in three typewritten, double-spaced copies executed in the style recommended for other publications of the School) for review by the Doctoral Program Committee of the School and by other appropriate individuals. Its acceptance is a necessary condition for the passing of the Preliminary Examination.
Table 3
Suggested Preparation for the Ph.D. Preliminary Examinations in Information and Computer Science*

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Suggested Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>(Preparatory Coursework)</td>
</tr>
</tbody>
</table>
| 1. Fall | ICS 404-Topics in Linguistics  
          Math 405-Modern Algebra  
          ICS 445-Logistic Systems  
          ISyE 639-Experimental Statistics |
| 2. Winter | ICS 452-Logic Design and Switching Theory  
           ICS 642-Advanced Semiotics  
           ICS 706-Theory of Abstract Systems  
           ICS 726-Theory of Automata |
| 3. Spring | ICS 608-Syntax of Natural Language  
            ICS 626-Information Processes  
            ICS 645-Advanced Logic |
| 4. Summer | ICS 627-Information Processes II  
            ICS 629-Information Measures  
            ICS 646-Philosophy of Mind  
            ICS 652-Advanced Computer Organization |
| 5. Fall | (Additional coursework as required) |

* It is assumed that the student will have practical knowledge of computer use at least equivalent to ICS 458-Computer Systems, and ICS 705-Theory of Programming Languages.
The Preliminary Examination is offered in the Fall Quarter, and it should be taken no later than the fifth quarter in residence after admission to the School. Failure to pass the Examination (or to gain acceptance to the doctoral program of the School for other reasons, such as unavailability of positions or faculty advisors) does not disqualify students from obtaining the M.S. degree, provided the requirements for that degree have been met.

Language Examination

Foreign language examination is required by the Georgia Institute of Technology. The requirements are at present under revision; the examination may be taken at any time prior to admission to candidacy for the Ph.D. degree.

Advanced Study and Comprehensive Examination

Each student who has successfully taken the Preliminary Examination will be promptly assigned, by the Director of the School, an advisor who forms the student's Guidance Committee and serves as its Chairman. The Guidance Committee will specify, jointly with the student, his Ph.D. study program, further strengthening his formal preparation for the research area of his choice. A "Ph.D. Study Program" form will be executed by the Chairman of the student's Guidance Committee and forwarded for approval and record to the School Director. The Chairman should see to it that the credit hours for coursework or guided study correspond to the amount of work expected, and that the student registers appropriately for all such work. (For residence requirements see the Graduate Catalogue.)

Upon the completion of the coursework and guided studies outlines in the approved "Ph.D. Study Program" document, doctoral students may take the Comprehensive Examination. The Comprehensive Examination shall cover areas of knowledge relevant to the student's intended doctoral research; its principal objective is to demonstrate the student's competence and readiness to undertake independent research leading to a doctoral thesis. The subject range of this Examination is thus given by the selected research area (submitted and discussed by the student as part of this Preliminary Examination), by a reasonable spectrum of ramifications of this research area, and by his advanced studies subsequent to the Preliminary Examination.

The Comprehensive Examination is given and evaluated by an Examining Committee selected by the student's Guidance Committee. The Chairman of the Guidance Committee serves as Chairman of the Examining Committee, and he is responsible for scheduling and properly administering the Examination. The total number of examiners shall be no less than four and may include faculty members from other departments of the Institute.
The mandatory portion of the Comprehensive Examination is written, and the time of the students' response will not exceed five days. The student will receive from the Chairman of his Examining Committee a set of written questions at least 24 hours before the beginning of the Examination. At the option of the Examining Committee, the written examination may be followed by an oral exam; the latter should be given with minimal delay and immediately upon the evaluation of the student's written response.

Ph.D. Thesis Proposal

Since the purpose of the Comprehensive Examination is to demonstrate the student's competence and readiness for thesis research, the School will not approve thesis proposals until this Examination has been passed. The motivation for this procedure is to assure that a substantial portion of thesis research is carried out when the student is adequately prepared, and to prompt students to proceed with their program of study without undue delay.

The recommended sequence of steps in proposing the dissertation research topic is the following. Having selected, in consultation with his Guidance Committee, a qualified Thesis Advisor, the student prepares a detailed written research proposal containing (1) an up-to-date review of previous relevant work, (2) a detailed statement of the problem, (3) objectives and goals of proposed research, (4) research approach and methodology, (5) the significance and utility of expected research results, and (6) a time schedule he expects to follow for obtaining the Ph.D. degree. This proposal is presented, with the recommendation of the proposed Thesis Advisor, for approval to the Guidance Committee.

Next, the Chairman of the Guidance Committee schedules a public seminar at which the student presents the proposed dissertation research, allowing for questions from the audience. Following this seminar, the student's Guidance Committee considers the thesis proposal. After it is approved, the Chairman of the Guidance Committee informs the Director of the School in writing that the student has met the candidacy requirements.* (In his letter to the Director, the Chairman includes the following information: (1) the date and result of the Comprehensive Examinations; (2) the names of the members of the Examining Committee; (3) a statement when and how the language requirements were met; (4) the topic, objectives and methodology of doctoral research; and (5) the name of the Thesis Advisor.)

*The requirements governing the admission to candidacy for the Ph.D. degree are the following: (1) passing the Comprehensive Examination; (2) passing the Language Examination; and (3) submitting and having approved a formal statement setting forth a topic and methodology of a planned research project and naming a Thesis Advisor.
The student is formally admitted to candidacy for the Ph.D. degree by
the Dean of the Division of Graduate Studies and Research, at the recom-
mendation of the School Director.

**Doctoral Thesis Research, Review and Defense**

Immediately following the student's admission to candidacy, his
Guidance Committee is automatically dissolved, and its advisory function
is assumed by the Thesis Advisor. The Advisor recommends to the
School Director the appointment of a Thesis Advisory Committee consist-
ing of himself (as Chairman) and two Readers, at least one of whom should
be from another department of the Institute. The Committee jointly
reviews the progress of the candidate's research, and its members assist
him by guidance and advice. The Thesis Advisor carries the principal
responsibility for supervising and, if necessary, guiding the candidate's
research.

When the Thesis Advisory Committee finds a draft of the dissertation
satisfactory, the School will invite a distinguished authority on the topic
of the dissertation to serve as an external or visiting reader and review
the draft for the benefit of the student and the Committee.

Subsequently, upon the recommendation of the Thesis Advisory Com-
mittee, the candidate is called for an oral examination in defense of his
thesis. The Thesis Defense is administered by an Examining Committee
appointed by the Dean of the Division of Graduate Studies and Research,
and it is open to the public. The Defense may not be held earlier than six
months following the student's admission to candidacy.

**Certification of the Ph.D. Degree**

The requirements for certifying the degree of Doctor of Philosophy in-
clude submitting and having approved a doctoral thesis, and passing an oral
examination in defense of the thesis.

The Institute holds Commencement four times a year, at the end of
each academic quarter.
ADMISSION REQUIREMENTS

Students applying for admission to the graduate degree programs of the School of Information and Computer Science must have earned a Bachelor's degree from an accredited institution, and offer evidence of their ability and motivation to pursue advanced degree work. While the undergraduate major field of study is not specified, the prospective student's preparation should include substantial work in the mathematical sciences and in computer programming. The minimum requirements, described below, are to be considered essential by all full-time students entering the School's graduate programs in the Fall Quarter. Meeting these requirements is the applicant's responsibility; since college transcripts do not permit an in-depth evaluation of the student's academic background, acceptance to the graduate School of Information and Computer Science does not necessarily imply a judgment on the part of the School that the applicant fully meets the admission requirements.

All graduate degree curricula of the School are planned and offered on a 12-month basis starting with the Fall Quarter. Therefore, it is mandatory that all prospective full-time students having a background weaker than that specified below plan to enter the School in the preceding Summer Quarter, to take the coursework necessary to fully satisfy the admission requirements (or acquire such knowledge by other means, e.g., independent study, or comparable coursework at another institution). The School may schedule a diagnostic entrance examination prior to the Fall Quarter, in order to determine students' preparation in the subjects prerequisite for admission.

The minimum entrance requirements, applicable both to students entering either the M.S. or the Ph.D. program, are stated below. Suggested texts are given, and appropriate remedial courses (offered at the Institute) indicated.

Calculus and Linear Algebra

Working knowledge of the calculus, partial differentiation, multiple integrals, complex numbers and functions. Elements of linear algebra, including vector analysis and foundations of matrix theory with applications.

Texts: Thomas, Calculus and Analytic Geometry (4th ed.)
      Shields, Elementary Linear Algebra

Remedial Courses: Math 208, Math 236
Differential Equations

Linear and simple non-linear differential equations, with applications.

Text: Spiegel, Applied Differential Equations
Remedial Course: Math 208

Logic

The first order pure predicate calculus; a reasonable mastery of proof techniques. First order theories or axiom systems; theory of definitions; completeness and consistency of the predicate calculi.

Texts: Suppes, Introduction to Logic (Part I);
Kleene, Introduction to Logic (through the pure predicate calculus)
Remedial Course: PHS 339

Set Theory

Naive set theory. Thorough familiarity with the set theoretic notions of functions, relation and the elementary portion of the theories of cardinals and ordinals.

Text: Halmos, Naive Set Theory
Remedial Courses: Math 239; Math 438

Algebra (Ph.D. Students Only)

Universal algebraic theory of semigroups, rings, fields and Boolean algebras, with special attention to the latter. For the mentioned algebraic systems the student should have a knowledge of the following principal topics: filters, ideals, kernels, and morphisms; sub-algebras, quotients, and products; representation theory.

Texts: Abbott, Sets, Lattices, Boolean Algebras;
Birkhoff, Bartee, Modern Applied Algebra;
Birkhoff, McLane, Survey of Modern Algebra;
McLane, Birkhoff, Algebra
Remedial Course: Math 405
Probability and Statistics

Probability spaces and their construction; Bayes' and DeMoivre-Laplace theorems; random variables and functions; discrete and non-discrete probability distributions; laws of large numbers; linear regression; analysis of variance.

Texts: Myer, Introductory Probability and Statistical Applications; Tucker, An Introduction to Probability and Mathematical Statistics

Remedial Courses: Math 315, or ISyE 335

Computer Programming

Working knowledge of computer programming including the algorithmic processes of problem solving; reading and construction of flow charts; and writing programs in a higher language such as ALGOL or PL/1.

Remedial Course: ICS 151

Computer Organization and Use

Working knowledge of machine and assembly language for either an actual or a pseudo machine, including machine instructions, registers, memory, internal data representation, index registers, indirect addressing, and the assembly process. Familiarity with the characteristics of various storage devices and media (cards, tape, disk, drums, core, etc.) and their relation to programming.

Texts: Gear, Computer Organization and Programming; Maurer, Programming: An Introduction to Programming Languages and Techniques.

Remedial Course: ICS 256

Information Structures and Processes

Familiarity with: representation and processing of information in digital computers; data structures and their representation both in single level memories (array, lists) and in multi-level memories (file structures); and the various techniques of processing data: searching, sorting, and list processing, including recursive programming techniques.

Texts: Barron, Recursive Techniques in Programming; Foster, List Processing; Gear, Computer Organization and Programming; Knuth, The Art of Computer Programming (Vol.I); Maurer, Programming: An Introduction to Programming Languages and Techniques.

Remedial Course: ICS 355
SCHOOL OF INFORMATION AND COMPUTER SCIENCE

FACULTY

Director--Vladimir Slamecka; Professors--Lucio Chiaraviglio, James Gough, Jr., Gordon Pask (Visiting), Edward G. Roberts, Vladimir Slamecka, James W. Sweeney (Visiting), Miroslav Valach, Pranas Zunde; Associate Professors--Robert B. Cooper, Philip J. Siegmann; Assistant Professors--Albert N. Badre, John J. Goda, Jr., William I. Grosky, Michael D. Kelly, David E. Rogers, Robert M. Siegmann (Adjunct); Instructors--Charles R. Pearson, Robert I. Winner, Special Lecturer--John M. Gwynn, Jr.; Senior Research Engineer--Alton P. Jensen; Research Engineers--John M. Gehl, Charles H. Hooper; Assistant Research Engineer--P. C. Hankamer; Assistant to Director--Edmond F. Rumiano.

NOTE. This advance bulletin is a slight expansion of the programs and courses of the School of Information and Computer Science described in the official 1973/74 Catalogue of the Georgia Institute of Technology.
GENERAL INFORMATION

The goal of the discipline of the information, computer and systems sciences is to enhance the problem solving ability of man's mind, by designing information processing automata and systems and delegating to them some of the functions of the human mind. During the last decade, the use of computers has become indispensable in science, engineering, management, health care, education, and other advanced professions; and many believe that in the near future information processing will become the nation's largest industry, and its disciplines centrally important in both science and society.

Georgia Tech's School of Information and Computer Science reflects this growth and potential. Established in 1963, with the sponsorship of the National Science Foundation, as the world's first academic program in information science, the School today is the largest graduate department of the Institute, and among the largest computer science schools in the United States. It offers the B.S., M.S., and Ph.D. degrees in computer, information and systems sciences, both for professional and research oriented careers, and in many areas of specialization. Of particular note is the School's degree program in biomedical information processing, offered jointly with the Emory University School of Medicine. In addition to its degree programs, the School also offers carefully designed course sequences in computing for the majors of other departments.

ICS students have free access to the School's extensive computer laboratory which includes three computer systems (a large time-shared Burroughs B-5500, a PDP 11/45, and a PDP 8/I) and a wide array of special information processing devices. Other computing resources available to students of the School are the UNIVAC 1108 computer in the Georgia Tech Computer Center and an IBM 360/158 computer by special arrangement with the Atlanta Public Schools.

Details of the academic and research programs of the School are described in brochures available upon request. Please write to Director, School of Information and Computer Science, Georgia Institute of Technology, Atlanta, Georgia 30332, specifying the program of your interest.
UNDERGRADUATE PROGRAM

The undergraduate program, established in 1972, leads to the designated degree of Bachelor of Science in Information and Computer Science. It provides comprehensive education in the information, computer and systems sciences and professions, hospitable to multi-disciplinary objectives. The program has two primary directions:

(1) Acquisition of marketable knowledge and skills for professional careers in the following areas:
   a) Computer systems design
   b) Programming systems and languages
   c) Numeric computation
   d) Natural language processing
   e) Information systems design (for management, health care, education, etc.)
   f) Modeling and simulation of complex systems

(2) Preparation for theory-oriented graduate work in the following areas:
   a) Computer science
   b) Information science
   c) Systems science
   d) Artificial intelligence
   e) Logic
   f) Linguistics

A total of 194 credit hours are required for graduation. The 54 hours of electives include 24 hours of course work in one of the areas listed above.

Students considering studying information and computer science should plan their high school schedules to include the following required courses: English 4; Algebra 2; Plane Geometry 1; Advanced Algebra 1/2 (elementary functions, mathematical analysis, or analytical geometry are acceptable substitutes; Solid Geometry is NOT an acceptable substitute); Trigonometry 1/2; Chemistry 1; History 1; Lab Science 1. Detailed information regarding admission and application forms may be obtained by writing to the Director of Admissions, Georgia Institute of Technology, Atlanta, Georgia 30332.
### B.S. Program and Curriculum

#### Freshman Year

<table>
<thead>
<tr>
<th>Course No.</th>
<th>Subject</th>
<th>1st Qtr.</th>
<th>2nd Qtr.</th>
<th>3rd Qtr.</th>
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<td>General Chemistry</td>
<td>4-3-5</td>
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<td>1307/1308/1309</td>
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<td>1001/1002/1003</td>
<td>Analysis of Literature</td>
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<td>P. T.</td>
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<td>1100</td>
<td>Information, Computers, Systems: An Introduction</td>
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<td>1110</td>
<td>Reasoning and Computation</td>
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<td>3-0-3</td>
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<td>1400</td>
<td>Introduction to Algorithms and Computing</td>
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<td>2-3-3</td>
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<td></td>
<td>Electives c)</td>
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#### Sophomore Year

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<td>Particle Dynamics</td>
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<td>2123</td>
<td>Optics and Modern Physics</td>
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<td>Introduction to Set-Theoretic Concepts</td>
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<td>3003</td>
<td>Introduction to Structural Linguistics II</td>
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<td>3303/3304</td>
<td>General Psychology A, B</td>
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<td>2400</td>
<td>Computer Programming</td>
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<td>2600</td>
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<tr>
<td>2250</td>
<td>Technical Information Resources</td>
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<td>Hum/ML/SS</td>
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#### Junior Year

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<td>Introduction to Higher Algebra</td>
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<td>Principles of Economics</td>
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<td>Current Developments in Linguistics</td>
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<td>3215 d)</td>
<td>Problems in Probability and Statistics</td>
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<td>Introduction to Systems Theory</td>
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<td>Information Structures and Processes</td>
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<td>3150</td>
<td>Introduction to Mathematical Logic</td>
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<tr>
<td>3600/3601</td>
<td>Computer Systems I, II</td>
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<tr>
<td>4810</td>
<td>Logic Design and Switching Theory</td>
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<td>Electives e)</td>
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#### Senior Year

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<td>4120/4121</td>
<td>Introduction to Information Processes I, II</td>
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<td>4800</td>
<td>Selected Topics in ICS</td>
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<td>Electives e)</td>
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</tr>
</tbody>
</table>

a) With the consent of the School, these courses may be substituted by other empirical science courses relevant to the student's program.

b) Two of the following three courses shall be taken: P. T. 1020, P. T. 1040, P. T. 1050. A maximum of 3 credits of Physical Training may be applied toward the B.S. degree.

c) Free elective courses, to be taken at any time during the course of study. If basic ROTC is selected to satisfy these six credit hours, it must be scheduled beginning the first quarter of the Freshman year.

d) May be substituted by ISyE 335.

e) Electives in the Junior and Senior year will include 24 credit hours in one of several areas of specialization recommended and approved by the School of Information and Computer Science.
PROFESSIONAL GRADUATE PROGRAM

The objective of this one-year graduate program is to offer career education terminating with the designated degree of Master of Science in Information and Computer Science. The professional program is designed primarily for persons holding college or university degrees in quantitative fields other than computer science: in mathematics, the physical and natural sciences, engineering, or the medical sciences. Graduates of this program qualify for senior technical and management careers in the information processing industry and for appropriate positions in government, health care, education, and the military.

To earn the M.S. degree, students must complete at least 50 quarter hours, of which a minimum of 35 must be in courses at the 6000-8000 level. A Master's thesis is not required; qualified students may, however, request to write a thesis in lieu of 17 credit hours of graduate course work. The four-quarter program begins in the Fall Quarter, and its flexible curriculum draws on over 20 graduate level courses in applied information, computer and systems science. Typical curricula in this program include courses in systems design, computer software, computer systems, information processing applications, as well as appropriate courses in management science, operations research, numerical analysis, industrial psychology, and the social sciences. The 1973/74 schedule of these courses is shown on the next page; students may design their curricula from this schedule.

Students applying for admission to the professional M.S. degree program must have earned a Bachelor's degree from an accredited institution. While the undergraduate major field of study is not specified, the prospective students' preparation should include substantial work in mathematics, at least through the calculus, differential equations, set theory, and introductory probability and statistics. Computing competence of the entering students should include higher level and assembly language programming, data structures, and knowledge of searching and sorting algorithms. Students having a weaker background are expected, without exception, to enter the School in the preceding Summer Quarter (or earlier), and to take the course work necessary to meet these admission requirements.
### Professional M.S. Degree Program - Courses and Schedule

<table>
<thead>
<tr>
<th>Course No.</th>
<th>Course Title</th>
<th>Hours</th>
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<td>Su74</td>
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<tr>
<td><strong>Computer Systems</strong></td>
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<tr>
<td>ICS 3600</td>
<td>Computer Systems I</td>
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<td>3113</td>
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<tr>
<td>ICS 3601</td>
<td>Computer Systems II</td>
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<tr>
<td>ICS 6620</td>
<td>Advanced Computer Organization</td>
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<td>4610</td>
<td>x</td>
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<tr>
<td>ICS 6621</td>
<td>Equipment of Info. Systems (Lab.)</td>
<td>1-6-3</td>
<td>6620(coreq.)</td>
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<tr>
<td>ICS 7430</td>
<td>Evaluation of Computer Systems</td>
<td>2-3-3</td>
<td>6430</td>
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<td>Computer Networks</td>
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<td><strong>Computer Software</strong></td>
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<tr>
<td>ICS 3113</td>
<td>Info. Structures and Processes</td>
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<tr>
<td>ICS 3422</td>
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<td>3601</td>
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</tr>
<tr>
<td>ICS 6431</td>
<td>Design of Operating Systems</td>
<td>1-6-3</td>
<td>6430</td>
<td>x</td>
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<tr>
<td><strong>Information Systems</strong></td>
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<tr>
<td>ICS 4300</td>
<td>Information Systems</td>
<td>3-0-3</td>
<td></td>
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<td>ICS 6300</td>
<td>Advanced Systems Design</td>
<td>3-0-3</td>
<td>4300</td>
<td>x</td>
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<tr>
<td>ICS 6301</td>
<td>Problems in Systems Design</td>
<td>0-6-2</td>
<td>6300(coreq.)</td>
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<tr>
<td>ICS 6370</td>
<td>Information Control Methods</td>
<td>3-0-3</td>
<td></td>
<td>x</td>
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<tr>
<td>EU-BICS 300</td>
<td>Health Care Processes &amp; Systems</td>
<td>3-0-3</td>
<td></td>
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<tr>
<td>EU-BICS 310</td>
<td>Biomedical Literature &amp; Libraries</td>
<td>3-0-3</td>
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<tr>
<td>EU-BICS 330</td>
<td>Medical Information Systems</td>
<td>3-0-3</td>
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<tr>
<td><strong>Information Processing Applications</strong></td>
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<tr>
<td>ICS 3510</td>
<td>Computer-Oriented Num. Methods</td>
<td>2-3-3</td>
<td>3601, 3422</td>
<td>x</td>
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<tr>
<td>ICS 4350</td>
<td>Data Management Systems</td>
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<td>x</td>
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<tr>
<td>ICS 4370</td>
<td>Information Storage/Retrieval</td>
<td>3-0-3</td>
<td>3113, Ling3003</td>
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<td>Computer Graphics</td>
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<tr>
<td>ICS 6363</td>
<td>Pattern Recognition</td>
<td>3-0-3</td>
<td>Math 3215</td>
<td>x</td>
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<tr>
<td>ICS 6530</td>
<td>Graph Theory</td>
<td>3-0-3</td>
<td></td>
<td>x</td>
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<tr>
<td>EU-BICS 320</td>
<td>Medical Instrumentation &amp; Techniques</td>
<td>3-0-3</td>
<td></td>
<td>x</td>
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<tr>
<td>EU-AH 305</td>
<td>Biomedical Electronics</td>
<td>3-0-3</td>
<td></td>
<td>x</td>
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<tr>
<td><strong>Management</strong></td>
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<tr>
<td>ISyE 8734</td>
<td>Operations Research</td>
<td>5-0-5</td>
<td></td>
<td>x</td>
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<tr>
<td>Mgt 8000</td>
<td>Management Accounting &amp; Control</td>
<td>3-0-3</td>
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<td>To be arranged</td>
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<tr>
<td>Mgt 6101</td>
<td>Organizational Design</td>
<td>3-0-3</td>
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<tr>
<td>ISyE 6103</td>
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<td>3-0-3</td>
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<tr>
<td>Mgt 6160</td>
<td>Management Theory</td>
<td>3-0-3</td>
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<tr>
<td>ICS 6240</td>
<td>Organiz. &amp; Mgt. of Info. Industry</td>
<td>3-0-3</td>
<td>Mgt 6160</td>
<td>x</td>
</tr>
</tbody>
</table>
DOCTORAL PROGRAM

The objective of the doctoral program of the School of Information and Computer Science is the preparation of exceptionally qualified individuals for research, academic, and policy-level management careers. The degree of Doctor of Philosophy is awarded by the Georgia Institute of Technology for conducting independently an original study resulting in a significant contribution to the body of knowledge of the discipline, or for innovative applications of this knowledge that have an important impact on the field.

The doctoral program extends for a period of approximately three years. The first year of residence, which terminates with evaluating his progress, is devoted to the student's formal preparation in the foundations of the discipline and its branches; his demonstration of creative problem solving; and his commitment to one of the major areas of the discipline as his research domain. The second phase of the Ph.D. program stresses individual study and guided research, leading toward the formulation of a thesis project. Thesis research and the dissertation defense complete the Ph.D. program.

The faculty of the School of Information and Computer Science is prepared to guide doctoral research in the following broad areas:

1. Theory of information, information processes, and information measures;
2. Systems theory, and modeling and simulation of complex systems;
3. Metatheory of computer science, including logic, automata theory, formal languages, and computational complexity;
4. Theory of computer systems, including design and evaluation;
5. Human and social information processes, including man-machine communication; and

Students applying for admission to the doctoral program should offer evidence of exceptional scholastic ability, intellectual creativity, and research motivation. Preferable undergraduate preparation includes computer science, mathematics, logic, or other disciplines of science that encourage mathematical formalisms and abstract thought. The students are assumed to be competent in the use of computers.
**Ph.D. Program - Recommended First-Year Curriculum**

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Course No.</th>
<th>Course Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>ICS 4110</td>
<td>Topics in Linguistics</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td>ICS 4150</td>
<td>Logistic Systems</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td>ICS 6130</td>
<td>Philosophy of Mind</td>
<td>3-0-3</td>
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<tr>
<td></td>
<td>ICS 8001</td>
<td>(Research) Seminar</td>
<td>1-0-0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elective</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Winter</td>
<td>ICS 4120</td>
<td>Introduction to Information Processes I</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td>ICS 4156</td>
<td>Theory of Abstract Machines</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td>ICS 4380</td>
<td>Artificial Intelligence and Heuristics</td>
<td>3-0-3</td>
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<tr>
<td></td>
<td>ICS 8002</td>
<td>(Research) Seminar</td>
<td>1-0-0</td>
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<td></td>
<td></td>
<td>Elective</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Spring</td>
<td>ICS 4121</td>
<td>Introduction to Information Processes II</td>
<td>3-0-3</td>
</tr>
<tr>
<td></td>
<td>ICS 4157</td>
<td>Theory of Computability</td>
<td>3-0-3</td>
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<tr>
<td></td>
<td>ICS 6140</td>
<td>Systems Theory I</td>
<td>3-0-3</td>
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<tr>
<td></td>
<td>ICS 8003</td>
<td>(Research) Seminar</td>
<td>1-0-0</td>
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<td></td>
<td></td>
<td>Elective</td>
<td>3-0-3</td>
</tr>
<tr>
<td>Summer</td>
<td>ICS 8501</td>
<td>Special Problems **</td>
<td>15-0-15</td>
</tr>
</tbody>
</table>

* This program is normally followed by the entering student who is yet uncommitted to any research area in the discipline. The program may be modified as soon as he and a faculty advisor formulate more precisely the student's educational and research objectives.

** Guided study in a subject area of the student's and the School's research interest, intended to acquaint the student with the state of the art in that domain and leading to a written "research essay."
GRADUATE PROGRAMS
IN BIOMEDICAL INFORMATION AND COMPUTER SCIENCE
(jointly with Emory University School of Medicine)

In 1972, the Georgia Institute of Technology introduced pioneering graduate degree programs in biomedical information processing, intended for persons seeking inter-disciplinary careers in the milieu of health care and medicine. The programs, which strive at a pedagogic integration of information/computer/systems science with medicine, are offered jointly by the School of Information and Computer Science and the Emory University School of Medicine, with support of the National Institutes of Health. They lead to the degree of Master of Science in Information and Computer Science, and Doctor of Philosophy, awarded by the Georgia Institute of Technology.

In format, the two degree programs parallel the regular graduate programs of the School of Information and Computer Science. The professional, terminal M.S. program emphasizes the engineering design of advanced information processing applications and systems in health care. The doctoral program stresses research in those areas of information, computer and systems science that are relevant to biomedicine and health care. The curricula of these programs include substantial course work and internships at the Emory University School of Medicine, its clinical laboratories, affiliated hospitals, and libraries (see Page 20 for listing of Emory University courses).

These programs should prove attractive to two groups of persons seeking professional or research careers in biomedical information processing: recent college graduates in the abstract, natural or premedical sciences; and persons holding advanced degrees in medicine. As a minimum, applicants for admission must have earned a Bachelor's degree from an accredited institution, and should show evidence of their ability and motivation to pursue advanced work in biomedical information/computer science. While the undergraduate major field of study is not specified, all applicants seeking admission to these programs should have preparation in mathematics and in the use of computers.

The degree requirements and standards of the graduate programs in biomedical information and computer science are identical to those of the regular graduate programs of the School of Information and Computer Science.
ELECTIVE MINI-CURRICULA AND MINORS

Computing competence is rapidly becoming an indispensable element of the skills of all learned professions; consequently, quality education in science, engineering and management increasingly emphasizes formal instruction in computing. The School of Information and Computer Science offers all Georgia Tech students, regardless of their degree major, elective course sequences in computing, specifically designed to support the objectives and needs of their future professions.

For undergraduate students, five elective "mini-curricula" are offered, each comprising six courses totalling 18 credit hours:

(1) Computing for Science and Engineering
(2) Computing for Industrial Management
(3) Computing for Social Science and Humanities
(4) Computer Systems
(5) Information Systems

The first three mini-curricula serve students interested in the application of information processing and computing techniques to their respective field of knowledge or professions; the last two should appeal to students having deeper interest in applied information and computer science, and those who may be leaning towards graduate work in this field. Detailed course schedules are available from the office of the School of Information and Computer Science.

Information, computer and systems science is an appropriate minor field of study for the doctoral students of the Institute. Graduate students majoring in other departments of the Institute are encouraged to formulate, in consultation with their advisers and ICS faculty, programs of study that include formal training in computing tailored to their educational objectives.
COURSES OF INSTRUCTION

NOTE: The four-digit course numbering system of the School of Information and Computer Science has several mnemonic features. The first digit indicates the course level (1xxx-4xxx undergraduate; 6xxx-9xxx graduate). The second digit designates the subject orientation of the course; theory and foundations (x1xx); professional milieu (x2xx); computing applications (x3xx); computer software (x4xx); numeric computing and mathematics (x5xx); computer hardware and systems (x6xx); service courses (x7xx); and special problems (x8xx). The last three digits in the range x200 through x699 are identical with the subject codes of Computing Reviews, thus facilitating the student's access to the current literature related to these careers.

ICS 1100 — Information, Computers, and Systems: An Introduction
An orientation to the discipline and professions of information, computer and systems science, and to their functions in science and society. Visits to selected installations. 2-3-3

ICS 1110 — Reasoning and Computation
Elementary survey of the function of signs in thought and action, problem recognition, beliefs, language, meaning, information, inference, formalization, logic, programs and computation. 3-0-3

ICS 1400 — Introduction to Algorithms and Computing
First course on problem solving using computers. The concept, properties, and notation of algorithms. Problem analysis, development of algorithms, and their implementation in BASIC. 2-3-3

ICS 1700 — Digital Computer Organization and Programming
Algorithmic processes of problem solving; properties of algorithms; development of algorithms for the solution of numerical and non-numerical problems. The FORTRAN programming language. (No credit for ICS majors) 2-3-3

ICS 2250 — Technical Information Resources
Introduction to the literature and information services of science, engineering and management. Effective uses of the Georgia Tech Library. 1-0-1

ICS 2400 — Computer Programming
Prerequisite: ICS 1400
In-depth, parallel description of the syntax and semantics of FORTRAN and ALGOL; their effective use in the solution of problems. 2-3-3

ICS 2600 — Computer Organization and Programming
Prerequisite: ICS 2400
Introduction to computer organization, machine-language programming, and assembly systems. Internal data structures; selected programming techniques. 3-0-3

ICS 2700 — Computer and Programming Systems
Prerequisite: ICS 1700 or equivalent
Introduction to digital computer systems, computer organization, assembly language programming, and the structuring and processing of information. (No credit for ICS majors) 3-0-3

ICS 3110 — Semiotics
Basic concepts of signs relevant to natural and artificial sign processing systems. The representation relation; classification of signs. Analysis of sign systems. Examples and exercises. 3-0-3
ICS 3113 - Information Structures and Processes
Prerequisite: ICS 2400 or ICS 2700
Logical data structures and their machine representation. Processes on data structures, including scanning, searching and sorting, with emphasis on list processing techniques.

ICS 3116 - Philosophy of Grammar
Prerequisite: Ling 4002
Study of the philosophical foundations of prominent linguistic theories in history. Emphasis is on Indian, Greek, Latin, medieval, and rationalistic contributions to language theory.

ICS 3146 - Introduction to Cybernetics
History and branches of cybernetics. Concepts of system, structure, behavior, modeling, information, communication, self-organization and control are treated with respect to natural and artificial systems.

ICS 3150 - Introduction to Mathematical Logic
Prerequisite: Math 2020
Introduction to formal systems for the logical appraisal of inferences, including quantification and identity theory, referential interpretation, first order languages, soundness and completeness.

ICS 3151 - Proof Theory
Prerequisite: ICS 3150
Introduction to various facets of modern proof theory, including mechanical theorem proving and its application in computer science.

ICS 3342 - Introduction to Computational Linguistics
Prerequisites: ICS 3113, Ling 4002
Approaches to natural language processing by computer. Concordance construction; syntactic analysis; question-answering systems; mechanical translation; and computer programs for linguistic research.

ICS 3400 - Automatic Data Processing
Prerequisite: ICS 2400 or ICS 2700
Development of algorithms for the solution of business-oriented problems. File structure organization and processing on different types of storage devices. The COBOL programming language.

ICS 3422 - Survey of Programming Languages
Prerequisite: ICS 2400 or ICS 2700
Contrastive description of the linguistic constructs and implementation characteristics of widely used, representative programming languages such as ALGOL, FORTRAN, COBOL, SNOBOL 4, LISP, PL/I and APL.

ICS 3510 - Computer-Oriented Numerical Methods
Prerequisites: ICS 1700 or ICS 2400, Math 1309
Introduction to computer oriented numerical methods for error analysis, function evaluation, solution of systems of equations, curve-fitting, interpolation, numerical integration and differentiation.

ICS 3600 - Computer Systems I
Prerequisite: ICS 3113
Basic hardware and software components of computer systems. Topics include input/output, interrupts, storage devices, elements of operating systems, and microprogramming.
ICS 3601 – Computer Systems II
Prerequisite: ICS 3600, Math 3215 or equivalent

Study of hardware and software components of multiprogrammed computer systems including architecture, virtual memory, segmentation and paging, and parallel processing.

ICS 4110 – Topics in Linguistics

Study of selected topics in the grammar and semantics of natural language. The course is intended for graduate students with no prior background in linguistics.

ICS 4112 – Formal Semantics
Prerequisite: ICS 3150

Introduction to the relationship between formal languages and their possible interpretation, the latter being treated as abstract mathematical structures.

ICS 4117 – Introduction to Mathematical Linguistics
Prerequisites: ICS 3150, Math 3215, Ling 4002

Application of statistical and algebraic approaches to the study of linguistic structures from the viewpoint of their utility to a wide range of problems.

ICS 4120 – Introduction to Information Processes I
Prerequisites: ICS 1110, Math 2020, Math 3215 or equivalent

Explication of the information concept; its properties; information processes; content analysis and control; information sources; information transmission; channel capacity and efficiency, coding, noisy communication channels.

ICS 4121 – Introduction to Information Processes II
Prerequisite: ICS 4120

Perception, cognition, classification; data structures; choice of measurements; classification and clustering techniques; classification schemata in documentation; indexing; evaluation of classification and indexing. Pattern recognition.

ICS 4136 – Problem Solving
Prerequisite: ICS 3150

General approaches to problem solving, with emphasis on methods and techniques of formalizing intuitive heuristics. Structure of problems and goals; generation of alternatives, incomplete information.

ICS 4150 – Logistic Systems
Prerequisite: ICS 3150

An intermediate-level course dealing with formal systems for the logical appraisal of inferences. Introduction to the logic of programs.

ICS 4153 – Computing Languages
Prerequisites: ICS 3150, ICS 3422

Introduction to the formal study of programming languages, including languages construction based on Markov algorithms, complex languages features, data structures, embedding and extensibility.

ICS 4156 – Theory of Abstract Machines
Prerequisite: Math 2020

Study of fundamental concepts in the formal theory of automata emphasizing finite state machines, Turing machines, and computational power of machines.
ICS 4157 - Theory of Computability
Prerequisites: ICS 3150, ICS 4156
Introduction to formalizations of the notion of effective computability, with application to logic and automata. Turing computable and recursive functions; Godel's theorems.

ICS 4250 - Literature of Science and Engineering
Study of the reference and bibliographic sources of scientific, engineering and management literature, emphasizing strategies of manual and computer searching. Bibliographic project in student's discipline.

ICS 4300 - Information Systems
Prerequisite: ICS 2400 or ICS 2700
Major categories of information systems. Empirical methodology of analysis and design of computer-based systems. Definition of objectives; planning; analysis; design; implementation; evaluation. Case studies.

ICS 4305 - Science Information Systems
Prerequisite: ICS 4300
Information and communication in science. Design of science data banks, document repositories, information transfer services. Science information control at national and international levels.

ICS 4334 - Health Information Processing
Prerequisite: ICS 4300
Information processing applications in health care and biomedical research. Patient records; automation of clinical laboratory; hospital information systems; diagnostic decision making; biomedical documentation.

ICS 4350 - Data Management Systems
Prerequisites: ICS 3422, ICS 3601
Introduction to logical and physical structures of computer databases. Topics include file organization, directory decoding, searching, maintenance. Data Base Task Group Report.

ICS 4360 - Artificial Intelligence and Heuristics
Prerequisites: ICS 3150, ICS 3601
Heuristic vs. algorithmic methods for automatic problem solving. Study of machines and programs that deduce answers to questions from given facts, play games, prove theorems.

ICS 4370 - Information Storage and Retrieval
Prerequisites: ICS 3113, Math 3215, Ling 3003
Computer-aided organization and retrieval of bibliographic and natural-language information. Topics include statistical, syntactic, and logical analysis of information content; evaluation of retrieval effectiveness.

ICS 4380 - Data Communications
Prerequisite: ICS 3601
Comprehensive introduction to computer telecommunications, including: data codes; communication media; terminal devices and associated software; common carrier services; system design; cost analysis; telecommunications policy.

ICS 4390 - Computer Graphics
Prerequisite: ICS 3113
Introduction to computer graphics: underlying principles, devices, systems, and applications. Hands-on experience with available hardware and software packages. Programming projects in computer graphics.
ICS 4410 - Introduction to Compilers
Prerequisite: ICS 3601
Study of techniques for compiling the basic constructs of computer languages: arithmetic and Boolean expressions; iterative and conditional constructs; subprogram capability.

ICS 4430 - Introduction to Operating Systems
Prerequisite: ICS 3601
Survey of operating systems concepts, including: interrupt-driven systems; internal queues; memory and processor allocation; files; input-output; batch and remote; system accounting; instrumentation.

ICS 4500 - Mathematical Techniques for Information Science
Prerequisite: Permission of department
Mathematical topics of relevance in information, computer and systems science which are not explicitly included in the required core programs of the School.

ICS 4560 - Elements of Information Theory
Prerequisite: Math 4215
Shannon's mathematical theory of communication, concerning efficient transmission of information through noiseless and noisy channels, including proof of Shannon's fundamental theorem for discrete memoryless channels.

ICS 4600 - Computer Systems Laboratory
Prerequisite: ICS 3601
Intensive, hands-on computer laboratory for ICS majors. Machine-level operations; programming; computer interfacing.

ICS 4610 - Logic Design and Switching Theory
Prerequisite: ICS 3150
Theory and design of computer logic. Boolean algebra; AND/OR, NAND, NOR elements; maps, combinatorial circuits; sequential circuits; logic spaces; systems of simultaneous Boolean equations.

ICS 4611 - Computer Systems
Prerequisite: ICS 4610
Laboratory component of ICS 4610. Logical design of digital computers; construction and testing of prototype devices.

ICS 4800 - Selected Topics in Information and Computer Science
Prerequisite: Permission of department
Seminar designed to permit selected groups of students to pursue further study of significant areas of information, computer and systems science.

ICS 4810, 4811, 4812 - Design Project I, II, III
Prerequisite: Permission of department
An undergraduate thesis sequence consisting of an analytical or empirical investigation in an approved area of information, computer and systems science.

ICS 6112 - Advanced Semiotics
Prerequisite: ICS 4112
The semantics of higher order languages and various systems of non-standard logic. Topics include many-valued logics, intuitionistic logics, modal logics, and logics for programming languages.
ICS 6114 - Information Measures
Prerequisites: ICS 3150, Math 3215
Theory of quantitative methods of information measurement. Measure functions; syntactic, semantic, and pragmatic levels of information measurement; applications in communication systems, decision making, economic realms.

ICS 6116 - Syntax of Natural Languages
Prerequisite: ICS 4110 or Ling 4002
Study of natural language as a semiotic system with emphasis on a model or grammar incorporating the syntactic, semantic, and pragmatic dimensions of semiosis.

ICS 6117 - Mathematical Linguistics
Prerequisite: ICS 6116
Study of the mathematical structure of natural language, primarily from an algebraic viewpoint.

ICS 6130 - Philosophy of Mind
Prerequisite: Graduate standing
Higher mental processes including learning, concept formation, problem solving and perception, considered in relation to artificial intelligence. Linguistic and physiological models of human information processes.

ICS 6135 - Theory of Communication
Prerequisite: ICS 6130
Man-machine communication is analyzed by reference to studies of behavioral decision, conversational systems, and interactive measurement methods.

ICS 6140 - Systems Theory I
Prerequisite: Math 2020

ICS 6141 - Systems Theory II
Prerequisite: ICS 6140
Discrete dynamical processes, recurrence equations, and difference equations. Stability and convergence. Linearity, realizations, controllability and observability, response separation, and transfer functions. Sensitivity, control, and optimization.

ICS 6144, 6145 - Information Systems Design I, II
Prerequisite: ICS 4300
Analysis and synthesis of information systems, emphasizing mathematical modeling. Study of selected systems in areas such as data processing, management, command and control systems.

ICS 6146 - Cybernetics
Roles of various functions in living systems and their actual or potential realization in computers.

ICS 6147 - Theory of Models
Prerequisite: ICS 6140
ICS 6152 - Theory of Automata
Prerequisite: ICS 4156

Study of the significant results concerning finite automata, push-down automata, linear bounded automata, and Turing machines; recognizers of the four Chomsky phrase-structure languages.

ICS 6157 - Advanced Logic
Prerequisite: ICS 4157

Advanced treatment of the theory of recursive functions. Topics include recursively enumerable sets and relations, the recursion theorem, and degrees of unsolvability.

ICS 6210 - Communication and Control of Information

Effects of information control on human activities are analyzed at the individual, group and societal levels. Methodological issues are illustrated in the interpretation of empirical studies.

ICS 6240 - Organization and Management of Information Industry
Prerequisite: Mgt 6160

Principles of organization, operation and management of the information industry: computing services and centers, software companies, information brokers. Vendor relationship. Functions of government, professional associations.

ICS 6300 - Advanced Systems Design
Prerequisite: ICS 4300 or equivalent experience

Study of techniques useful in the empirical design of information proving systems, emphasizing quantitative methods of systems analysis, modelling, simulation, synthesis and evaluation.

ICS 6301 - Problems in Systems Design
Prerequisite: Permission of department

Advanced practicum in the analysis, synthesis, modelling, simulation, or evaluation of information processing systems or their components. Small-group or individual student projects.

ICS 6350 - Computer Techniques for Information Storage and Retrieval
Prerequisite: ICS 4350

Study of the state of the art in data base design. Approaches to data base formalisms and standardization. Term project.

ICS 6360 - Artificial Intelligence
Prerequisites: ICS 3151, ICS 4360

Advanced study of topics from heuristic search, automatic theorem proving, semantic information processing, representation theory, and robot research.

ICS 6363 - Pattern Recognition
Prerequisite: Math 3215 or equivalent

Selected topics from statistical pattern recognition. Examination of the problems of extracting useful information from pictures by automatic means.

ICS 6370 - Information Control Methods

Study of methods of information control, including: assessment of information needs; data collection and reduction; manual and automatic indexing, abstracting, and classification; evaluation and performance.
ICS 6410 - Computer Language Design
Prerequisite: ICS 3601
Detailed study of the basic techniques of compiler implementation, including: lexical scan, translation to intermediate language, object code generation and optimization.

ICS 6412 - Syntax Directed Compilation
Prerequisite: ICS 6410
Techniques for automating compiler construction, given appropriate descriptions of the syntax and the desired object code for the language being compiled.

ICS 6430 - Computer Operating Systems
Prerequisite: ICS 3601
Comprehensive study of the structure and implementation of computer operating systems for a spectrum varying from mini-computers to large time-sharing systems.

ICS 6431 - Design of Computer Operating Systems
Prerequisite: ICS 6430 or permission of department
Laboratory project in operating system design. Typically, students design, test and merge independent modules to form the nucleus of an operating system.

ICS 6530 - Graph Theory
Algorithmic combinatorics, including topics in permutations, combinations, enumeration, graphs and trees, with applications in information, computer and systems science.

ICS 6620 - Advanced Computer Organization
Prerequisite: ICS 4610
Study of formal transition from a given algorithm to the corresponding hardware structure, its timing, control, and optimization.

ICS 6621 - Equipment of Information Systems
Prerequisite or Corequisite: ICS 6620
Laboratory component of the professional graduate programs principally related to ICS 6620 and emphasizing the hardware/software interface at the logic level of digital computers.

ICS 7000 - Master's Thesis
Prerequisite: Permission of department
Credit to be arranged

ICS 7115 - Philosophy of Language
Prerequisite: ICS 6116
Study of selected topics in linguistics arising from philosophic discussion of language. Emphasis on contributions of Russell, Carnap, Quine, and Stevens to modern linguistic thought.

ICS 7120, 7130 - Information Processes I, II
Prerequisite: Permission of department
Advanced seminars in the theory and formalization of complex semiotic processes (e.g., classification, communication, problem solving, decision making), treated from the viewpoint of artificial intelligence.

ICS 7145 - Information Systems Optimization
Prerequisite: ICS 6145
Study of structures and behavior patterns which optimize information systems performance relative to selected efficiency criteria. Applications of queueing theory, network theory, and mathematical programming.
ICS 7430 - Evaluation of Computer Systems
Prerequisites: ICS 6430, Math 3215

Methods of evaluating performance of large-scale computer systems, with emphasis on performance analysis through simulation and queueing models.

ICS 7999 - Preparation for Ph.D. Qualifying Exams
Prerequisite: Permission of department

Credit to be arranged

ICS 8001, 8002, 8003 - Seminar
Prerequisite: Permission of department

1-0-0

ICS 8101, 8102, 8103 - Special Topics
Prerequisite: Permission of department

3-0-3, 3-0-3, 3-0-3

ICS 8501, 8502, 8503 - Special Problems
Prerequisite: Permission of department

Credit to be arranged

Small-group or individual investigation of advanced topics in information, computer, and systems science. Guided study and research.

ICS 8999 - Ph.D. Thesis Preparation
Prerequisite: Permission of department

Credit to be arranged

ICS 9000 - Ph.D. Thesis
Prerequisite: Permission of department

Credit to be arranged
COURSES IN BIOMEDICAL INFORMATION AND COMPUTER SCIENCE

EU-AH 200 - Medical Terminology 1-0-1
Study of the language of medicine. Word construction, definition, and use of terms related to the medical sciences, hospital service, and the allied health specialties.

EU-AH 300 - Anatomy 3-0-3
Lectures, demonstrations, and laboratories for non-medical students emphasizing the systemic approach to the structural organization of the human body.

EU-BICS 300 - Health Care Processes and Systems 3-0-3
Systematic introduction to the various approaches for delivering diagnostic and therapeutic health care. Medical specialties. Organization of hospitals, clinics, and public health facilities.

EU-AH 303 - Medical and Surgical Diseases 3-0-3
An introductory course to study the nature and cause of diseases.

EU-AH 305 - Biomedical Electronics 4-0-4
Applications of electronics in the health sciences. Passive and active circuits containing solid state and vacuum tube elements, amplifier configurations and logic circuits. Biomedical devices.

EU-AH 310 - Concepts of Scientific Inquiry 3-0-3
Philosophy of science and measurement. Sampling, experimental design, interview and questionnaire construction, empirical observation, index construction and scaling, and content analysis and coding.

EU-BICS 310 - Biomedical Literature and Libraries 3-0-3
Survey of (1) biomedical information resources and their organization, and (2) current medical library and network organization services. Information management and delivery for health care.

EU-BICS 320 - Medical Instrumentation and Techniques 3-0-3
Study of diagnostic instrumentation and techniques with emphasis on the informational contents of the various procedures. Interfacing diagnostic devices to information processing systems.

EU-BICS 330 - Medical Information Systems 3-0-3
Systematic study of the processing of medical information. Information sources; diagnostic and therapeutic decision-making. Organization and dissemination of clinical data.
APPENDIX

STATUS REPORT ON THE PRINCIPAL RESEARCH ACTIVITIES OF THE GEORGIA TECH SCIENCE INFORMATION RESEARCH CENTER, UNDER THE PARTIAL SUPPORT OF THE NATIONAL SCIENCE FOUNDATION

NSF Grant GN-655
May 20, 1972

School of Information and Computer Science
Georgia Institute of Technology
Atlanta, Georgia 30332
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**PRINCIPAL RESEARCH ACTIVITIES** (Georgia Tech Science Information Research Center)

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Project Title: Programming Languages
Principal Investigator: Lucio Chiaraviglio, Professor of Information and Computer Science
Collaborators: (New), Professor of Information and Computer Science
Richard A. DeMillo, Graduate Research Assistant

Research Results (1971/72). The central problem countenanced in this project is that of articulating appropriate concepts of validity and inference that will legitimate inferences from programs to programs. This is the essential task of logic. The accomplishment of this task contributes to the stated general objectives by providing the foundations for the appraisal of programs and, more generally, plans of action. Such a foundation is critically needed for programs that intend to model actual plans. Programs are often viewed as subspecies of plans of action that are relatively cheaply executed in limited and controllable artificial environments. Thus programs are increasingly used as test models for more general plans. The modelling analogy that runs from plans to programs is that plans stand in a relation to real world events they aim to control as programs stand to some of the events of their execution. The logic of programs aims to furnish the criteria of appraisal for programs, and extensions of the logic of programs to plans aim to furnish the criteria of appraisal for plans. The appraisal of the modelling analogies requires both the logic of programs and the logic of plans.

The results obtained in this project during the year 1971/72 may be summarized as follows:

a) An adequate syntax of formation that is the basis for the command structure common to most programming languages has been ascertained. This syntax of formation generates programming languages PL over arbitrary first order languages L.

b) The semantics of the generated languages PL have been ascertained. These semantics are based on the referential (model theoretic) semantics of L by considering abstract computers constructed from the carriers of the models of L. The analogue of satisfaction of a formula of L relative to an assignment is the notion of a program achieving a goal relative to some state of the universe of execution or abstract computer. The analogue
of truth of a formula of L in a model is the notion of a program achieving a goal for all states of the universe defined by the model. A number of theorems that relate the semantic properties of PL to the semantic properties of L have been shown.

c) A number of transformational syntaxes for PL which are appropriate to a selection of goal properties of programs (more properly goal properties of the executions of programs) have been constructed. For a distinguished subset of programs of PL (those that behave like sentences of L in that they achieve or fail to achieve the goal properties for all states of the universe of execution), the structures engendered by the transformational syntaxes are Boolean algebras. More generally the transformational syntaxes engender on PL the structures of functional Boolean algebras with transformations. These Boolean algebras have been related to the polyadic algebras of the base languages L thus unifying the logic of programs and the classical logics of first order languages.

Publications.


Proposed Research (1972/73). The proposed research for 1972/73 will consist of the following extensions of the results described:

a) We shall seek to extend the results described to a universal class of goal properties. At present the goal properties selected, viewed extensionally, form a field of sets over the property of termination. This field does not contain every subset of the termination set.

b) We shall seek to extend the logic of PL to languages L that are capable of expressing the goal properties of programs of PL. In these extended programming languages it will be possible to countenance programs of the form 'do G' where G is an arbitrary formula of PL and expresses relative to some model of L the sought goal. This extension represents an
important step towards a logic of plans in general.

c) We shall initiate full-scale studies of the metalogic of pro-
gramming languages and their extensions.
Research Results (1971/72). The central problem of this project is to articulate a mathematical model of digital computers and to study the principal properties of these machines and their processes in a precise algebraic setting. We envisage this to be the core task of a unified theory of computation that is capable of dealing with the concrete modern paradigm of computation. The accomplishment of this task contributes to the stated general objectives by providing an encompassing theory to cover the present and ever-increasing range of informational phenomena that are the manifestation of our expanding use of digital computers.

The results obtained in this subproject during the year 1971/72 may be summarized as follows:

a) The extant theory of recognizers (automata) has been embedded in the algebraic theory of abstract digital computers. For each class of automata in the hierarchy of recognizers (finite state, pushdown store, linear bounded, Turing machines, and their nondeterministic counterparts) an abstract digital computer has been constructed which captures all the computations of the machines in the class up to changes of state, head positions and tapes. Abstract digital computers are algebras and it has been shown that the theory of morphisms for these algebras is sufficient to recapture the hierarchy of automata.

b) The extant theory of degrees of unsolvability has been embedded in the algebraic theory of abstract digital computers. For each class of functions of a given degree an abstract digital computer has been specified which computes the function of that class. It has been shown that the theory of morphisms for these abstract computers is sufficient to recapture the hierarchy of degrees.

The mentioned results constitute a test of the adequacy of the proposed theory of abstract digital computers. The proof of the sufficiency of the theory to house the principal aspects of the extant mathematical theory of computation is evidence for the adequacy and universality of the theory.
Proposed Research (1972/73). The proposed research in this area for the year 1972/73 may be summarized as follows:

a) We shall seek to show that there is a version of the theory of abstract digital computers that is both necessary and sufficient to house a mathematical theory of computation. As has been mentioned, we have shown that the present concept of an abstract digital computer is sufficient to discriminate the mathematical distinctions of computational power. We shall try to show that each category of computers distinguishes a degree of computational power.

b) In order to carry out the above task we shall construct an algebraic generalization of the notion of degree of control. This algebraic generalization of control will be used to define computer categories. The notion of control that is relevant for this investigation is that of the internal control of digital computers. The notion of external control -- that control which is obtained through programming -- is the main concern of the next task.

c) We shall seek to establish the relationships that hold between external control, programming, and the internal control of abstract digital computers. The accomplishment of this task will build a bridge between the considerations developed in the study of the logic of programs and the algebraic study of digital computers.
Research Results (1971/72). The object of this study is to ascertain a range of alternatives to the modern digital computer. Our first objects of study are interactive, parallel, locally controlled information processors. We have formulated two theoretical models of such devices, both within combinatorial logic. The first model is called a "combinatonic computer." The second is called a "combinatory tessellation automaton." The latter model falls within our investigation of the general theory of arrays of intercommunication machines.

Results obtained during the year 1971/72 were as follows:

a) We have characterized the set theoretic structure of combinatonic computers. Such an identification is necessary for the algebraic study of combinatonic computers and the study of their relationship to abstract digital computers.

b) We have formulated the notion of a generalized tessellation automaton in order to unify all the previously done work on arrays of intercommunicating machines under a common methodological framework. Furthermore, we have shown that all sequences of configurations may be realized as the evolution of some initial configuration of some automaton of this type.

c) We have studied some range of trade-offs which exist between various constraints that may be imposed on general tessellation automata. In particular, the notion of a combinatory tessellation automaton has been developed.

d) A combinatory tessellation automaton has been shown to be universal in the sense of it being able to simulate a broad spectrum of previously studied cellular automata.

e) An n-dimensional analogue of combinatory abstraction has been identified. This n-dimensional analogue of abstraction will yield effective constructions for configurations whose evolution through time embodies some calculation or construction.
f) The problem of completeness has been studied for nondeterministic one-dimensional tessellation automata when nonuniformity is allowed in the application of the local state transition function.

Publications.


Proposed Research (1972/73). The proposed research in this area for the year 1972/73 may be summarized as follows:

a) We shall seek to determine the algebras of combinatonic computers and relate them to the algebras of abstract digital computers.

b) We shall continue our studies of the trade-offs which exist between various constraints that can be imposed on generalized tessellation automata and the resulting power of the automaton. Of particular interest here are the effects of these trade-offs on simulation.

c) We shall refine the aforementioned n-dimensional analogue to abstraction in order to develop a precise methodology for the effective construction of initial configurations which evolve in given ways.
d) The application of combinatory tessellation automata to processes of evolution, growth and development will be studied. Among the applications countenanced are biological modelling and the modelling of the growth and evolution of knowledge in specific sciences.

e) We shall study the decomposability of tessellation automata. The approach taken will be that of allowing the nonuniformities of neighborhood structure and local transition functions of one automaton to be controlled by another.
Project Title: Extended Effects of Information Processes and Processors

Principal Investigator: Lucio Chiaraviglio, Professor of Information and Computer Science

Collaborator: Warren T. Jones, Graduate Research Assistant

Research Results (1971/72). During the course of the year 1971/72 it was decided that some field of science would constitute a promising field for the study of the extended effects of information technologies. The factors on which the decision was based were: a) there exists a body of data pertinent to the transmission and origination of knowledge in science; b) a portion of this data is available in forms adapted to automatic processing; c) the importance of science to society and the rapidly increasing use new information technologies in science make the restriction of our studies to some science a reasonable strategic choice. The central problems countenanced in this project are twofold. The first is concerned with the transmission and origination of knowledge in a science. The second is concerned with the effect of new information technologies on the transmission and origination processes.

The results obtained during 1971/72 may be described as follows:

a) A methodology for studying and describing quantitatively the phenomena of transmission and origination of knowledge in science has been identified. The methodology is an adaptation of the genetic map construction techniques developed in classical genetics and the statistical techniques of population genetics. In the adapted methodology concepts are the analogues of genes. They are viewed as stable factors inherited in the process of knowledge transmission. The origination of concepts is viewed as mutational events. The articles, monographs and other products transacted in the process of communication which are the surface expressions of concepts are viewed as the phenotypic expression of these concepts. The processes of transmission (e.g., as exemplified by the citation processes) are viewed as the inheritance mechanisms.

b) A concrete setting for testing and refining the adapted methodology has been identified. Arrangements have been made for accessing data banks that contain reference information, abstract, texts and attendant indexing systems in the area of physics. Programs have been devised for accessing the
relevant data and constructing maps. These programs are currently in use to perform the initial retrodictive experimental tests of the adapted methodologies.

**Proposed Research (1972/73).** The proposed research in this area for the year 1972/73 may be summarized as follows:

a) Adapted genetic maps for some subareas of physics during periods for which we have sufficient data will be constructed. These maps will represent the structure of these subareas of physics that is produced by the processes of transmission. We aim to ascertain the changes of these structures through time and correlate them with changes in the environment of the science.

b) Once adapted genetic maps have been constructed for different time periods we can study the flow of concepts through time with the techniques adapted from population genetics. This extension of the task will require the expansion of the data bank to include indexing and bibliographical information not presently available in formats appropriate to computer processing.

c) An expansion of the presently available data banks will be made. This expansion will be accomplished largely by constructing data banks that contain both indexing systems and reference information from data banks that contain these features separately.
Project Title: Semiotic Studies of Natural Language
Principal Investigator: James Gough, Jr., Professor of Information and Computer Science
Collaborator: Charls R. Pearson, Graduate Research Assistant

Research Results (1971/72). Our linguistic research this past year has centered on four main areas: (1) Development of ostensive grammar; (2) Referential theory of meaning; (3) Use of ostensive theory of meaning to produce definitions in terms of ostensive structures; and (4) Development of a measure of ostensive information. The results will be discussed in the above order.

1. Development of ostensive grammar. During the course of the past year we have come to look upon the ostensive grammar as a semantic generator, reflecting a semantics created in the prehistory of man, a semantics general, coherent, and mathematic-like enough to support a linguistic symbolism (indeed, any and all) capable of realizing and representing man's most fruitful atomization of the extensive continuum confronting him, while simultaneously isolating him from the very same continuum. History has stamped this product as the crowning achievement of man's symbol creativity, the climax coming already in the first act. Civilizations emerge and submerge, science and culture in general progress, yet the ancient semantics, the primitive linguistic semantics forged by ancient man, stands ready to be used again and again in the genesis of cultures, their subcultures (myth, religion, philosophy, science, everyday discourse) and the lexicons and propositions appropriate to and for them. One is tempted to see in this timeless semantic system an impersonal intellectual legacy bestowed upon subsequent generations by an unknown and unknowing giver. It is perhaps the very feature of language to which Dufrenne (Language and Philosophy, 1968) is alluding, when he speaks of the "impersonal intelligence [in language], which awakens the individual and directs him into the ways of intelligence."

Thus, we are proceeding counter to most current linguistic research. Instead of increasing the depth and scope of an already developed grammatical model, we have chosen to proceed in an inverse direction: Seek the simplest possible semantics, build on it and generate complexified levels of semantics. Seek a semantics that is both prior to and necessary for all subsequent semantics, indeed, a semantics primitive enough to participate in the genesis of grammar and hence language.
This primitive semantics seems to be present in a single category, that of the indexical symbol. It represents an integrated, logically coherent schema, reflecting the simplest of egocentric semiotic drives, the desire to ostend, to point, and in pointing, to structure, to atomize the extensive continuum and thereby parce out objects, so that world stands objectified. This symbolism, ostensive in nature and egocentrically pragmatic, is uniquely referential and quantificational, yielding a logical proper-noun structure. It originates with the particular -- the particular unique object, the particular unique code-user. The genesis of this one single category with its internal logical coherency represents in our system the genesis of grammar.

We begin with the following set of ostensive primitives:

\[
\{ \text{THIS (IT)}, \text{HERE}, \text{NOW}, \text{HENCE}, \text{HITHER} \} \quad (1)
\]

de the members of which are values of idealized acts of ostension, abstracted from the set of indexical symbols, symbols that people in fact use to point to concrete things. The elements of (1) evidence a logical coherency, being interrelated by semantic rules of ostensive entailment:

\[
\begin{align*}
\text{HENCE} & \rightarrow \text{HERE}, \text{HENCE} \rightarrow \text{NOW} \\
\text{HITHER} & \rightarrow \text{HERE}, \text{HITHER} \rightarrow \text{NOW} \\
\text{HERE} & \rightarrow \text{THIS (IT)}, \text{NOW} \rightarrow \text{THIS (IT)}
\end{align*} \quad (2)
\]

and hence transitively:

\[
\text{HENCE} \rightarrow \text{THIS (IT)}, \text{HITHER} \rightarrow \text{THIS (IT)} \quad (3)
\]

The intensional significance of ostensive entailment is this: The semantic structure of the implicans includes the semantic structure of the implicate. In extensional terms, it means that whatever is denoted by THIS (IT) can also be denoted by HENCE, HITHER, HERE, NOW; and whatever is denoted by HERE or NOW can also be denoted by HENCE or HITHER. The elements of (1) are thus identical in their extensional semantic potential. They differ, however, in the non-ostensive component of their intensional semantics. Thus, the THIS (IT) value ((IT) being a free variable) represents a simple object ostension, the HERE and NOW values only add a spatial-temporal dimension to the simple object ostension, while the HENCE and HITHER values assign respectively an origin and goal semantics to the simple object ostension and thus to the HERE and NOW as well. Eventually these non-ostensive
semantic components affect the generation of general term symbols, of
case and the like. They reflect in part the genesis of grammar.

In our ostensive schema, we have come to look upon HENCE and HITHER
as initially forming one unit symbol and HERE and NOW as forming a second.
Thus, we introduce the following semiotic bi-entailments:

- HENCE if and only if HITHER
- HERE if and only if NOW

whereupon we write the ordered pairs:

- \(<\text{HENCE, HITHER} >\
- \(<\text{HERE, NOW} >\

which in view of (2) and (3) gives us the following ostensive entailment
schemata:

- \(<\text{HENCE, HITHER} \rightarrow \langle \text{HERE, NOW} > , \langle \text{HERE, NOW} >> (4)\)
- \(<\text{HERE, NOW} > \rightarrow \text{THIS (IT)} > (5)\)

and hence transitively:

- \(<\text{HENCE, HITHER} \rightarrow \langle \text{THIS (IT)} , \text{THIS (IT)} > > (6)\)

In (5) the THIS (IT) doublet of (2) collapses to a single space-time
ostensive value.

Our ostensive grammar in its present development begins with the
propositional schema:

- \(<\text{THIS (IT)} > \text{BE} <\text{THIS (IT)} > (7)\)

Here the terms appear in angular brackets. The sole primitive predicate
is BE, abstracted from the English verb "be." In a sense, it is a
predicate variable, its intensional semantics being defined by the in-
tensional semantics of the terms bracketing it.

We have developed a set of non-zero semantic transformations
that exploit the intensional and extensional semantic dimensions of the
indexical category and its internal coherency. Various alternate ostensive
semantic configurations that are potentially inherent in the original

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ostensive schemata are transformationally generated. For example, the intensional semantics of the implicate <THIS (IT)> is increased to that of the implicans <HERE, NOW>, so that the simple object ostension value is spatialized and temporalized. The desired intensional identity can be effected in several ways: initial forced-generation of a prepositional category with its spatial-temporal intensional semantics; subsequent proper choice of common noun, subsequent proper choice of verb, and the like. Non-zero semantic transformations also exploit the set-subset properties of the indexical symbols. All of the transformations reflect the linguistic creativity programmed in the system. We have attempted to generate various subclasses of nouns, predicates, prepositions, case, etc., all on the basis of the potential semantic interrelationships that may exist among the members of (1). These require further refinement and regimentation.

2. Referential theory of meaning. Over the last 2500 years many students and philosophers have found various regularities in the natural language phenomena that we loosely refer to as "meaning." However, these have never been collected in one place, catalogued, and systematically analyzed. The results of a literature search on this subject has yielded a beginning on this task. One result that stands out strikingly is that most of the investigators have enjoyed no mutual agreement and understanding. That is, each means something different, when he uses the term "meaning". These different meanings of "meaning" have been systematically collected and successfully analyzed, using a semiotic definition and analysis of the dimensions of semiosis and the components of meaning.

These results set certain bounds on the shape any successful theory of meaning can take. These limitations have been surveyed to show the broad outlines that any theory of meaning will have.

The following steps of our study have been completed and are in the process of being written up: (a) Literature survey of studies in meaning for natural language; (b) Cataloguing of natural laws of meaning and philosophical requirements for a theory of meaning; (c) Semiotic definition and analysis of the components of meaning; and (d) Systematic analysis of Item (b) according to Item (c) for the purpose of surveying the limitations implied for a theory of meaning.
3. **Use of ostensive theory of meaning to produce definitions in terms of ostensive structures.** An important problem in the testing of any theory of semantics is the production of an adequate data base. In order to test the ostensive theory of semantics a large number of words whose meanings have been defined in terms of ostensive structures should be available. The ostensive theory of meaning (usually called ostensive grammar) itself can serve as the tool for framing these definitions. To illustrate this point we propose to show how the ostensive theory of meaning may be used to define the ostensive part of meaning of the word "angle" in terms of ostensive structures.

4. **Development of a measure of ostensive information.** By comparing the computer addressing function to the ostensive function of natural language, a measure of information based on the ostensive grammar of Gough has been developed that appears to be useful for measuring information associated with computer addressing, indexing, and data-structuring phenomena. The mathematical details for Fortran-like data arrays have been worked out.

**Proposed Research (1972/73).** Our studies of natural language will continue to concentrate on the following topics: 1. Further development of ostensive grammar; 2. Referential theory of meaning; and 3. Development of a measure of ostensive information. Our proposal will be discussed in the above order.

1. **Further development of ostensive grammar.** We will continue our efforts to explore the creative power residing in the ostensive grammar. The fascinating question is whether and how the internal logically coherent semantic structure of but a single category may foreshadow the entire primitive semantic structure of grammar. This would require increased regimentation and integration of the present development of ostensive grammar. Other indexical symbols must be introduced into the system and the appropriate transformations developed that lead to greater semantic complexity. The entire study must then be coordinated with the insights and findings of the semiotic studies presently being carried out in particular by Pearson.

2. **Referential theory of meaning.** Many theories of meaning have been seriously proposed for natural language. Most of these violate one or more of the constraints established for a theory of meaning in our earlier study of the natural laws of meaning according to a semiotic definition and
analysis of the components of meaning. Several new theories that may be proposed appear to satisfy all these requirements and in addition predict many of the natural laws of meaning catalogued in this study. These will be checked in detail and redesigned as necessary to make sure that this is so.

These theories may be evaluated from several standpoints. The more of the known laws predicted, the more powerful a theory is, and hence a theory may be judged on its relative "power." Some theories may yield more insight than others, some may be easier to calculate with, some may be "simpler" in some sense of this word. It is hoped that only one theory will stand out as the best in all of these evaluations. If not, some judgment will be made, so that the final task will be to work out the algebraic details of one of the successful theories.

The present study will be carried in the following steps: (a) Cataloguing of all serious theories of meaning for natural language. (b) Analysis of Item (a): This involves a systematic analysis of the natural laws of meaning and philosophical requirements for a theory of meaning according to semiotic definition and an analysis of components of meaning; (c) New proposals for a theory of meaning that satisfies all requirements; (d) Evaluation of theories according to power, predictability, usefulness, simplicity, and other such criteria; and (e) Development of the algebraic details for the theory judged "best" according to Item (d).

3. Development of a measure of ostensive information. In an earlier study, the computer addressing function was compared to the ostensive function of natural language and a measure of information based on the ostensive grammar of Gough has been developed that appears to be useful for measuring information associated with computer addressing, indexing, and data-structuring phenomena. The mathematical details for Fortran-like data arrays have been worked out. The completion of this project involves extension of the mathematical results to arbitrary noun phrases of natural language and arbitrary data structures of computer languages.
Project Title: Adaptive Scheduling of Computer Tasks

Principal Investigator: John M. Gwynn, Jr., Assistant Professor of Information and Computer Science

Collaborator: Edgar M. Pass, Ph.D. Student

Research Results (1971/72). This research is concerned with devising and testing an adaptive microscheduler (the processor assignment portion of the operating system) which will assign the processor to jobs in the internal queue in an attempt to optimize with respect to some measure of system effectiveness. It will be adaptive in the sense that it will modify itself to account for time variations in the composition of the internal queue and in the processing characteristics of jobs in the queue.

A general measure of system effectiveness was proposed; changes in the parameters of the measure cause optimization with respect to the measure to reflect maximum processor utilization, maximum throughput, maximum system revenue, and minimum unused system components, to name a few.

Simulators were written in SIMULA for the B-5500 to allow comparison of various microschedulers with respect to the proposed measure of system effectiveness. The simulators take into account the system time required by each microscheduler.

Data was collected in the form of job profiles from the actual workload of the B-5500 at Georgia Tech's Rich Electronic Computer Center. The simulators were written to accept a workload in this format.

Publications.


Proposed Research (1972/73). The adaptive microscheduler will be devised and implemented in the simulators. It will be compared, through simulation, with some conventional microschedulers, including roundrobin, first-come-first-serve, and one based on a fixed formula involving job parameters. The comparisons will be made with respect to system effectiveness measures.
which reflect throughput, system revenue, and component utilization. The job streams chosen for comparison will reflect the live workload of the B-5500 at Georgia Tech.
Project Title: Study of Mass Memories
Principal Investigator: Michael D. Kelly, Assistant Professor of Information and Computer Science
Collaborators: Saurindra M. Basu, Graduate Research Assistant T. Vincent Gayle, Graduate Research Assistant

Research Results (1971/72). The objective of this project is an investigation and evaluation of very large digital mass memories and devices for the storing and management of science information. The investigation has focused on assessing the technical characteristics of very large mass memories (of the order of $10^{12}$ bits) and studying and evaluating such memories for the storing and management of audiographic learning materials.

The first phase of the project was concerned with determining the state of the art of very large mass memory devices. This investigation reviewed current technology according to the following three approaches:

1. Common storage media were examined to determine their suitability for $10^{12}$ bit, on-line, memories. Storage media examined included semiconductor memories, ferrite-core memories, thin-film memories, optical memories, and magnetic storage devices such as drums, discs, and tapes. For each media cost per bit, power consumption size (volumetric efficiency) and volatility were evaluated. For common storage media it was concluded that only magnetic tape and optical recording offered practical and economical trillion bit on-line storage.

2. New, experimental digital storage techniques were examined. Among these techniques are laser recording systems, holographic memories, and magnetic bubble storage devices. In terms of the parameters listed above, these new devices hold great promise for trillion bit memories. The current art however does not permit synthesis of large arrays of these devices.

3. The technical characteristics of three commercially available trillion bit memories were studied in detail. These were the IBM 1360 Photo-Digital Storage System, the Ampex Terabit Magnetic Memory, and the Grumman Data Systems Corp. Masstape.
The second phase of this project was concerned with evaluating the practicality of trillion bit memories for actual use in a large scale information delivery system. The Audiographic Learning Facility (ALF)\(^2\) is such an information delivery system. A large scale ALF system would put demands on a large digital storage unit which are quite unlike the demands of a computer central processor in its traditional use of mass storage. The difference is the sustained high speed information flow which an information delivery system requires. The ALF system strongly requires this high speed, continuous information flow. Accordingly, a detailed design was attempted on a large scale ALF system using very large digital memory. The conclusions of this study may be summarized as follows:

1. The Grumman Masstape unit would give the best cost and performance for a system of this type.
2. A large buffer storage of magnetic core memory and magnetic disk memory will be required. This is because none of the current trillion bit memory systems possess true random access characteristics.
3. Sophisticated queueing and rescheduling techniques will be necessary to maximize the effectiveness of such a system.

Proposed Research 1972/73. The objective of the proposed research is the development of a simulation model of a large, digitally based information delivery system. The project, as completed to date, has collected and analyzed data on large digital storage devices. The design phase of the project has translated the extracted information into desirable system characteristics, reflecting the assessment of digital technology for applications in information systems.

A computer model of the resultant system will be written and tested, using the General Purpose System Simulator (GPSS) on the Univac 1108 computer of the Rich Electronic Computer Center of the Institute. The testing and evaluation of this model should lead to a measurement of the design soundness and economics of a large-scale audiographic learning system. Detailed processes, data evaluation procedure, and algorithms will be developed as part of the proposed effort.

*Slamecka, V., and Jensen, A.P. The Audiographic Learning Facility: Objectives and Design. Atlanta, Ga., Georgia Institute of Technology (School of Information and Computer Science), 1970. Research Report, GITIS-70-08, 44p. -20-
Apart from the significance of the proposed study to the Georgia Institute of Technology Audiographic Learning Facility, the issue of data management in very large mass memories is of current and crucial import to other areas, e.g., science information storage and retrieval, biomedical data banks, and social information systems for urban and regional management. The findings of the proposed study will be of direct interest to all these important areas.
Research Results (1971/72). Surveillance of the development of national science information systems in six countries with planned economies (Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Yugoslavia) was continued in 1971/72. In earlier phases of the study a series of reports and papers was published providing detailed descriptive and, when possible, quantitative surveys of the development and apparent effectiveness of the national systems for scientific, technical, and economic information in the six countries. Subsequently preparations were made for the publication of an abridged and updated version of the reports in book form; the M.I.T. Press had agreed to publish such a book. The preparations included visits to the principal information centers of four of the six countries (Bulgaria, Hungary, Poland, and Romania) through which additional information was gathered and arrangements were made for the procurement of literature not generally available in the United States.

The aforementioned book, *National Science Information Systems* with the subtitle *A Guide to Science Information Systems in Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Yugoslavia*, was prepared in photo-ready copy form and submitted to the M.I.T. Press in the Fall of 1971. It comprises a series of nine essays: Development of Scientific, Technical, and Economic Information Systems in Eastern Europe; International Center of Scientific and Technical Information; Bulgaria; Czechoslovakia; Hungary; Poland; Romania; and Yugoslavia. Each of the essays by country is accompanied by a directory of documentation and information centers in that country and a list of publications of these centers. A current bibliography was supplied for each of the essays; an appendix of information received after the book had been prepared for publication was added, and a subject index supplied. After a series of publication delays, the book is now scheduled to appear in June 1972.
Following the preparation of the book for publication, a special study was made of the Hungarian library and documentation system.

Publications.


Proposed Research (1972/73). (None).
Research Results (1971/72). The purpose of this project has been to provide insight towards synthesis (e.g., indexing and automatic abstracting) of information in natural language form. A concept-based grammar can be considered to begin with either (a) all semantics applicable to the expression to be generated or (b) only some minimum amount of semantics, the remainder being specified by the choice of rules to be applied. The rules are of two types, conditionals, which test the state of a given data element for the selection of a set of rules, and imperatives, which transform a data element.

The following specify the data elements considered by the rules:

Primitives:

- **T** = set of terminal characters.
- **N** = set of nonterminal characters.
- **Names** = categories to which strings of characters or sets of strings of characters may belong.
- **Concepts** = senses which can be associated with strings of characters or sets of strings of characters.

**Atom**: An atom of the grammar is an ordered triple, \([A,B,C]\), where 
\[A \in (T \cup N)^*\]

- **B** = a set of names which apply to A before the application of any rules of the grammar.
- **C** = a set, possibly null, of concepts which apply to A before the application of any rules of the grammar.

**Primitive Item**: A primitive item of the grammar is an ordered triple \([A,B,C]\) where \([A,B,C]\) is an atom or 
\[A \in (T \cup N)^*\]

- **B** = a set of names
- **C** = a set of concepts
Item: An item of the grammar is an ordered triple \([A, B, C]\), where

\([A, B, C]\) is a primitive item or

\[A \in \{\text{items}\}^*\]

\[B = \text{a set of names}\]

\[C = \text{a set of senses}\]

The rules are arranged in sets, each set applicable to data elements of a specific category. Current work is concentrating on the relationships between the selection of a set of statements, context-sensitivity of rules, and the deletion of a member of \(A\) and/or of \(C\). A computer program to test hypotheses has been partially written in SNOBOL4.

Research Results (1972/73). The continuation of this research has the following specific goals: (1) the determination of the context-sensitivity of the set of rules concerning verbal roots; (2) the determination of the rules selecting the assignment of a name (a member of \(B\)) to a data element; and (3) the specification of the effect of deletion of a member of \(A\) and/or of \(C\). The further development of the SNOBOL4 program is necessary to carry out these goals.
Project Title: Translation of English Text into the Lower Predicate Calculus with Additions

Principal Investigator: David E. Rogers, Assistant Professor of Information and Computer Science

Collaborators: Lucio Chiaraviglio, Professor of Information and Computer Science
Raymond van Wolkenten, Graduate Research Assistant

Research Results (1971/72). The object of this project has been to determine the feasibility of using the lower predicate calculus as the principal formal mechanism for monitoring and bringing under operational control the coherence of abstracts for the purpose not only of assigning index terms to the abstract but also of providing a basis for question-answering.

The task of translating English texts into the lower predicate calculus with additions can be considered to consist of three areas. The first is how to extend the rules of formation of predicate calculus to provide sufficient syntactical structure to adequately represent the natural language structure of interest. The second is to determine the axioms and rules of inference for this extended system. The third area is to determine algorithms to translate into this system from the surface of the natural language text all the information necessary to make meaningful manipulations of the translated text.

Extension of the rules of formation has previously focused on two areas, the addition of specific quantifiers to capture more closely the natural language counterparts and the introduction of new categories of symbols. While the former do not appear to be essential but appear only to provide structures which are more convenient to our intuitions, the introduction of new categories of symbols (e.g., adverbs) appears quite significant and unavoidable.

The difficulty in these efforts center on the fact that the axioms for these extended systems are undesirably specific. We cannot, for example, put temporal operators such as "past" in the same category as modal operators such as "necessarily." Both operators have the same domain of sentences, but different axioms apply to each. This indicates the unpleasant possibility that descriptive axioms must be introduced for each temporal and for each modal operator to be used in the language.
In lieu of having a solution to this problem, we first tested the question of how much of natural language could already be translated into the predicate calculus without extending the axioms. An abstract was translated into the predicate calculus with tense and modality being represented as sentential operators. Besides the already recognized problems with adverbs and tense, it was evident that sentence adjuncts were quite significant in maintaining the connectedness of the abstract and that the translation may have atomized the structure too finely, thereby losing the identity of the text's topic.

Next, we considered a paper by Bohnert and Backer which dealt with the algorithmic translation from a restricted form of English to the predicate calculus. We applied their approach to the same abstract. However, we modified their approach by using adjective plus noun constructions as primitive terms, adverbs plus verb as primitive predicates, special quantification symbols for plural terms, and predicates which accept sentences as arguments. The result was a better representation of the topic of the abstract, but the relation between terms in one sentence and those in another was obscure and the inability to disengage the adjectives and adverbs from the terms they modify left the representation less applicable than it would be if, for example, the same noun could be identified with or without the adjective.

For this reason, a third analysis was made using the results of the second together with adjectival and adverbial properties to determine what rules might be used to identify inter-sentential reference which was known to exist. Using the notion that the abstract discussed a set of individuals and that at least one individual must be referenced by each of two adjacent sentences, a more adequate representation was achieved. Clues as to which terms might refer to the same individuals included the use of deictics such as these and a comparison of properties attributed to the individuals by the terms in the text.

Analyses of other abstracts has emphasized the importance not only of such items as sentence adjuncts, tense, modals, deictics and properties attributed to the individuals by the terms in the text, but also of a special class of words which we call "metatext words". These words, e.g., process, method, and use, are extremely important to the coherence
of an abstract, for they relate not only nouns but also descriptions of verbal activities.

Proposed Research (1972/73). The continuation of this research has the following specific goals: (1) the further identification and formal specification of the function metatext words play in the coherence of abstracts; (2) the further specification of the use of sentence adjuncts and function words (e.g., deictics) in the coherence of English abstracts; and (3) the formal specification of the semantic burden of tense and modality in the coherence of abstracts.
Research Results (1971/72). A previous description of this project noted several aspects of synthesizing scientific information such as existing procedures utilized by review writers, the development of computer based facilities to assist reviewers, and the feasibility of an operational analysis of scientific concepts for increasing the coherence of scientific information.

On the basis of an assessment of the above aspects and available resources effort was concentrated on the development of computer based facilities to assist reviewers. Two functions were studied: (a) the editing-redacting function and (b) a conversational information retrieval and management function.

The study of the first function was limited to an evaluation of existing text editing systems, and the design specifications for a proposed system which meets user requirements.

Implementation of the design has been delayed in view of associated costs and the lack of an appropriate user population for an adequate test of the system.

The second function has been thoroughly analyzed, and an experimental system has been implemented and demonstrated. The following is a brief description of the system and its capabilities.

The system provides for two modes of interaction: (a) a discussion mode which responds to the user's natural language query and (b) a tutorial mode in which the system presents blocks of information in fixed sequence reflecting the structure of the initial input.

A wide range of control commands are provided which permit a conversational interaction with the file, and which enables the user to obtain a comprehension display of the structure of the information content in the file. Input to the system is modular, and items may be added or subtracted from the system without disruption of the system. The system has been demonstrated in a task which displays the index terms and associated definitions for a topic area in computer science. The demonstration to date
consists of a case study of a number of users who have interacted with the system to obtain specified information. A detailed analysis of these interactions indicate the feasibility of an interactive conversational retrieval system. Such a system appears to be of significant value in assisting reviews and others in the syntheses of scientific information.

Proposed Research (1972/73). It is proposed that research continue on the conversational retrieval system, and specifically that the following topics be studied.

1. The present system has been tested with relatively well specified input, namely, index terms and their definitions. Consideration will be given to the utilization of other input materials such as are available in current machine readable files of scientific information (e.g., indices and abstracts.)

2. The query capability of the system appears to be adequate to support interaction with users given the structured input noted above. It appears, however, that the pattern recognition capability of the system will require extension given either less sophisticated users or a less structured input file.

3. The present system has limited memory for monitoring the interaction with the user. For proposed applications, a more extensive monitoring capability appears desirable and it is planned to extend the system in this area.

4. In its present configuration, the user cannot add, relate, or modify content in the system. The desirability of such capabilities will be considered and implemented if required by the review task.

5. The system will be tested on a review task using as input files derived from existing machine readable files of scientific information. On the basis of the study recommendation will be reached on effectiveness of the system in supporting review writers and others interested in locating and synthesizing scientific information.
Project Title: Study of Data Structure
Principal Investigator: Philip J. Siegmann, Associate Professor of Information and Computer Science
Collaborator: Margaret E. Dexter, Ph.D. Student

Research Results (1971/72): The project on data structure has limited its consideration to the specification of those structures required to support man-machine interaction, and the analysis of these interactions to provide a basis for the efficient use of levels of memory in computer systems.

The data structure under consideration consists of:
(a) A randomly accessed sequentially organized file to support machine controlled interaction.
(b) A list structure to support machine response to user controlled interaction.
(c) An algorithm for generating suitable list structures from a sequentially organized file and a specific vocabulary.
(d) A file organization that is designed to permit extension to include use of different levels of machine memory.

Since the file structure under consideration involves assumptions as to the nature of man-machine interaction, an experimental facility has been implemented to test these assumptions. These assumptions include (a) the nature of an adequate response to natural language query in cases where the machine contains significant information relative to the user; (b) feedback utilization by users in monitoring their query input and other interaction with the system; (c) degree of structuring required for input files for effective man-machine interactions given the proposed system.

A demonstration case study has been conducted as noted in the project report on the synthesis of scientific information. The results support the assumption listed concerning the appropriate data structures required to support man-machine interaction.

Publications.
Proposed Research (1972/73). An issue which remains unanswered on the basis of present data is the effective utilization of machine memory in the context of the present project. The experimental system is designed to handle file content as follows:

(a) Primary memory contains a list structure which utilizes pointers into a data structure contained in secondary memory.

(b) Secondary memory contains a sequentially organized file for a single specific topic area.

(c) Third level memory which can contain similar structure for other topic areas which can be transferred to lower levels of memory as required.

The current test of the data structure concept has been limited to a single topic area and consequently has not utilized the third level of memory.

To determine the efficiency of the application of the data structure concept to levels of computer memory the following is required:

(a) Specification of the level of monitoring required to determine the rules for a machine controlled shift of topic areas based on interaction vs. users.

(b) Detailed analysis of programming requirements for the system as extended to several topic areas.

(c) Generation of several topic areas and an empirical test of the monitoring requirement as noted.

The result of this research promises to provide a basis for specifying data structure and related machine memory requirement as determined by a range of man-machine tasks.
Research Results (1971/72). Text structuring research has been conducted in 1971/72 along the following lines:

1. Evaluation and improvements of the existing concepts referred to as Q-graph Parser for English Sentence GRAPAR (Research 1970/71: Annual Progress Report by the Science Information Research Center, School of Information and Computer Science, Georgia Institute of Technology, Atlanta, Ga., 1971. Research Report, GITIS-71-03, pp. 24-33);

2. Interpretation of the text, referred to as TEXSTR in same as 1;

3. Linking of the syntactical structure of the given text with the structural representation of the system described by the text $T$, as a valuable by-product of our research.

A new version of the program GRAPAR has been written implementing a more flexible representation of the sentence grammar for parsing in a Q-graph. So far, each possible position of the word in the sentence has been represented by one exclusive node in the Q-graph. The improvement is in the new multilevel structure of the Q-graph, where each word group of the sentence (such as adjectival, noun phrase, prepositional phrase, embedded clause, simple clause, etc.) is represented only once in the graph, being a subgraph of higher level nodes. For example, an adjectival group is a subgraph of the noun phrase which is a subgraph of the prepositional phrase which is a subgraph of the simple clause, etc.

The new arrangement of the graphs into levels provides the following convenient features.

(a) It drastically reduces the size of the graph.

(b) It allows the use of various subgraphs recursively.

(c) It allows the representation of a sentence graphically, choosing different levels of representation (e.g., a complex sentence as a structure of simple clauses, or a simple clause as a structure of noun phrases, prepositional phrases and verb groups, etc.)
(d) It simplifies introduction of new desirable features in the graph merely by changing the representation on the selected level, without the need for reconstruction of the whole graph.

It was discovered that the speaker communicates—in addition to his message—how that message is to be interpreted as well. Two different forms are used to communicate the interpretation:

Form 1: Renaming of the noun signaled by a subjective complement that in the syntactical structure corresponds to the substitution of a noun-node in the sentence tree (sentence diagram) that replaces all the structure below the node by a new structure (e.g., "Boolean expression on the left side is a sum of four implicants" signals that the node "expression" can be substituted by the node "sum" replacing all the tree "Boolean expression on the left side" by the tree "a sum of four implicants."

Form 2: Renaming of the verb (predicate) that in syntactical structure corresponds to the renaming of the substitution of the verb-node. The substitution requires a more complex transformation, that is signaled by the speaker using "means," "represents," etc.

Following is an example of the TEXIN subroutine:

Input 1. "Move A from B to C" means "replace the coordinates of B by the coordinates of C."

2. "Move the book from the right shelf to the desk in the kitchen."

Output of TEXIN if the meaning of 2 is requested. "Replace the coordinates of the right shelf by the coordinates of the desk in the kitchen."

Using Form 1 and 2, reinterpretation of the text can be made such that it is the speaker (and not the built-in rules of TEXIN) who directs TEXIN toward the desirable interpretation of the content.

Following are some of the features and the possible uses of TEXIN:

(1) The directions for the interpretation of the meaning are given by the speaker in the same manner as they would be given to the human listener.

(2) By inputting directions (e.g., for interpretation of an algorithm, where both directions and the algorithm have been described in natural language), the system will be able to directly write a computer program.
(3) Given the directions for interpretation of certain transformations (e.g., "John gave a book to Judy" means "Judy was given the book by John") the system is able to accept both versions as an equivalent wording or to use both of them in any other manner that is again communicated in natural language to the system.

(4) The way the system accepts, interprets and acts is controlled by the speaker who communicates with the system. The TEXIN, TEXPRO, TIXSYN merely provide the system with the capability of being controlled by the speaker rather than controlling the system actions. For example, from the nine following sentences it can be demonstrated that a system is able to interpret that "Move the point A to its neighbor place" means 
\[(n_1, n_2) = (n_1 n_2) + 1.\] The nine sentences are:

1. Move point to the neighbor square of A
2. Move A1 from A2 to A3 means replace A2 by A3
3. Neighbor square of Q1 is the square which has the coordinates greater than the coordinates of A1 by 1
4. Q2 greater than Q3 by 1 means Q2 is equal to Q3 + 1
5. Move point A means move point from the square of A
6. Replace square Q4 by square Q5 means replace the coordinates of the square Q4 by the coordinates of the square Q5
7. The coordinates of point A are \((n_1, n_2)\), the coordinates of the square of point A are \((n_1 n_2)\)
8. Q6 of Q8, which has Q6 equal to Q7 is Q7 (e.g., the color of the desk, which has the color equal to green is green, or e.g., A which has A equal to C is C)
9. Replace Q9 by Q10 means Q9 + Q10

(5) Studies in the nature of the control of interpretation by a speaker led our research toward a very valuable by-product. It is well known that any description of a system is (a) a description of the elements of the system and (b) a description of the relations among the elements (i.e., a description of the system's structure).

We were able to demonstrate that there is a very strong correspondence between the structure ST of the system S and the syntactical structure SST of the description of S where the description is given in natural language.

The significance of this is that

1) the description of a system can be looked at as another equivalent form of representation of the system with an established formal link between the two -- whereas so far we had primarily merely an intuitive
notion of the relation between the description of the structure and the structure itself.

(2) Due to the existing link, algorithms can be written that transform the description into the system structure or, vice versa, the structure of the system into its description (the descriptions being in natural language).

This considerably increases the utilization of natural language in communication with the computer.

Proposed Research 1972/73. The following activities are proposed:

1. Link together the following programs: Parsing, transition to the sentence diagram, text structuring and interpretation (involving packages SEN, TEX and modified MOD and KNO) with the goal of having a complete system that will enable us to demonstrate both the feasibility and the integrated features of our system.

2. Concentrate mainly on TEX -- the interpreter that promises among others new avenues of approach to the man-machine and natural language communication.

3. Identify areas of applications (e.g., library systems, medical information processing, management system control, etc.);

4. Publish our findings, which will require adaption of the results to various areas of interest and application; and

5. Work out and publish theoretical aspects of our new findings.

We feel quite confident that our results bring new and promising approaches to the problem of utilization of natural language (and specifically English) in direct communication with the computer with valuable consequences in theoretical areas such as artificial intelligence, problem solving, cybernetics and linguistics, as well as in pragmatic fields such as document retrieval, abstracting, medical information processing and others, in all of which the possibility of controlled interpretation will bring new dimensions to problems of manipulation.
Project Title: Hardware Processor for Natural Language

Principal Investigator: Miroslav Valach, Professor of Information and Computer Science

Research Results (1971/72). This study is closely related to the project Structural Representation of Natural Language (described elsewhere in this report), and it has been assumed that the algorithm for the hardware processor will be tested in the program version as GRAPAR and PST subroutines of that project. Our new multilevel Q-graph approach to parsing considerably reduces the capacity of the memory (either core memory, or microprogrammed permanent memory) so that even micrcircuit memory will be one of the alternatives in the final project. Estimated capacity for Q-graph memory is less than 2000 bits. The existing algorithm for parsing was used in our course ICS 652 (Algorithms and Processors) as a project for derivation of the hardware structure, without detailed representation of the Q-graph.

Though the advancement of the project was inseparable from the advancement of the above-mentioned project on Structural Representation of Natural Language, the final phase will have to branch again to a research effort conducted quite separately, once the corresponding algorithms have been verified.

Another consideration, however, arises from the results of our research on the hardware version of the facilities for use of natural language in man-machine communication.

The control of the communication can be completely carried out by the speaker as a result of two components that are (1) the content of his message and (2) the communicated signalization of the interpretation. The algorithms that predetermine a computer for this type of communication are basically algorithms that provide various substitutions on the structural representation of the communicated content (be it text, message, paragraph, etc.). The algorithms do not participate by any decision on the conveyed message, being both independent of and indifferent to the content of the communication. Processing is concerned merely with structural properties rather than with any content interpretation (the latter is left entirely to the speaker). It is therefore logical also to consider building the structural algorithms into the hardware of a natural language processor (in this case languages that are based on syntactical-pair sentence structures).
Such a processor would have the following features:

(1) Processing natural language independently of other processors of a computer.

(2) Having its own time-sharing or multiprogramming environment so that it can be part of the system shared by all users without interfering with other computation.

(3) Independent natural language processor, which would open the door for new (hopefully very powerful) communication with the computer that in some cases might also decrease the need for user training or decrease the necessary level of understanding in using the computer.

While we do not intend to incorporate the above-mentioned considerations into the final phase of our research (they are not proposed in the subsequent section), it is nevertheless this grant that both initiated and brought to our attention all the results and that helped us to lay out a firm foundation on which we will be able to pursue these considerations later to the full extent they deserve.

Proposed Research (1972/73). We propose:

1. rewriting of the algorithm for parsing and sentence structuring into a form suitable for more detailed hardware design;
2. design of the hardware structure in such a way that it will be possible to make meaningful estimates of the cost, time factors and hardware requirements;
3. writing more detailed specifications for such hardware with the estimate of other parameters of interest;
4. publication of primary results;
5. report on the whole research;

The concept of the processor is now: 2,000 bit memory, 2 parallel binary 7-bit adder, auxiliary registers.

The main detailed part of the hardware project will include new multilevel Q-graph and will be continued after the testing of the corresponding programs of the above-mentioned pilot project has been finished (estimated for Fall 1972).

It is assumed that the processor will be working in parallel with other processors or units of the computer, independently and assynchronously.
The output of the processor will be a parsed sentence and possibly its syntactic-pair structure (not decided as yet).

There is a good chance that the substantial part of the grammar will be stored as a content of the memory and not as built-in hardware. Therefore any later changes based on the advancement of linguistic knowledge will be reflected as changes in the memory content rather than hardware modifications. This circumstance will be also among the considerations of the design.
Research Results (1971/72). The main areas of concentration of the research in 1971/72 were:

1. Explication of basic constructs of information science such as the nature and scope of information, signs and sign processes, significance, relevance, information value, etc.
2. Analysis of various approaches to information measurement and syntactic, semantic, and pragmatic aspects of such measurements.

The overall structural framework of relevant topics which were considered in this research project is given below:

1. PRELIMINARIES
   I.1. Formal Analysis of Statements on "Information."
   I.2. Information and Communication, Communication Processes and Patterns.

2. SEMIOTIC PROCESSES AND INFORMATION
   II.5. The Concept of Information. Basic Definitions. Interaction, Reflexion, and Information. Structural Information and Information Dynamics.

III. INTERPRETATION OF INFORMATION MEASURES


A set of notes on the above topics are in preparation. Portions of these notes have been published in professional journals during 1971/72, and the list of these publications is given below.

Publications.


Proposed Research (1972/73). The main objective of the research efforts for fiscal year 1971/72 is to complete the analysis and description of basic constructs of information science as outlined in the preceding section. In particular, attempts will be made to formalize the description of information processes. For example, the following is a typical statement about the whole process in an information situation: "X receives from Y information I about e by means of m". Now, the formal presentation of this statement involves either a five-place predicate P which means "receives" or a four-place predicate P_I which means "receives information"
or "is informed." Thus, there are two types of formulation of this sort of statement:

\[ P(X, Y; I, e; m) \]

or

\[ P(I)(X, Y; e; m) \]

This sentential type can be considered also to include propositions which are formal-logical conversions of the relations \( P \) and \( P_I \). The first formulation, where "information" is an independent factor, also includes propositions like "\( X \) provides \( Y \) with \( I \) about \( e \) by means of \( m \)," "\( I \) about \( e \) passes from \( X \) to \( Y \) by means of \( m \)," "by means of \( m \), \( I \) about \( e \) is passed from \( X \) to \( Y \)." The second formulation, in which the information process is taken as a whole, also includes propositions such as "\( X \) informs \( Y \) about \( e \) by means of \( m \)" and "by means of \( m \), \( Y \) is informed by \( X \) about \( e \)."

Elliptical expressions result from expressing only partial relations of the total relations, i.e., from abstracting from one or more terms of the relations. Thus, "\( X \) supplies \( Y \) with information \( I \)" corresponds to the partial relation

\[ P'(X, Y; I) \]

where "\( P'(X, Y; I) \)" stands for "(∃ \( e,m \)) \( P(X, Y; I, e; m) \). And "\( Y \) is informed about \( e \)" then corresponds to

\[ P'_I(B; e) \]

with "\( P'_I(B; e) \)" standing for "(∃ \( X,m \)) \( P'_I(X,Y; e; m) \)."

Similarly, propositions which refer to the means of communication, like "\( m \) transmits \( I \) about \( e \)" are

\[ T'(I; e; m) \]

or

\[ T'_I(e; m) \]

Since one is here interested in the relation between \( m \) and \( e \), no further distinction need be made between process and state represented by \( m \). Again, one has to conceive the two formulations as partial relations which are abstracted from two relations, i.e.

\[ T'(I,e; m) \] for (∃ \( X,Y \)) \( T(X, Y; I, e; m) \)

and

\[ T'_I(e; m) \] for (∃ \( X,Y \)) \( T'_I(X, Y; e; m) \)

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School of
Information and Computer Science
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GITIS-72-03
(Research Report)

RESEARCH 1971/1972:
ANNUAL PROGRESS REPORT

School of Information and Computer Science    1972
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia
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VLADIMIR SLAMECKA
Project Director
ABSTRACT

The report presents a summary of research activities of the School of Information and Computer Science, Georgia Institute of Technology. Included are project reports on research in information science, computer science, and systems science; on information and computer systems research; and on education in the information sciences. Also presented is a summary of research activities at the Information/Computer Science Laboratory. The report concludes with a bibliography of publications for the period of 1971/72.
This report presents a summary of the major research activities of the School of Information and Computer Science, Georgia Institute of Technology, for Fiscal Year 1972. It is the third annual research report of the School.

The research program of the School of Information and Computer Science is guided by its perception of the long-term social mission of the information sciences. We believe this mission to be the design of information processing automata that perform increasingly complex functions of man: problem solving (in science, health care, law, etc.); decision making (in management, government, etc.); and instruction (in education). The objective underlying the design of these automata is to increase the cost effectiveness of man's problem solving resources and professions.

In general support of this long-term mission, the School of Information and Computer Science pursues a theoretical research program in the information, computer, and systems sciences, seeking to increase our understanding of information processes and processors. The research projects of this program are described in the first three chapters of this report. The School's applied investigations, emphasizing at present the design and evaluation of computer systems, learning systems, and science information systems, comprise the fourth chapter. Activities of the School's information processing laboratory, the partial purpose of which is to introduce graduate students to research and development projects, are described in the fifth chapter.

Established in 1963, the School of Information and Computer Science is the largest graduate department of the Georgia Institute of Technology. During 1971/72 its faculty devoted an extensive effort to the design of an undergraduate program of education in the information, computer and systems sciences. This new program, to be offered beginning Fall 1972, is believed to provide an attractive foundation for education in the entire realm of the cybernetic sciences and professions. The sixth chapter briefly outlines the new baccalaureate program of the School. Finally, a bibliography of publications for FY 1972 is given.

As in previous years, the research program of the School of Information and Computer Science has been supported in part by the Office of Science Information Service, National Science Foundation (NSF Grant GN-655). The
administration of the Georgia Institute of Technology and the faculty and students of the School of Information and Computer Science are deeply grateful for the Foundation's generous support, and appreciative of its commitment to research in the discipline.

VLADIMIR SLAMECKA
Director

August 1972
Atlanta, Georgia 30332
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RESEARCH IN INFORMATION SCIENCE

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One might surmise that verbal signs became language only after ancient man had evolved a semantics general, coherent, and mathematic-like enough to support a linguistic symbolism capable of consistently realizing and representing his most variant atomizations of the extensive continuum he perceived confronting him. Such a systematicalness realized in the creation of categoricity, intracategoricity, and ultimately intercategoricity heralded the genesis of grammar. History would seem to look upon this product as the crowning achievement of man's symbol creativity, the climax coming already in the first act. Civilizations emerge and submerge, science and cultures progress, yet the semantic system forged by ancient man in prehistory stands ready to be used again and again in the genesis of cultures and their subcultures (myth, religion, drama, philosophy, science, everyday discourse), of the lexicons and propositions appropriate to and for them. It is tempting to see in this "timeless" semantic system an impersonal intellectual legacy bestowed upon subsequent generations by an unknown and unknowing giver. It is perhaps the very feature of language to which Dufrenne (Language and Philosophy, 1968) is alluding, when he speaks of the "Impersonal intelligence in language," which awakens the individual and directs him into the ways of intelligence."

The isolation of the semantic systems underlying language is a formidable task. Modern linguists have begun in recent years to concern themselves increasingly with the semantic dimension of language. It seems a fair assessment to say that their efforts to date can be characterized generally as being amplifications of an already developed grammar model. However these amplifications may have come about (through special structuring of the lexicon, novel characterizations of semantic representations and presuppositions, introduction of case, incorporation of logic), they make their appearance within the context and constraints of a syntax-dominated grammar, under the burden of surface language realization with its multiplicity of various systems of semantics. This is hardly a reason to gainsay the significance of these efforts. In such a context, however, the investigation of semantics is complexified at the very outset, arousing the fear that the primitive "timeless" semantics envisaged above as a "grammaticized semantics" might be totally obscured and overlooked in the analysis. Such a state of affairs suggests an inverse strategy: Seek a semantics that is both prior to and necessary for all subsequent semantics, indeed, a semantics primitive enough to be equatable, once grammaticized, with the genesis of language itself.

Our research efforts represent such an inverse strategy: Beginning with the semantics of a single category, that of the indexical symbol, it seeks to construct a grammar that generates semantic structures, that is, to grammaticize semantics. Such a symbolism reflects the simplest of semiotic drives, the desire on the part of the symbol user (designer) to ostend, to point and in pointing to structure, to atomize the extensive continuum and thereby to assign it a significance based solely in its objectification relative to him the code-user. The category of the indexical symbol, created in the simple symbolic role of pointing, becomes
internally complexified, yielding initially an intracategoricity that by virtue of being in reality an integrated, logically coherent schema gives rise, when set in a propositional context, to an intercategoricity. Thus emerges a grammar-regimented semantics and hence the base semantics of language. This symbolism, ostensive in nature and egocentrically pragmatic, is uniquely referential and quantificational, reflecting a logical proper-noun structuring of the continuum. It originates in the experience of the particular -- the particular unique code-user beholding and deictically symbolizing the particular unique object. Generalization, general-term genesis, comes later.

Our system presupposes only the following set of substantival ostensive semantic primitives:

\{ THIS (IT) , HERE , NOW , HENCE , HITHER \}  \hspace{1cm} (1)

the members of which are values of idealized acts of ostension, abstracted from the set of English indexical symbols that people in fact use to point to concrete objects. As such, they possess the intensional semantics (sense à la Frege) characteristic of indexical symbols:

a) They essentially represent pointings having their origo in the code-user (Buehler, Sprachtheorie, 1934). The egocentric dimension (pragmatic commitment and symbol behavior of the code-user sense-semantically regimented in the symbol) is posited initially as being a quasi-ubiquitous projection of the code-user vis-à-vis the extensive continuum. The primitives thus function as universal (egocentric) selective indexes that provide the code-user with the symbolism to confront the total extensive continuum, to range over it, and to select uniquely it or any portion thereof, with the unlimited potential for infinite division of reference and quantification.

b) This deictic symbolism thus expresses unique reference and quantification, yielding a logical proper-noun structuring of the extensive continuum into distinct and singular objects.

c) The elements of (1) exhibit a semiotic coherency, being related by semantic rules of ostensive entailment (\( \Rightarrow \)):

\[
\begin{align*}
\text{HENCE} & \Rightarrow \text{HERE} , \quad \text{HENCE} \Rightarrow \text{NOW} \\
\text{HITHER} & \Rightarrow \text{HERE} , \quad \text{HITHER} \Rightarrow \text{NOW} \\
\text{HERE} & \Rightarrow \text{THIS (IT)} \\
\text{NOW} & \Rightarrow \text{THIS (IT)}
\end{align*}
\]

and hence transitively:

\[
\begin{align*}
\text{HENCE} & \Rightarrow \text{THIS (IT)} \\
\text{HITHER} & \Rightarrow \text{THIS (IT)}
\end{align*}
\]
The significance of ostensive entailment is this: The intensional semantic structure of each implicans includes the intensional semantic structure of its implicate.

The logical proper-noun symbolism resides in its primitive form as a pure deictic substantival, solely in the element THIS (IT) [(IT) being a free variable]. Inasmuch as the latter is the one element that occurs simply as an implicate, its intensional semantic component becomes by virtue of the entailment rules the core semantics of the other members of (1). Herein lies the categoricity of the indexical symbolism for each of the other elements (HENCE, HITHER, HERE, NOW). Each, however, is distinguished by an intensional semantic component proper to it alone. These components are, in contrast, non-ostensive. The following table lists the respective intensional semantic characterizations uniquely proper to each:

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>INTENSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>HENCE</td>
<td>ORIGIN</td>
</tr>
<tr>
<td>HITHER</td>
<td>GOAL</td>
</tr>
<tr>
<td>HERE</td>
<td>SPACE</td>
</tr>
<tr>
<td>NOW</td>
<td>TIME</td>
</tr>
</tbody>
</table>

Herein is established the intra- or subcategoricity of indexical symbolism. But it should be noted again that subcategoricity is essentially based on non-ostensive components. Each of these elements, while expressing the intensional semantics of THIS (IT), increases the intensional semantics of the latter in terms of a non-ostensive semantic component.

In view of these semantic features, interpretation of (2) and (3) as a matrix should provide great insight into the grammaticized semantical significance of the ostensive entailment rules. So interpreted we have:

<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>GOAL</th>
<th>SPACE</th>
<th>TIME</th>
<th>LOGICAL PROPER NOUN</th>
</tr>
</thead>
<tbody>
<tr>
<td>HENCE</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>HITHER</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>HERE</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>NOW</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>THIS (IT)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>
The indexical symbols are listed in the rows, the semantic features in the columns. A plus sign indicates inclusion of a given intensional semantic component in element, a minus sign indicates absence. Here it becomes evident that HENCE and HITHER differ only as to the features ORIGIN and GOAL, while HERE and NOW differ only as to SPACE and TIME. All share the core semantics of THIS (IT). HENCE and HITHER both share the core semantics of SPACE and TIME.

The symmetry of the boxed submatrices along the diagonal has led us to regard HENCE/HITHER and HERE/NOW primitively as unit symbols. Thus, we introduce the following semiotic bi-entailment:

\[
\text{HENCE if and only if HITHER}
\]

and

\[
\text{HERE if and only if NOW}
\]

whereupon we write the ordered pairs:

\[
< \text{HENCE, HITHER} >
\]

and

\[
< \text{HERE, NOW} >
\]

regarding them primitively as unit symbols.

Reinterpretation of the above matrix in terms of unit symbols gives us:

\[
< \text{ORIGIN, GOAL} > \quad < \text{SPACE, TIME} > \quad \text{LOGICAL PROPER NOUN}
\]

\[
< \text{HENCE, HITHER} > + \quad + \quad +
\]

\[
< \text{HERE, NOW} > - \quad + \quad +
\]

\[
\text{THIS (IT)} - \quad - \quad +
\]

From the above matrices and (2) and (3) we derive the following additional ostensive entailment rules:

\[
< \text{HENCE, HITHER} > \quad \Rightarrow \quad << \text{HERE, NOW} >, < \text{HERE, NOW} > >
\]

\[
< \text{HERE, NOW} > \quad \Rightarrow \quad < \text{THIS (IT), THIS (IT)} >
\]

and hence transitively:

\[
< \text{HENCE, HITHER} > \quad \Rightarrow \quad << \text{THIS (IT), THIS (IT)} >, < \text{THIS (IT), THIS (IT)} > >
\]
Also:

\[
\text{< HENCE, HITHER > } \Leftrightarrow \text{< HERE, NOW >}
\]

\[
\text{< HERE, NOW > } \Leftrightarrow \text{THIS (IT)}
\]

and hence transitively:

\[
\text{< HENCE, HITHER > } \Leftrightarrow \text{THIS (IT)},
\]

The ostensive entailment rules underlie the various grammatical rules that we propose for term generation. Indeed, they underlie the logic of the selective features selected and the genesis of a primitive categoricity that is free of general terms.

Our ostensive grammar in its present development begins with the propositional schema:

\[
\text{< THIS (IT) > } \quad \text{BE} \quad \text{< THIS (IT) >}
\]

(4)

Here the terms appear in angular brackets. The sole primitive predicate is BE, abstracted from the English verb "be." In a sense, it is a predicate variable, its intensional semantics being defined by the intensional semantics of the terms bracketing it. Unless transformed, the above schema becomes our identity format. We have, however, developed a set of primarily non-zero semantic transformation rules that operate on terms, exploiting the intensional semantics of the indexical category and its internal coherency to generate various alternative ostensive semantic configurations. For example, the intensional semantics of the implicate \(<\text{THIS (IT)}\>) is increased to that of the implicans \(<\text{HERE, NOW}\rangle\), so that the simple object ostension value is spatialized and temporalized. The desired intensional identity can be effected in several ways: initial forced-generation of a prepositional category with its spatial-temporal intensional semantics; subsequent proper choice of common noun, subsequent proper choice of verb, and the like. Non-zero semantic transformations also exploit the set-subset properties of the indexical symbols. All of the transformations reflect the linguistic creativity programmed in the system. We have attempted to generate various subclasses of nouns, predicates, prepositions, case, etc., all on the basis of the potential semantic interrelationships that may exist among the members of (1). These require further refinement and regimentation.

References


The object of this project has been to determine the feasibility of using the lower predicate calculus as the principal formal mechanism for monitoring and bringing under operational control the coherence of abstracts for the purpose not only of assigning index terms to the abstract but also of providing a basis for question-answering.

The task of translating English texts into the lower predicate calculus with additions can be considered to consist of three areas. The first is how to extend the rules of formation of predicate calculus to provide sufficient syntactical structure to adequately represent the natural language structure of interest. The second is to determine the axioms and rules of inference for this extended system. The third area is to determine algorithms to translate into this system from the surface of the natural language text all the information necessary to make meaningful manipulations of the translated text.

Extension of the rules of formation has previously focused on two areas: the addition of specific quantifiers to capture more closely the natural language counterparts [4,8] and the introduction of new categories of symbols [7]. While the former do not appear to be essential but appear only to provide structures which are more convenient to our intuitions, the introduction of new categories (e.g., adverbs) appears quite significant and unavoidable.

The difficulty in these efforts centers on the fact that the axioms for these extended systems are undesirably specific. We cannot, for example, put temporal operators such as "past" in the same category as modal operators such as "necessary." Both operators have the same domain of sentences, but different axioms apply to each. This indicates the unpleasant possibility that descriptive axioms must be introduced for each temporal and for each modal operator to be used in the language.

In lieu of having a solution to this problem, we first tested the question of how much of natural language could already be translated into the predicate calculus without extending the axioms. The following abstract was translated into the predicate calculus with tense and modality being represented as sentential operators.

It was commonly noted that the highest caries rates were exhibited in families that had higher incomes. Although even in these families where there was some dependence on traditional foods, there was a greater relative dependence on refined carbohydrates and flour from the local store than in the poorer families. Thus, the role of diet in caries prevalence must be considered. The high caries rate in the village may be due to the ability to purchase refined carbohydrates and flour with ease and a decreasing dependen
on traditional diet. With an increase in the amount of money available for purchasing food, as well as increased contacts with nonresidents who may contribute to the desire for more attractive and more cariogenic foods of European culture, the caries experience may be expected to increase significantly in the future.

Besides the already recognized problems with adverbs and tense, it was evident that sentence adjuncts were quite significant in maintaining the connectedness of the abstract and that the translation may have atomized the structure too finely, thereby losing the identity of the text's topic.

Several authors [3,6] have noted that connected discourse relies heavily on intersentential reference. The assumption that a text is coherent is used by the interpreter to resolve ambiguity. At the same time, the interpreter is forced to make certain presuppositions about the author's views. It was noticed that some of the processes by which people handle these tasks may be related to the use of inductive reasoning as opposed to deductive. For example, the second sentence of the abstract is apparently introducing the primary theme (as indicated by the third sentence) indirectly. In this instance, there is a well-marked referential (these) pointing back to families that had higher incomes in sentence one. This relates the relation of higher income and high caries rates expressed in the first sentence to the dependence on traditional foods or on refined carbohydrates and flour expressed in the second sentence. Thus, cross-reference indicates that higher income is correlated with greater dependency on refined foods, and some dependency on traditional foods. But the although tells the reader to ignore the dependency on traditional foods. Because the reader knows from the title, Dental caries in the eskimos of Wainwright, Alaska and from the surface subject of the first sentence that the subject of the abstract is caries, he can and must make the presupposition that caries are related to refined foods. The reasoning of the reader is essentially deductive in nature, within the constraints imposed by the assumption that the text is coherent, his knowledge of the subject, the structure of the text, and the cross-reference that must exist. But the word although in the abstract is used because the author recognizes and expects the interpreter to use inductive reasoning. The word although signals the interpreter to ignore one possible inductive base and use another.

Next, we applied to the same abstract Bohnert and Backer's [4] algorithmic translation from a restricted form of English to the predicate calculus. However, we modified their approach by using adjective plus noun constructions as primitive terms, adverbs plus verb as primitive predicates, special quantification symbols for plural terms, and predicates which accept sentences as arguments. The result was a better representation of the topic of the abstract, but the relation between terms in one sentence and those in another was obscure and the inability to disengage the adjectives and adverbs from the terms they modify left the representation less applicable than it would be if, for example, the same noun could be identified with or without the adjective.
For this reason, a third analysis was made using the results of the second together with adjectival and adverbial properties to determine what rules might be used to identify intersentential reference which was known to exist. Using the notion that the abstract discussed a set of individuals and that at least one individual must be referenced by each of two adjacent sentences, a more adequate representation was achieved. Clues as to which terms might refer to the same individuals included the use of deictics such as these and a comparison of properties attributed to the individuals by the terms in the text.

Analyses of other abstracts has emphasized both the importance of such items as sentence adjuncts, tense, modals, and deictics and that the relationships between noun phrases were not through common extensional reference but through a relationship holding between the entities to which the terms referred. There were indications that these relationships were signalled through the use of a special class of words which we call "metawords."

Metawords are related to cases which have been treated extensively not only in recent linguistic literature [5,1] but also in the time of American structuralism [2] and within the Indian grammatical tradition [9]. With metawords we do not examine simply those cases which can occur in a sentence, but rather those which can occur relative to an activity. Traditional cases such as agent, object, location, instrument, have been studied relative to sentences. But the same things that can be marked via syntactic devices within a sentence can be marked by means of metawords operating beyond the sentence. For example, cases which are syntactically marked in the sentence John hit the nail with the hammer are marked partially by metawords and partially by grammatical structure in the connected text: An action occurred. This was the hitting of an object. The object was the nail. John performed the action using the hammer. Certainly if the above simple event is to be stated, the single sentence is considerably better than many. But, if a highly complex event involving many component actions with any given entity manifesting a plurality of cases is to be described, then it would most probably be stated in many sentences.

In scientific and technical literature the use of metawords is very widespread. For example, in a text a sentence may contain the metaword procedure and the following sentence may contain a term which is identified as used in that procedure. In an analysis based strictly upon examining terms it may be recognized that the entities referred to by these terms are related in some unspecified manner. However, the use of metawords enables recognition not only that they are related but also how they are related. Therefore our more recent efforts have been an examination of the functions of metawords in providing intersentential reference. To assist in the analysis of texts a stemming algorithm has been programmed in SNOBOL4 and a dictionary of metawords and suffixes with appropriate markings is currently under development.
References


Text structuring research has been conducted during the past year along the following lines: evaluation and improvement of the existing concepts referred to in a previous report as Q-graph Parser for English Sentence GRAPAR [1]; interpretation of the text referred to in the same report as TEXSTR; linking of the syntactical structure of the given text with the structural representation of the system described by the text T, as a by-product of the research.

A new version of the program GRAPAR has been written implementing a more flexible representation of the sentence grammar for parsing in a Q-graph. So far, each possible position of the word in the sentence has been represented by one exclusive node in the Q-graph. The improvement is in the new multilevel structure of the Q-graph, where each word group of the sentence (such as adjectival, noun phrase, prepositional phrase, embedded clause, simple clause, etc.) is represented only once in the graph, being a subgraph of higher-level nodes. For example, an adjectival group is a subgraph of the noun phrase which is a subgraph of the prepositional phrase which is a subgraph of the simple clause, etc.

The new arrangement of the graphs into levels provides the following convenient features: it drastically reduces the size of the graph; it allows the use of various subgraphs recursively; and it allows the representation of a sentence graphically, choosing different levels of representation (e.g., a complex sentence as a structure of simple clauses, or a simple clause as a structure of noun phrases, prepositional phrases and verb groups, etc.); and it simplifies introduction of new desirable features in the graph merely by changing the representation on the selected level, without the need for reconstruction of the whole graph.

In the interpretation of the graph, three facts should be kept in mind:

First, the purpose of the graph is to provide an analytical tool. The assumption that a correct English sentence is being analyzed allows certain simplifications that otherwise would have to be included and that would result both in a larger graph and a longer time necessary for analysis. If, in addition to analysis, the graph had to serve to accept or reject the given sentence, a different version would have to be constructed.

Second, the nodes are grouped into subgraphs primarily for the purpose of context-free parsing. Although the groups are given names as close as possible to the grammatical categories of English grammar, they do not necessarily represent all groups recognized in grammar, because grammar covers a much wider field than sentence parsing. For example, the adverbial phrase is a prepositional phrase used as an adverb to modify a verb adjective or adverb. Since for the parsing it is not important to establish the fact that a prepositional phrase functions as an adverbial phrase, the adverbial phrases do not occur in Q-graphs under their grammatical name; they simply are recognized and handled by the parser as prepositional phrases.
Third, although the terminology for names of different configurations of various phrases, clauses and other word groups may be satisfactory for some purposes, a more detailed and more systematic nomenclature would be very desirable for the construction of a general graph of the English sentence. In the absence of such nomenclature, use of current adjectives is extended to some forms, e.g., compound adjective and extended noun phrase.

### Compound Form

Let

\[ W_n \]

be a certain structure of functional classes at a level \( n \) called a core;

\[ W_n \]

be another functional class or Q-structure of functional classes (called in some cases head) such that \( W_n \neq W_n \);

\( \text{conj} \)

be a so-called "level" of the Q-structure

Let

\[ P_n \]

be a rule that combines \( W_n \) and \( W_n \) into a new Q-structure called simple Q-structure \( W_{n+1}^s \) such that

\[
W_{n+1}^s = P_n (W_n, W_n)
\]

Generally, (W1) can be written as

\[
W_{n+1}^s = P_n (W_n^1, W_n^2, \ldots, W_n^1, W_n^2, \ldots)
\]

in which case more than one core and more than one addition are present in formation of the core \( W_{n+1}^s \).

Then, a compound core \( W_n^c \) at level \( n \) is a Q-structure found from a simple core of the level \( n \) and conjunction class \( \text{conj} \), as follows:

\[
W_n^c = W_n^c \quad \text{conj} \quad W_n^s
\]

The conjunction is attached to the simple core in a feedback fashion, allowing repeated use of the core infinitely. The kind of conjunctions used in a practical case is related to the logical structure of the compound form, being important to the syntax of the form rather than to the problem of parsing.

Let us consider, for example, an adjectival Q-structure immediately preceding a noun as structure in level 1 (core 1) such that

\[ W_1^s = \text{ADJ} \] (adjectival structure)
Let \( W_1 \) consist from an article and noun where the noun is called the head and let the \( P_n \) group all of them into a structure (from \( (W_2) \))

\[
\begin{align*}
W_2^s & = \text{art} \rightarrow \text{ADJ} \rightarrow \text{noun} \\
\end{align*}
\]

then \( W_2^s \) has its name "noun phrase" from the class of the head; also where

\[
\begin{align*}
W_2^s & = P_2 (\text{ADJ}, \text{art}, \text{noun}) \\
\end{align*}
\]

having the name "noun" phrase from the head with the attribute "simple." Then compound noun phrase according to \((W_3)\) is

allowing, for example, the sequence

\[
\begin{align*}
\text{the tall girl, a yellow car and John,} \\
\end{align*}
\]

\[
\begin{align*}
W_2^s & \quad \text{conj} \quad W_2^s \quad \text{conj} \quad W_2^s \\
\end{align*}
\]

in which, indeed, sequences inside the adjectival group would depend on ADJ that we did not specify in any more detail.

Let us call \( W_2^c \) symbolically \( NP^c \) (compound noun phrase). Then similarly,

\[
\begin{align*}
W_3^s & = P_3 (W_2^c, \text{prep}) \\
\end{align*}
\]

called the simple prepositional phrase and from \((W3)\)

14
is obtained a compound prepositional phrase.

Continuing, we have

\[ W_{4}^{S} = (PP^{C}, \text{participium}) \]

simple participial phrase \( P_{t}^{P} \) and from (3)

\[ W_{4}^{C} = P_{t}^{P} S = \quad \] 

compound participial phrase.

It can be observed that the formation of the compound groups (W3) is a repeatedly used pattern in natural language.

Let us call (W4) expanded noun phrase such that NP is followed by its adjectival phrase that from the parsing point of view is a prepositional or participial phrase. Then

Then from (W3) the compound expanded noun phrase is

\[ \text{blue car and yellow truck} \quad \text{from the garage on the corner}, \]

\( \text{NP}^{C} \quad \text{PP}^{C} \quad \text{conj}. \)
Taking a closer look at (W7) we find

magnifying expanded noun phrase up to the level of all involved noun phrases. (For the simplicity of our examples we will not elaborate here on possible expansions of prepositions, participles, clauses, etc., since it does contribute anything new to the presented problem of compound forms in the sentence.)
It is important to notice that all the structures (W1 through W12) are given as compound forms, which is not always the case. There is a syntactical difference between compound form (W7) and a simply repeated form that does not have conjunction in its feedback:

\[ W_n \]  

(W13)

For example: "the car from the house on the right side" (W14) in (W10). The two PP-s describe different things, i.e., the first one describes the car, the second one describes the house. Whereas in the case of the compound form:

"the car from the house and on the right side" (W15)

both PP-s describe the car.

While these rules are subject to modifications by the presence of other possible markers or by the dependency on the context, both forms have to be recognized in many cases. Examples would include the following: a compound sentence does not have the alternative of repeated clauses without conjunctions; a prepositional phrase does have unlimited feedback; a noun phrase can be repeated only twice in case of indirect-direct object sequence.

In relation to other related fields it would seem proper to call compound forms also parallel-connected forms and to call simply repeated forms (feedback without conjunction) serial forms or serially connected forms.

**Latest Q-Graph**

The following text shows the Q-graph that is prepared for testing by the latest Q-parser modified for recursive graphs. Among the sub-structures that will be included later are infinite clauses and some subordinate clauses. Various remarks are written following specific subgraphs.
List of symbols used in the subgraphs

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AjP</td>
<td>Adjectival Phrase</td>
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Compound Noun Phrase CdNP

(See remarks concerning participial phrase structure.)
The noun phrase structure allows for the use of phrases such as

the upper index \( n \)

the \textit{adj noun symbol}

or

the Q-graph \( B \)

the \textit{symbol dash noun symbol}

In the case of more complicated symbols such as indexed variables or even algebraic expressions, algebraic symbolic language would have to become a subset of natural language. A study has been conducted in this respect under the title, "Hardware Processor for Natural Language."

Conjunction in the feedback loop makes the clause a compound CL. It is however not clear whether or not in the case of the compound CL, the form given by the middle line can be mixed with the form in the lower line; that is, for example

Mary was at home all the year and

at the college was John this summer.

However, the acceptance of the above graph as it is does not seem to present any side-problems for parsing, while simplifying the graph.
There are many considerations that have to be constantly applied when a general Q-graph is being formed. For example, participial phrase $P_tP$:

1. The three conjunctions in the feedback loop could be removed from their places to the place $A$ where only one node $\text{conj.}$ would exist instead of three nodes.

   **Pro:** Simplifies the graph, reducing total number of nodes and allowing faster analysis (a little bit).

   **Con:** Recognizing three different nodes when classifying the conjunction prepares more efficient syntactical analysis that follow parsing.

2. The structure around two parts can be replaced by the following structure built around one part.

   **Pro:** Eliminates 3 nodes from the graph; makes the analysis faster.

   **Con:** In the place of participial structure, it allows an adverbial structure (without any participium) to occur that might lead to improper parsing. However, it has not been decided whether the suspicion is legitimate.
(Compare with ADJ where the second choice is shown with the same question in mind.)

The above considerations are illustrations of the evolving feelings that the form of the Q-graph will have to be decided on by the criteria that specify more exactly the purpose and use of the parser, while the problem of the research is to find the various configurations and offer their evaluations from different points of view, besides the search for one final form.
Conditional Clause CC

Relative Clause RC
Subordinate Clause SC

\[
\text{conj} \rightarrow S \text{ Conj} \rightarrow CL
\]

Complete noun phrase $C_tNP \ (RC)$

\[
C_tNP \ (RC) \equiv\]

including Relative Clause

\[
\text{conj} \rightarrow \text{RC} \rightarrow \text{PP} \rightarrow F_tP
\]

CdNP
In our research we have seen that the speaker also communicates—in addition to his message—how that message is to be interpreted. Two different forms are used to communicate the interpretation:

Form 1: Renaming of the noun signaled by a subjective complement that in the syntactical structure corresponds to the substitution of a noun-node in the sentence tree (sentence diagram) replacing all the structure below the node by a new structure (e.g., "Boolean expression on the left side is a sum of four implicants" signals that the node "expression" can be substituted by the node "sum" replacing all the tree "Boolean expression on the left side" by the tree "a sum of four implicants").

Form 2: Renaming of the verb (predicate) that in syntactical structure corresponds to the renaming of the substitution of the verb-node. The substitution requires a more complex transformation, that is signaled by the speaker using "means," "represents," etc. Following is an example of the TEXIN subroutine:

Input 1. "Move A from B to C" means "replace the coordinates of B by the coordinates of C."
2. "Move the book from the right shelf to the desk in the kitchen."

Output of TEXIN if the meaning of 2 is requested: "Replace the coordinates of the right shelf by the coordinates of the desk in the kitchen."

Using Form 1 and 2, reinterpretation of the text can be made such that it is the speaker (and not the built-in rules of TEXIN) who directs TEXIN toward the desirable interpretation of the content.

Following are some of the features and the possible uses of TEXIN:

1) The directions for the interpretation of the meaning are given by the speaker in the same manner as they would be given to the human listener.

2) By inputting directions (e.g., for interpretation of an algorithm, where both directions and the algorithm have been described in natural language), the system will be able to directly write a computer program.

3) Given the directions for interpretation of certain transformations (e.g., "John gave a book to Judy" means "Judy was given the book by John") the system is able to accept both versions as an equivalent wording or to use both of them in any other manner that is again communicated in natural language to the system.

4) The way the system accepts, interprets and acts is controlled by the speaker who communicates with the system. The TEXIN, TEXPRO, TEXSYN merely provide the system with the capability of being controlled by the speaker rather than controlling the system actions. For example, from the nine following sentences it can be demonstrated that a system is able to interpret that "Move the point A to its neighbor place" means "\((n_1, n_2) = (n_1, n_2) + 1\)." The nine sentences are:
1. Move point to the neighbor square of A
2. Move A1 from A2 to A3 means replace A2 by A3
3. Neighbor square of Q1 is the square which has the coordinates greater than the coordinates of A1 by 1
4. Q2 greater than Q3 by 1 means Q2 is equal to Q3+1
5. Move point A means move point from the square of A
6. Replace square Q4 by square Q5 means replace the coordinates of the square Q4 by the coordinates of the square Q5
7. The coordinates of point A are \((n_1, n_2)\),
   the coordinates of the square of point A are \((n_1, n_2)\)
8. Q6 of Q8, which has Q6 equal to Q7 is Q7 (e.g. the color of the desk, which has the color equal to green is green, or e.g., A which has A equal to C is C)
9. Replace Q9 by Q10 means Q9 + Q10

5) Studies in the nature of the control of interpretation by a speaker led our research toward a very valuable by-product. It is well known that any description of a system is (a) a description of the elements of the system and (b) a description of the relations among the elements (i.e., a description of the system's structure).

We were able to demonstrate that there is a very strong correspondence between the structure ST of the system S and the syntactical structure SST of the description of S where the description is given in natural language.

References


Extended Effects of Information Processes and Processors

L. Chiaraviglio, W. T. Jones

During the course of the year 1971/72 it was decided that some field of science would constitute a promising field for the study of the extended effects of information technologies. The factors on which the decision was based were: a) there exists a body of data pertinent to the transmission and origination of knowledge in science; b) a portion of this data is available in forms adapted to automatic processing; c) the importance of science to society and the rapidly increasing use of new information technologies in science make the restriction of our studies to some science a reasonable strategic choice. The central problems countenanced in this project are twofold. The first is concerned with the transmission and origination of knowledge in a science. The second is concerned with the effect of new information technologies on the transmission and origination processes.

The results obtained during 1971/72 may be described as follows:

a) A methodology for studying and describing quantitatively the phenomena of transmission and origination of knowledge in science has been identified. The methodology is an adaptation of the genetic map construction techniques [1,12] developed in classical genetics and the statistical techniques of population genetics [2,3,10,11,12,13,14]. In the adapted methodology concepts are the analogues of genes. They are viewed as stable factors inherited in the process of knowledge transmission. The origination of concepts is viewed as mutational events. The articles, monographs and other products transacted in the process of communication which are the surface expressions of concepts are viewed as the phenotypic expression of these concepts. The processes of transmission (e.g., as exemplified by the citation processes) are viewed as the inheritance mechanisms.

b) A concrete setting for testing and refining the adapted methodology has been identified. Arrangements have been made for accessing data banks that contain reference information, abstract, texts and attendant indexing systems in the area of physics. Programs have been devised for accessing the relevant data and constructing maps. These programs are currently in use to perform the initial retrodictive experimental tests of the adapted methodologies.

The programs developed are used for experimental tests of the analogy between the processes of gene transmission and mutations and the processes of conceptual transmission and innovation. The tasks that these programs carry out are as follows:

Let us consider two populations of articles P and F (parental and filial) such that P contains all the articles cited by the articles in F. Let I be the set of indices associated with the articles in F U P. For every article A in F U P we obtain a set of markers G_A which is constituted by the elements of I marked with a '+' if they are associated to A, and marked with a '-' if they are not.
$G_A$ is taken to be the set of markers that are members of the grammosome of $A$. $G_A$ is a subset of the total set of markers $+_I$, where $i$ is in $I$ iff both $+i$ and $-i$ are in $+_I$.

For any two indices $i,j$ in $I$ we subdivide the parentals $P$ into two disjoint subsets $P+/-j$ and $P+/-j$, $P+/-j U P+/-j = P$. An article $A$ is in $P+/-j$ if both $+i$ and $-j$ are in $G_A$. An article $B$ is in $P+/-j$ if both $-i$ and $+j$ are in $G_A$. It is clear that $B$ and $A$ must be different articles. Let $F(+i-j x -i+j)$ be the subset of $F$ which contains all and only articles that cite both members of $P+/-j$ and members of $P+/-j$. The analogue of $F(+i-jx-i+j)$ in the set of filials that result from crosses of parents of the type $+i-j$ with parents of the type $-i+j$. Among such filials we can discriminate $F+i-j, F-i+j, F+i+j$ and $F-i-j$ which are disjoint (possibly empty) subsets of $F(+i-j x -i+j)$ whose union is this set. Hence the frequency of the types $+i-j, -i+j, +i+j, -i-j$ must sum up to one, $f(+i-j) + f(-i+j) + f(+i+j) + f(-i-j) = 1$.

We test for dosage effects in the filial population just described. Let us suppose that $F_1(+i-j x -i+j)$ is a subset of $F(+i-j x -i+j)$ such that every member of this subset cites as many articles in $P+/-j$ as it does articles in $P+/-j$. Then if the analogy holds to a typical (but not the only possible) biological situation we should expect that the filial frequencies be related as follows: $f(+i-j) = f(-i+j) = f(+i+j)$. That is, an approximation to this relation should hold for increasingly larger populations of the description $F_1(+i-j x -i+j)$. Similarly we should expect that for filial populations $F_2(+i-j x -i+j)$ such that every one of its members cites articles in $P+/-j$, the frequencies should be related by a factor $r$. For those indices for which these expectations are met we can say that the analogy tentatively holds. Such indices can be organized in a map where distances between $i$ and $j$ can be taken as the frequency $f(+i+j)$ that issues from crosses of the type $+i-j x -i+j$ or $+i+j x -i-j$. The notion of distance can be taken seriously when the frequencies in question behave as genuine metrics for some postulated structure for the set of indices in question.

Further empirical checks of the assumed structure are conducted by discriminating multifactor parental populations and the observed frequencies of the filials. For example for indices $i,j,k$ for which two factor crosses yield expected results we discriminate the parentals $P+/-j+k$ and $P+/-j-k$ and observe the eight possible subpopulations of $F(+j+k x -i-j-k)$ and their frequencies. Evidence gathered in this fashion is relevant to the structural hypothesis.

Once some confidence is gained in some postulated structure for some subset $I'$ of $I$ attention is given to the remaining indices. The guiding hypothesis here is that the indices in $I-I'$ are to be associated with the indices in $I'$. Let us suppose for the sake of simplicity that the structure of $I'$ is linear. That is to say that according to the observed frequencies we can define a three-place relation between that holds for any three indices in $I'$ and is the analogue of "between" for points on a line.
we can discriminate any other subset \( I'' \) of \( I-I' \) on which this relation also holds, then the indices of \( I'' \) are associated to the indices of \( I' \) via a homomorphism. The homomorphism \( h \) has to meet the additional conditions that if \( h \) maps \( I'' \) into \( I' \), then \( f(+i''+h(i'')) \) has to be equal to zero and if \( h(i'') = h(j'') \), then \( f(+i''+j'') \) must be smaller than or equal \( f(+k''+l) \) for any two indices \( k \) and \( l \) such that \( h(i'') \) is between \( k \) and \( l \). If these conditions are met, then we can say that the region marked by \( h(i'') \) includes the regions marked by \( i'' \) and \( j'' \).

The confidence we can place on the proposed analogy as a predictor of the minute and local features of transmission relative to a given indexing system depends on the success encountered in organizing the indices in the manner described. In contradistinction prediction of the overall dynamics of transmission is less dependent on the idiosyncrasies of the indices chosen.

A first task in ascertaining the overall patterns of transmission is the establishment of the effects on the number and sizes of citation threshold subpopulations with time as the total population of articles varies in size. Similar observations are made for varying environmental factors (e.g., varying support levels, varying number of workers in the field, etc.). Once the index set associated with a citation threshold subpopulation is known we observe: a) the overall patterns of transmission under changing growth levels; b) the overall patterns of transmission under changing environmental conditions, and c) the correlations between growth levels, environmental factors and index transmission. None of the above observations depend on knowledge of the index set structure. These observations yield the basic data for which analogical interpretation can be sought once the index set structures is obtained.

It may be noted that the relevant concept of time to be used in the study is given by the citation process. The ordering of articles so obtained may not square with chronological time. Segments of chronological times consonant with citation times are to be obtained in order to correlate external factors that change in chronological time with the citation and transmission phenomena.

Indices may be introduced and lost from the index set of a population independently of the transmission processes. The formulation of consistent interpretations to these types of phenomena constitute a large part of the task of explaining the macrostructures of transmission in terms of the minute features of index set structure. Let us suppose that we have discriminated a parental population \( P \) and a filial population \( F \) within some citation threshold subpopulation. Further, suppose that an index \( i \) is associated with the elements of \( P \) and not associated with the elements of \( F \). That is to say, all the members of \( P \) are of type \(+i\) and all the members of \( F \) are of type \(-i\). We discriminate the type of the event of going from \(+i\) to \(-i\) in terms of the index set structures of \( G_P \) and \( G_F \). The index sets of the parental \( P \) and filials respectively. For example, the event \(+i\rightarrow-i\) is a deletion mutation if for indices \( j,k \) such that \(
is between \( j \) and \( k \) and \( j \) and \( k \) are nearest neighbors of \( i \) in \( G_p \), then \( j \) and \( k \) are nearest neighbors in \( G_p \). Entirely similar expediencies discriminate events that may be said to be point mutants, deletion mutants of various sizes, insertions, translocations, etc.

The correlation obtained between environmental factors, overall growth patterns and the transitions events of which the passage from \( +i \) to \( -i \) is an example furnish the basis for further tests of the basic analogy. The tests are retrodictive in the sense that if certain correlations are obtained in one segment of the data, then it is to be tested in other segments of the data that exhibit similar situations. We are forced to conduct retrodictive tests since our ability to experiment is very small.

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Abstract Digital Computers

L. Chiaraviglio, J. R. Horgan, R. C. Roehrkkase

The central problem of this project has been to articulate a mathematical model of digital computers and to study the principal properties of these machines and their processes in a precise algebraic setting. We envisage this to be the core task of a unified theory of computation that is capable of dealing with the concrete modern paradigm of computation. The accomplishment of this task contributes to the stated general objectives by providing an encompassing theory to cover the present and ever-increasing range of informational phenomena that are the manifestation of our expanding use of digital computers.

Work prior to 1971 characterized an abstract digital computer as an algebra and investigated its theory of morphisms and representation. The details of this work may be found in [3]. The outline of the theory developed is as follows:

An abstract computer is composed of a set of states $S$, a set of actions $A$, and a control unit $C$. The triplet $(S,A,C)$ meets the following requirements: a) $S$ and $A$ are disjoint nonempty sets; b) $A$ is a subset of $S^S$; and c) $C$ is in $A^S$. The computer $(S,A,C)$ operates by having $C$ "read" or "interpret" a state $s$ in $S$, obtaining the action $C(s)$ in $A$, and applying this action to $s$ to obtain the "next" state $(C(s))(s)$ in $S$. The state-transition function $T$ for a computer $(S,A,C)$ is given by $T(s) = (C(s))(s)$ for every $s$ in $S$. There will be generally many computers with the same state-transition function.

The computer is said to be iterative, ordinarily recursive, or an omega computer if $T^a$ is defined for every finite ordinal $a$. That is to say $T^0$ is the identity on $S$ and $T^{a+1} = T^a T^a$. The computer is said to be synchronous if time runs as the powers of $T$. If at time $t_0$ the computer is in the state $s$, then at time $t_\alpha$ the computer is in the state $T^\alpha (s)$.

The set of processes of an iterative synchronous computer is the set of all sequences $p$ in $S^\omega$ such that for every $\alpha$ in $\omega$, $p(\alpha) = T^\alpha(p(0))$. The process $p$ is terminating if there exists an $\alpha$ in $\omega$ such that $p(\alpha) = p(\alpha+1)$. The computer is said to stop at the state $p(\alpha)$ when started in the state $p(0)$ if $p(\alpha) = p(\alpha+1)$. We may note that since $T$ is a function, computers are capable of generating only two types of processes, namely: processes that are nonrepeating and processes that are periodic after some finite delay. Terminating processes are those which after some finite delay are of period one. Omega computers, if they stop, do so after some finite delay.
Abstract computer processes are determined uniquely by the choice of initial state and by the control unit. The choice of initial state is the "external" control of the process. The "internal" control is given by the control unit. Programming is the choice of initial state. Thus computers that require choice of initial states are said to be programmable. Computers whose internal control is given by one control function are said to be centrally controlled. Computers whose states are disjoint from the action are said to be internally noninteractive.

Abstract digital computers are a special case of iterative, synchronous, centrally controlled, programmable, noninteractive, abstract computers that have Boolean algebras for their sets of states. If B is a Boolean algebra that is the set of states of some abstract digital computer it is obtained from a zero-one valued functional Boolean algebra by endowing the elements of this algebra with a structure. This structure mirrors the organization of actual digital computers into registers of given word size, that are further organized into memory registers, arithmetic unit registers, etc.

Abstract digital computers can mirror what seem to be the essential characteristics of actual digital computers. Actual digital computers are stored program devices whose states have the type of internal organization mentioned. They process synchronously by repeating interpretative and action cycles. The interpretative cycle reads a portion of the stored program and "interprets" it by selecting an operation from a fixed set of finitary operations. The selected operation is applied to the current state of the device and this constitutes the action cycle. Succeeding states are reached by iteration of the interpretative and action cycles. Entering a program into the workload of an actual computer amounts to selecting a class of first states or alternatively it may be also viewed as the process of selecting a first state for the computer that results from restricting the original computer to the work space assigned to the program. Even though actual computers may have a plurality of processing units they are all centrally controlled. All existing digital computers are internally noninteractive. No state of these devices can act on any other state. Indeed synchronicity and central control seem to be inconsistent with interaction. Thus the defining properties of abstract digital computers seem to capture the operational essence of the actual devices.

There are three ways of viewing an abstract computer. An abstract computer is composed of a set of states, a set of actions, and a control function. We may abstract from the set of actions and view the computer as a set of states together with a transition function or we may view it as a set of processes closed under certain operations. In all of its characterizations an abstract computer is an algebra and for all such algebras we may elaborate theories of morphisms, representation, and in some cases duality.

The results obtained in this project during the year 1971/72 fall into two groups:

a) The extant theory of recognizers (automata) has been embedded in the algebraic theory of abstract digital computers. For each class of
automata in the hierarchy of recognizers (finite state, pushdown store, linear bounded Turing machines, and their nondeterministic counterparts) an abstract digital computer has been constructed which captures all the computations of the machines in the class up to changes of state, head positions and tapes. Abstract digital computers are algebras and it has been shown that the theory of morphisms for these algebras is sufficient to recapture the hierarchy of automata.

b) The extant theory of degrees of unsolvability has been embedded in the algebraic theory of abstract digital computers. For each class of functions of a given degree an abstract digital computer has been specified which computes the function of that class. It has been shown that the theory of morphisms for these abstract computers is sufficient to recapture the hierarchy of degrees.

The mentioned results constitute a test of the adequacy of the proposed theory of abstract digital computers. The proof of the sufficiency of the theory to house the principal aspects of the extant mathematical theory of computation is evidence for the adequacy and universality of the theory.

Details of the embedding of the theory of recognizers in abstract digital computers may be found in [4,5]. We summarize this work as follows:

The abstract digital computer that captures the computation of a given class of recognizers is monomorphic to the abstract digital computers that capture the computations of more powerful classes of recognizers. There is a precise sense in which these morphisms preserve input tapes up to a relabeling of the alphabets. Thus the relations between classes of recognizers and their grammars are obtained in the theory of abstract digital computers as morphisms between the appropriate computers.

The general procedure used in the construction of abstract digital computers that will recapture the computations of a class of automata is as follows: Each automaton in a class is specified originally by a set theoretic predicate of the form 'x is an automaton of class α', where x is an ordered n-tuple composed of a finite set of states, one or more finite alphabetic sets, one or more finite sets of actions, a function that maps the Cartesian product of state and alphabet sets into the Cartesian product of state and action sets, and some distinguished states labeled as initial and terminal. From this set theoretic specification we may obtain a configuration function that maps the Cartesian product of state set, tape sets, and head positions. We may order all the machines in the class and relabel states and alphabets so that no two machines will share states or alphabetic symbols. We may use the natural numbers, N, for such relabeled states and symbols. Thus for example the class of all Turing machines with one-way tapes will have all of their states and head positions represented by N and all of their tapes will be functions in N^N. For each such Turing
machine its configuration function will be a partial function on $N \times N \times N^N$. The union of all these configuration functions will also be a partial function on $N \times N \times N^N$ since we have relabeled state and alphabetic sets so that they will be disjoint. The union of the configuration functions may be extended to a total function $T_M$ by declaring $T_M$ to be the identity where the original functions were not defined. The pair $(N \times N \times N^N, T_M)$ is an abstract computer. The computer $(O^N \times N \times N^N, T_M)$ is its digital counterpart, where $T_M$ is the identity on non-atoms and for atom $a$, then $T_M(a)$ is the atom that has the value one for $X = T_M(a^{-1}(1))$.

The abstract digital computer that captures all the computations of all pushdown store automata will have the form $(O^N \times N \times N^N \times N \times N^N, T_{PDA})$, where the first, second and third $N$ are the states, input head position, and stack head position respectively and some of the functions in the first $N$ are input tapes and some of the functions in the second $N$ are stack tapes. Some monomorphism $H$ which preserves tapes is required to show that for every pushdown store automaton there exists a Turing machine which recognizes the same input tapes.

The passage from abstract computers to abstract digital computers allows us an easy generalization of the methods sketched to the non-deterministic case. In the nondeterministic case the total configuration function maps configurations into finite subsets of configurations. Correspondingly the state transition of the abstract digital computer maps some of the atoms of the algebra into finite Boolean elements (i.e., elements $b$ such that $b^{-1}(1)$ is finite). Thus we may obtain the state-transition function of the abstract digital computer by an atom-wise extension to all the finite elements of the algebra. Abstract digital computers carry out the branching computations of nondeterministic machines simultaneously. Every finite element of the state set represents a finite set of configurations and every transition from a finite element to a finite element represents a simultaneous transition from a finite set of configurations to a finite set of configurations.

The results established by the methods sketched are that there exist recognition preserving morphisms between the abstract digital computers of finite automata and pushdown automata, between the abstract digital computers of pushdown automata and linear bounded automata, and between the abstract digital computers of linear bounded automata and Turing machines. Thus the theory of recognizers is embedded in the theory of abstract digital computers.

Details of the embedding of the theory of degrees of unsolvability in abstract digital computers may be found in [1]. We summarize this work as follows:
The techniques used in [2] and [3] of constructing abstract digital computers for Turing machines is suggestive here: suggestive because Turing machine, we recall, is an equivalent concept to recursive function. Therefore, as a first step we must construct abstract digital computers for equational calculi representing recursive functions. Then, that construction may be extrapolated to infinitary equational calculi for metarecursive functions. The main problem of constructing abstract digital computers for equational calculi concerns the algebraic character of abstract digital computers.

Recall that an abstract digital computer is a pair \((A,T)\) where \(A\) is a Boolean algebra and \(T\) is a transition function on that algebra. Thus, if Boolean structure can be imposed on equational calculi, an abstract digital computer can be recovered by defining the transition function to coincide with deduction. Fortunately, the theories of Lindenbaum-Tarski algebras, polyadic Boolean algebras and cylindric algebras indicate how Boolean structure may be found for various logical calculi. These theories are applicable because the equational calculus for ordinary recursive functions is a formal arithmetic, a predicate calculus with the axioms of arithmetic. Both the theory of polyadic Boolean algebras and the theory of cylindric algebras give methods for constructing algebras to represent formal arithmetics. An outline of the polyadic construction follows.

A polyadic Boolean algebra with equality is a functional Boolean algebra which satisfies requirements for quantifier, substitution, and equality operators. The pair consisting of the appropriate polyadic Boolean algebra \(A\), and the nonmaximal proper filter, \(F\), generated by the axioms of arithmetic, is called the polyadic logic of arithmetic. The concept of degree may be introduced in the following way. First quotient the algebra of arithmetic, \(A\), by the filter, \(F\), obtaining \(A/F\). Let \(\text{inf}(h)\) be the infimum of numeric equations representing the function \(h\) in extension. We say that \(h\) is recursive in \(g\) if \(\text{inf}(g)\) is an element of the principal filter, \(\pi\), generated by \(\text{inf}(h)\). Then if \(\text{inf}(g)\) and \(\text{inf}(h)\) are members of the intersection of \(\pi\) and \(\pi\) we say \(g\) and \(h\) are of the same degree. Now, we may obtain an A.D.C. on \(A/F/\pi\) by defining the transition function to coincide with derivation in the logic represented by \(A/F\).

Once recursive degrees are incorporated into abstract digital computers theory, their theory of morphisms allows the spectrum of degrees among abstract digital computers to be ascertained. Isomorphism partitions abstract digital computers into distinct classes and degrees are classes of these classes.

References


Universal Tessellation Automata

W. I. Grosky

All recent theoretical studies of tessellation automata have been concerned with those particular finite-state automata in which the neighborhood structure is spatially independent and fixed for all time, and in which the choice of the local state-transition function to be applied to a particular cell is independent of the position of that cell in the array, though it may be temporally dependent. As Yamada and Amoroso [7] point out, it might prove of interest to consider tessellation automata in which the above properties do not hold. Thus, in this study, we have addressed ourselves to the question of whether any advantages and/or insights accrue from formulating a not necessarily finite-state tessellation automaton in which the neighborhood structure of, and the choice of the local state-transition function to be applied to, a given cell at a particular time, depends on the total configuration at that time and the relative position of the cell in the array.

We have answered this question in the affirmative by formulating numerous individual, locally controlled tessellation automata of this latter type, each one of which can simulate a wide class of other tessellation automata, this class including all tessellation automata with the above uniformity properties. (This is done via the construction of appropriate initial configurations.) Thus, we have found the existence of many individual tessellation automata, each one of which can be said to be universal with respect to a wide class of other tessellation automata, this class including virtually all those tessellation automata in which people have had a theoretical interest in the past. For these universal tessellation automata, we have also demonstrated the fact that numerous constructions of initial configurations, whose evolution through time are meant to embody some calculation or construction, can be done in an effective manner, which is certainly not the case with previously studied tessellation automata. Thus, instead of being given a tessellation automaton and a procedure, and asking oneself whether the given tessellation automaton is capable of carrying out the given procedure, we have, in many cases, a method for effectively constructing an initial configuration for one of our newly formulated tessellation automata, whose evolution through time embodies the execution of this procedure. Hence, these newly formulated tessellation automata are also universal in the sense of not being procedure bound; that is, not being overly sensitive to the type of procedure which it is to carry out. This is not to say that previously formulated tessellation automata are all procedure bound, but, as in the investigations of Amoroso and Cooper [1] and Ostrand [6], some previously formulated tessellation automata were designed to accomplish one task -- such as the reproduction of patterns -- and it is not clear what else they can do.

In order to be more explicit about our newly formulated tessellation automata, as well as the class of tessellation automata which they can simulate, we must exhibit some definitions. The main definition, constructed in the spirit of Yamada and Amoroso [7], is that of a Euclidean tessellation automaton which does not necessarily possess the uniformities which previously formulated tessellation automata have had.
A generalized n-dimension tessellation automaton, TA, is an ordered 5-tuple of the form \( < S, E, Z^n, \alpha, \beta > \), where

1) \( S \) is an arbitrary set whose elements are called states;
2) \( E \) is an arbitrary set whose elements are called external inputs;
3) \( Z^n \) is the set of all \( n \)-tuples of integers. For \( j \in Z^n \), we refer to \( j \) as a cell of TA. Let \( CON = \{ c | c: Z^n \to S \} \). CON is called the set of array configurations. For \( s \in S \) and \( j \in Z^n \), we say that cell \( j \) contains \( s \) in the array configuration \( c \), if \( c(j) = s \).
4) \( \alpha: Z^n \times CON \times E \to \bigcup_{k \geq 1} (Z^n)^k \cup (Z^n)^\omega \).

For \( j \in Z^n \), \( c \in CON \), and \( e \in E \), let \( k^x \) be that element of \( \omega \cup \{ \omega \} \) which is such that \( \alpha(j,c,e) \in (Z^n)^{k^x} \). We call \( k^x \) the degree of interaction of cell \( j \) in array configuration \( c \) with respect to external input \( e \), and denote it by \( \deg j, c, e \).

\( \alpha(j,c,e) \) is called the neighborhood index of cell \( j \) in array configuration \( c \) with respect to external input \( e \). The element \( \theta \) of \( (Z^n)^{\deg j, c, e} \) is called the neighborhood of cell \( j \) in array configuration \( c \) with respect to external input \( e \), if, for each \( \xi \in \deg j, c, e \), we have that \( \theta(\xi) = j + \alpha(j,c,e)(\xi) \).

A process \( p \) of \( TA \), is that subset of \( CON^\omega \) which is such that, if \( p \in P_{TA} \), then, for each \( m, d \geq 0 \), \( p(m+1) = \tau_{\psi(m)}(p(m)) \), for some \( \psi \in (E(Z^n))^\omega \).

The process \( p \) is called uniform, if \( \psi(m)(j) = \psi(d)(j) \), for all \( m, d \geq 0 \), \( j \in Z^n \).

We say that \( TA = < S, E, Z^n, \alpha, \beta > \) is:

1) finite state, if \( |S| < \aleph_0 \);
2) **finitely variant**, if, for each cell \( j \in \mathbb{Z}^n \), and each \( c \in \text{CON} \), we have that, 
\[
| \{ \alpha(j,c,e) \mid e \in E \} \cup \{ \beta(j,c,e) \mid e \in E \} | < \aleph_0 ;
\]

3) **bounded neighborhood**, if there exists some \( \delta \in \omega \), such that, for each cell \( j \in \mathbb{Z}^n \), each \( c \in \text{CON} \), and each \( e \in E \), we have \( \deg_{j,c,e} \in \delta \);

4) **spatially uniform in neighborhood structure**, if \( \alpha \) is independent of its first argument;

5) **spatially uniform with respect to transitions**, if \( \beta \) is independent of its first argument;

6) **configurationally uniform with respect to neighborhood structure**, if \( \alpha \) is independent of its second argument;

7) **configurationally uniform with respect to transitions**, if \( \beta \) is independent of its second argument;

8) **neighborhood deterministic**, if \( \alpha \) is independent of its third argument;

9) **transition deterministic**, if \( \beta \) is independent of its third argument.

The preceding formulation of a tessellation automaton includes as special cases all other Euclidean formulations which have appeared heretofore in the literature. This formulation, in its full generality, might be said to be lacking in content, in that an appropriate tessellation automaton can easily be constructed to realize any process. This is akin to formulating the notion of a computer which can 'calculate' all \( 2^{\aleph_0} \) functions from \( \{0,1,2,\ldots\} \) to \( \{0,1,2,\ldots\} \) by definition. The point, though, is not that this formulation is so all-encompassing that it might be thought to be vacuous, but that it unifies all previously done work under a common methodological framework, in which various constraints may be introduced, as exemplified by the preceding nine definitions, and the resulting behavior examined. The value of the majority of these constraints would be directly related to the realizability of the resulting constrained tessellation automaton as a real world model for computation and construction. Those constraints not so realizable would be of purely theoretical interest, but of interest nevertheless.

The class of universal tessellation automata we formulate in this study will be infinite state, infinitely variant, unbounded neighborhood, spatially nonuniform in neighborhood structure and with respect to transitions, configurationally nonuniform with respect to neighborhood structure and transitions, neighborhood deterministic, and transition nondeterministic. The nonuniformities, though, are of a particularly simple kind, as will presently be made clear. We call these tessellation automata the class of combinatory tessellation automata. The formulation of them utilizes an \( n \)-dimensional generalization of combinatory logic -- see Curry and Feys [3] and Fitch [4]. Just as combinatory logic can be viewed as a syntactic
manipulation of strings of symbols, this generalization of it can be viewed as a syntactic manipulation of arrays of strings of symbols. To be more specific, the state set of a combinatory tessellation automaton will consist of some subset of the wffs of some formal system. What we have shown is that any one of our combinatory tessellation automata can simulate any other tessellation automaton which is finite-state, finitely variant, bounded neighborhood, and configurationally uniform with respect to neighborhood structure and transitions. It is also the case that a neighborhood and transition deterministic tessellation automaton of the preceding form can be simulated via a uniform process. With respect to the previously mentioned point that numerous initial configurations for a combinatory tessellation automaton, whose evolution through time embodies a particular calculation or construction, can be constructed effectively, the analogue of abstraction -- see, particularly, Fitch [4] -- for this formulation of a combinatory logic is used to show this.

We now formulate one particular 2-dimensional combinatory tessellation automaton, called CTA, in order to illustrate our methodology.

Define the set of primitive symbols, \( \text{SYM} = \{ B, C, I, K, W \} \cup \{ p_{i,j} / |i| + |j| \geq 1 \} \cup \{ g_{i,j} / |i| + |j| \geq 1 \} \).

The set of wffs are defined as follows:

1) All primitive symbols are wffs;
2) If \( X \) and \( Y \) are wffs, then \( (XY) \) is a wff;
3) If \( X \) is a wff, then it is shown to be so by virtue of 1) and 2).

We sometimes omit parentheses with the convention that grouping is from the left; i.e., \( XYZ \) is an abbreviation for \( ((XY)Z) \), and \( T(XY)Z \) is an abbreviation for \( ((T(XY))Z) \).

We now define various relations on the set of all wffs.

1) \( X >_B Y \leftrightarrow \bigvee_{T, U, V} \{ X = BTUV \land Y = T(UV) \} \)
2) \( X >_C Y \leftrightarrow \bigvee_{T, U, V} \{ X = CTUV \land Y = TVU \} \)
3) \( X >_I Y \leftrightarrow \bigvee_{U} \{ X = IU \land Y = U \} \)
4) \( X >_K Y \leftrightarrow \bigvee_{U, V} \{ X = KUV \land Y = U \} \)
5) \( X >_W Y \leftrightarrow \bigvee_{U, V} \{ X = WUV \land Y = UVV \} \)

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6) \[ X \succ_B Y \leftrightarrow [X >_B Y] \lor [X >_C Y] \lor [X >_I Y] \lor [X >_K Y] \lor [X >_W Y] \lor \]
\[ \lor T, U, V \{ T >_B U \land X = TV \land Y = UV \} \lor \]
\[ \lor T, U, V \{ T >_B U \land X = VT \land Y = VU \} \]

7) \[ X > Y \leftrightarrow [X > Y] \lor \{ X > Z \land Z > Y \} \]

8) \[ X \succ Y \leftrightarrow [X > Y] \lor [X = Y] \]

If \( X \succ_B Y \), we say that \( X \) is a **direct** \( B \)-**expansion** of \( Y \), and that \( Y \) is a **direct** \( B \)-**reduction** of \( X \). Similarly for \( >_C \), \( >_I \), \( >_K \), and \( >_W \). If \( X \succ Y \), we say that \( X \) is a direct expansion of \( Y \), and that \( Y \) is a direct reduction of \( X \). If \( X > Y \), we say that \( X \) is a proper expansion of \( Y \), and that \( Y \) is a proper reduction of \( X \). If \( X \succ Y \), we say that \( X \) is an expansion of \( Y \), and that \( Y \) is a reduction of \( X \). A wff which has no direct reduction is called **irreducible**.

Suppose \( X \succ Y \) and \( Y \) is irreducible. Then, \( Y \) is said to be the **normal form** of \( X \). Not all wffs possess normal forms, as, for example, the wff \( \neg WI(WI) \).

We now define the state set of CTA as consisting of all irreducible wffs. We let the set of external inputs be the set \( \{ I, CI, CII, CII, \ldots \} \), where, for \( n > 0 \), \( \Pi_n \) denotes a particular irreducible wff which represents the integer \( n \) — see Fitch [4]. (The wff \( \Pi \) is such that for any two wffs \( Y \) and \( Z \), we have that \( \Pi_n > Y(Y(\ldots(YZ)\ldots)) \).

Suppose cell \((j,k) \in Z^2 \) contains \( \rho_{p,q}^{X_1 \ldots X_m} \) in the array configuration \( c \), for some \( m > 1 \). Then, we say that cell \((j,k) \) is an **active transmission** mode to cell \((j+p,k+q) \) with respect to array configuration \( c \), while cell \((j+p,k+q) \) is in a **passive acceptance** mode from cell \((j,k) \) with respect to array configuration \( c \). We also call \( X_1 \) the active **message** from cell \((j,k) \) to cell \((j+p,k+q) \) with respect to array configuration \( c \). Suppose cell \((j,k) \) contains either \( \sigma_{p,q} \) or \( \sigma_{p,q}^{X_1 \ldots X_m} \) in the array configuration \( c \), for some \( m > 1 \). Then, we say that cell \((j,k) \) is in an active acceptance mode from cell \((j+p,k+q) \) with respect to array configuration \( c \), while cell \((j+p,k+q) \) is in a passive transmission mode to cell \((j,k) \) with respect to array configuration \( c \). In this case, we define the passive message from cell \((j+p,k+q) \) to cell \((j,k) \) with respect to array configuration \( c \), as follows:

1) It is \( I \), if cell \((j+p,k+q) \) contains \( \rho_{p,s} \) or \( \sigma_{p,s} \) in array configuration \( c \);
2) It is $z_1$, if cell $(j+p,k+q)$ contains $\rho_{r,s}z_1\ldots z_v$ or $\sigma_{r,s}z_1\ldots z_v$ in array configuration $c$, for some $v > 1$;

3) If the above two cases do not hold, then it is the contents of cell $(j+p,k+q)$ in array configuration $c$.

Now suppose the contents of cell $(j,k)$ in array configuration $c$ is $z$, and that $c$ is the array configuration of CTA at time $t = t_0$. Suppose, also, that at this time, cell $(j,k)$ is receiving the external input $X$. We now specify the contents of cell $(j,k)$ in array configuration $c'$, the successor array configuration of $c$; that is, the array configuration of CTA at time $t = t_0 + 1$.

1) Suppose $Z$ is of the form $\rho_{p,q}y_1\ldots y_m$, for some $m > 1$.

   a) If cell $(j,k)$ is in a passive acceptance mode from only one cell with respect to array configuration $c$, and this cell is $(r,s)$, then the contents of cell $(j,k)$ in array configuration $c'$ is either the normal form of $X(U(y_2\ldots y_m))$, where $U$ is the active message from cell $(r,s)$ to cell $(j,k)$ with respect to array configuration $c$, if such a normal form exists, or is $I$ otherwise;

   b) If cell $(j,k)$ is either not in a passive acceptance mode from any cell with respect to array configuration $c$, or is in a passive acceptance mode from more than one cell with respect to array configuration $c$, then the contents of cell $(j,k)$ in array configuration $c'$ is either the normal form of $X(y_2\ldots y_m)$, if such a normal form exists, or is $I$ otherwise.

2) Suppose $Z$ is of the form $\rho_{p,q}y_1$.

   a) If cell $(j,k)$ is in a passive acceptance mode from only one cell with respect to array configuration $c$, and this cell is $(r,s)$, then the contents of cell $(j,k)$ in array configuration $c'$ is either the normal form of $XU$, where $U$ is the active message from cell $(r,s)$ to cell $(j,k)$ with respect to array configuration $c$, if such a normal form exists, or is $I$ otherwise.

   b) If cell $(j,k)$ is either not in a passive acceptance mode from any cell with respect to array configuration $c$, or is in a passive acceptance mode from more than one cell with respect to array configuration $c$, then the contents of cell $(j,k)$ in array configuration $c'$ is $X$.

3) Suppose $Z$ is of the form $\sigma_{p,q}y_1\ldots y_m$, for some $m > 1$.

   a) If cell $(j,k)$ is in a passive acceptance mode from any cell with respect to array configuration $c$, then the contents of cell $(j,k)$ in array configuration $c'$ is either the normal form of $X(y_1\ldots y_m)$, if such a normal form exists, or is $I$ otherwise;
b) If cell \((j,k)\) is not in a passive acceptance mode from any cell with respect to array configuration \(c\), then the contents of cell \((j,k)\) in array configuration \(c'\) is either the normal form of \(X(U(Y_1 \ldots Y_m))\), where \(U\) is the passive message from cell \((j+p,k+q)\) to cell \((j,k)\) with respect to array configuration \(c\), if such a normal form exists, or is \(I\) otherwise.

4) Suppose \(Z\) is of the form \(a_{p,q}\).
   a) If cell \((j,k)\) is in a passive acceptance mode from any cell with respect to array configuration \(c\), then the contents of cell \((j,k)\) in array configuration \(c'\) is \(X;\)
   b) If cell \((j,k)\) is not in a passive acceptance mode from any cell with respect to array configuration \(c\), then the contents of cell \((j,k)\) in array configuration \(c'\) is either the normal of \(XU\), where \(U\) is the passive message from cell \((j+p,k+q)\) to cell \((j,k)\) with respect to array configuration \(c\), if such a normal form exists, or is \(I\) otherwise.

5) Suppose none of the above cases hold.
   a) If cell \((j,k)\) in a passive acceptance mode from only one cell with respect to array configuration \(c\), and this cell is \((r,s)\), then the contents of cell \((j,k)\) in array configuration \(c'\) is either the normal form of \(X(UZ)\), where \(U\) is the active message from cell \((r,s)\) to cell \((j,k)\) with respect to array configuration \(c\), if such a normal form exists, or is \(I\) otherwise;
   b) If cell \((j,k)\) is either not in a passive acceptance mode from any cell with respect to array configuration \(c\), or is in a passive acceptance mode from more than one cell with respect to array configuration \(c\), then the contents of cell \((j,k)\) in array configuration \(c'\) is either the normal form of \(XZ\), if such a normal form exists, or is \(I\) otherwise.

From Church [2] it can be shown that it is recursively undecidable whether a given wff has a normal form. From this, in turn, we can derive the fact that there is no algorithmic way of deciding the identity of the successor of an arbitrary array configuration of CTA. This does not pertain, however, when we carry out the aforementioned simulations and effective constructions of initial array configurations. In these cases, the processes of CTA are completely determined in an algorithmic fashion.

Many other combinatory tessellation automata have been formulated, including some with a finite primitive symbol set. These other formulations vary the position in the wffs where messages attach, the degree of destructiveness versus nondestructiveness in the sending and taking of messages, and the number of cells taking place in an individual information exchange.
As a final illustration of our methodology, we will now exhibit the construction of an initial array configuration for CTA, whose evolution through time embodies a particular construction. The process which will embody this temporal evolution will be uniform, in that if \( p(0) = c \), the given initial array configuration, then, for \( m \geq 0 \), \( p(m+1) = \tau_\gamma(p(m)) \), where \( \gamma = \{1\}(\mathbb{Z}^2) \). The particular construction we will carry out will be that of an originally unicellular organism which grows alternately one unit to the right and then one unit upward; that is,

\[
\begin{align*}
\text{Let wff } L_1 \text{ be } \lambda x y z (\rho_0,1(x y z)(x y z)), \text{ and the wff } L_2 \text{ be } \lambda x y z (\rho_1,0(x y z)(x y z)), \\
\text{this notation being defined in Curry and Feys [3] or Fitch [4]. We then let the wff } X \text{ be the normal form of } L_1 L_1 L_2, \text{ and the wff } Y \text{ be the normal form of } L_2 L_1 L_2. \text{ We now define the initial array configuration } c \text{ as follows:}
\end{align*}
\]

\[
c(\mathbb{J}) = \begin{cases} 
\rho_1,0^{XY} & \text{if } \mathbb{J} = \mathbb{J}_0 \text{ for some fixed } \mathbb{J}_0 \in \mathbb{Z}^2 \\
1 & \text{otherwise}
\end{cases}
\]

References


New Paradigms of Information Processing

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The object of this study has been to ascertain a range of alternatives to the modern digital computer. Our first objects of study have been interactive, parallel, locally controlled information processors. We have formulated two theoretical models of such devices, both within combinatory logic. The first model is called a "combinatonic computer"; the second is called a "combinatory tessellation automaton." The latter model falls within our investigation of the general theory of arrays of intercommunicating machines.

Results obtained during the year 1971/72 were as follows:

a) We have characterized the set theoretic structure of combinatonic computers [1]. Such an identification is necessary for the algebraic study of combinatonic computers and the study of their relationship to abstract digital computers.

b) We have formulated the notion of a generalized tessellation automaton in order to unify all the previously done work on arrays of intercommunicating machines under a common methodological framework. Furthermore, we have shown that all sequences of configurations may be realized as the evolution of some initial configuration of some automaton of this type.

c) We have studied some range of trade-offs which exist between various constraints that may be imposed on general tessellation automata. In particular, the notion of a combinatory tessellation automaton has been developed.

d) A combinatory tessellation automaton has been shown to be universal in the sense of it being able to simulate a broad spectrum of previously studied cellular automata.

e) An n-dimensional analogue of combinatory abstraction has been identified. This n-dimensional analogue of abstraction will yield effective constructions for configurations whose evolution through time embodies some calculation or construction.

f) The problem of completeness has been studied for nondeterministic one-dimensional tessellation automata when nonuniformity is allowed in the application of the local state-transition function.

References

The overall objective of this research has been the elucidation of the logic and metalogic of programs and plans. The central problem countenanced in this project is that of articulating appropriate concepts of validity and inference that will legitimate inferences from programs to programs. This is the essential task of logic. The accomplishment of this task contributes to the stated general objectives by providing the foundations for the appraisal of programs and, more generally, plans of action. Such a foundation is critically needed for programs that intend to model actual plans. Programs are often viewed as subspecies of plans of action that are relatively cheaply executed in limited and controllable artificial environments. Thus programs are increasingly used as test models for more general plans. The modeling analogy that runs from plans to programs is that plans stand in a relation to real world events they aim to control as programs stand to some of the events of their execution. The logic of programs aims to furnish the criteria of appraisal for programs, and extensions of the logic of programs to plans aim to furnish the criteria of appraisal for plans. The appraisal of the modeling analogies requires both the logic of programs and the logic of plans.

Work prior to 1971 had disclosed that it was desirable to characterize a syntax of formation that could capture the essential basis of the command structure common to most programming languages. This syntax of formation should be capable of generating programming languages over arbitrary first order languages. If such a syntax of formation could be found it was hoped that some extensions of the logic (syntax and semantics) of first order languages would constitute at least part of the logic of programming languages. The syntax of formation for a programming language PL over an arbitrary first order language L was specified as follows:

i) Primitive vocabulary. All of the primitive vocabulary of L plus the following additional logical constants:
   a. an infinite list of labels: '0', '1', '2', '3',...
   b. two imperative operators (imperators): 'goto', 'i'.
   c. one five-place connector:
      'If ___, then ___ and ___, else ___ and ___'.

ii) Rules of formation. All of the rules of formation of L plus the following additions:
   a. If $\ell$ is any label, then 'goto' followed by $\ell$ is a jump command.
   b. If t is any term of L, v is any individual variable of L, then v followed by 'i' followed by t is an unconditional command.
   c. If P is any formula of L, $j_1$ and $j_2$ any jump commands and $u_1$ and $u_2$ any unconditional commands, then:
      'If P, then $u_1$ and $j_1$, else $u_2$ and $j_2$' is a conditional command.
   d. If $\ell$ is any label and C any conditional command, then $\ell$ followed by C, 'iC' is a labeled conditional command.
e. If \( \ell_1, \ell_2, \ldots, \ell_n \) are \( n \) distinct labels and \( C_1, C_2, \ldots, C_n \) are any (not necessarily distinct) conditional commands, then the set:
\[
\text{Pr} = \{ \ell_1 C_1, \ell_2 C_2, \ldots, \ell_n C_n \}
\]
is a program.

f. Nothing is a program unless it be obtained from steps a. to e. above.

It is clear from the above description that the syntax of formation specified captures the essential command structures of languages such as ALGOL. This syntax of formation was the basis of our investigations during the year 1971/72.

If we were to proceed as in the usual presentation of the logic of propositions or the lower predicate calculus we would lay down a rule that would characterize the transformational syntax of PL. We shall not proceed in this fashion. We shall first set forth a portion of the semantics of PL in order to strengthen our intuitions as to what might be the appropriate transformational syntax of PL.

A number of concepts will be useful:

a) if \( \text{Pr} = \{ \ell_1 C_1, \ell_2 C_2, \ldots, \ell_n C_n \} \),
then the set of labels \( \{ \ell_1, \ell_2, \ldots, \ell_n \} \) is called the set of line labels of \( \text{Pr} \);

b) in the conditional command '\( \ell_1 \) if \( P \), then \( v_1 \) t_1 and go to \( \ell_1 \),
else \( v_2 \) t_2 and go to \( \ell_2 \).' \( \ell_1 \) is called the positive jump label,
'\( v \) t' is called the positive command, '\( v_2 \) t_2' is called the negative command and \( P \) is called the gate.

c) in a program \( \text{Pr} \) all the jump labels that are not also line labels are called exits; and

d) the least label in \( \{ \ell_1, \ell_2, \ldots, \ell_n \} \) is called the starting label of \( \text{Pr} \).

Let \( M = (D, I) \) be a model of \( L \) where \( D \) is nonempty and \( I \) an interpreting function such that:

a) if \( T \) is an individual constant of \( L \), then \( I(T) \in D \);

b) if \( P \) is an \( n \)-ary predicate of \( L \), then \( I(P) \subseteq D^n \); and

c) if \( F \) is an \( N \)-ary functor of \( L \), then \( I(F):D^n \rightarrow D \).

Let \( \text{Var} \) be the set of individual variables of \( L \), then the set of assignments over \( D \), \( \text{Assig}(D) \), is the set of all functions from \( \text{Var} \) into \( D \).

If \( d \in \text{Assig}(D) \) and \( t \) is a term of \( L \), then the interpretation of \( t \) relative to \( D \) in the model \( M = (D, I) \), is denoted by \( 't_d' \) and is given as usual.

'\( M \models [P, d] \)' and '\( M \models P \)' signify that the assignment \( d \) satisfies the formula \( P \) in \( M \) and \( P \) is true in \( M \) respectively. Satisfaction and truth are also defined in the usual fashion.
In the context of a discussion of the semantics of PL we can use the following suggestive terminology: Each D is a set of possible memory contents. Var is the set of addresses of memory registers. Assig(D) is the set of all possible memory states relative to a set of contents D.

For each model M = (D,I) of L and each unconditional command u of PL there is a unique function u* that maps the set Assig(D) into itself. Let u = 'v + t' for some individual variable v and term t of L then u* is given by:

1) \((u^*d)(w) = \begin{cases} td & \text{if } v = w \\ d(w) & \text{otherwise} \end{cases}\)

The interpretation of an unconditional command 'v + t' is a function u* that takes each "tape" d and "prints" in its v position the content I(t). We now know what it is to interpret unconditional commands of PL relative to each model model L. It is reasonable to suppose that the interpretation of a program of PL relative to some model will be a sequence of such functions. Each such sequence will be jointly determined by the gates, the jump commands and the unconditional commands of the program.

Suppose that: a) Pr = \{ l_1 C_1, l_2 C_2, ..., l_n C_n \} is a program of PL; b) for each i = 1, 2, ..., n, l_i C_i is of the form 'l_i' if \( P_i \), then \( u_{i,j} \) and go to j, else \( u_{i,k} \) and go to k'; c) M = (D,I) is a model of L; d) \( d \in \text{Assig}(D) \); and e) iden is the identity on Assig(D). Then the interpretation of Pr relative to d in a model M is a sequence \( P_r^* \) of functions from Assig(D) into itself determined as follows:

2) For \( l_1 \) the starting label of Pr, then
\[
\begin{align*}
P_r^*(0) &= \begin{cases} u_{i,j}^* & \text{if } M \models [P_i, d], \text{where } u_{i,j}^* \text{ is the positive command and } j \text{ the positive jump label of } l_1 C_1. \\
u_{i,k}^* & \text{otherwise, where } u_{i,k}^* \text{ is the negative command and } k \text{ the negative jump label of } l_1 C_1. \end{cases} 
\end{align*}
\]

3) For \( P_r^*(m) = u_{i,j}^* \) and \( j \) is a jump label but not a line label of Pr (i.e. \( j \notin l_i \) for all \( i \), \( 0 \leq i \leq m \)); then
\[
P_r^*(m+1) = \text{iden}.
\]

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4) For $Pr^*(n) = u^*_k$ and $j$ is both a jump label and a line label $l_k$ of $Pr$ for some $k, 0 \leq k \leq l$, then,

$$
\begin{cases}
  u^*_k j & \text{if } M \models [P_{k}, (Pr^*(n) \cdot Pr^*(n-1) \ldots Pr^*(0))d] \\
  & \text{where } u^*_k \text{ is the positive command and } j \text{ the positive jump label of } l_k.
\end{cases}
$$

Where $u^*_k$ is the positive command and $j$ the positive jump label of $l_k$.

$$Pr^*(n+1) = \begin{cases}
  u^*_k n & \text{otherwise, where } u^*_k \text{ is the negative command and } n \text{ the negative jump label }
  \text{of } l_k.
\end{cases}$$

Requirements 1) to 4) jointly specify that the interpretation of a program $Pr$ relative to some model $M = (D,I)$ and some initial state $d$ (assignment) of a memory whose contents are taken out of $D$ is a sequence of function $Pr^*$. Each such function is a mapping of $Assig(D)$ into itself. In other words the sequence $Pr^*$ specifies the state transitions that must occur in the execution of $Pr$. The sequence $Pr^*$ is said to terminate if there is an $n \geq 0$ such that for every $m \geq n$, $Pr^*(m) = iden$. In such a case the interpretation of $Pr$ relative to $d$ yields a terminal state:

$$d^n = (Pr^*(n) \cdot Pr^*(n-1) \ldots \cdot Pr^*(0))d.$$  

Expression 5) makes sense since each $Pr^*(i), i=0,\ldots, n$ is a function from $Assig(D)$ into $Assig(D)$.

The interpretation of a program relative to some state and model determines a unique sequence of states. If $d_0, d_1, d_2, \ldots, d_n, \ldots$ is a sequence of elements $Assig(D)$, then it may be called a process generated by $Pr$ in a model $M = (D,I)$ if and only if:

6) There is a $Pr^*$ which is an interpretation of $Pr$ relative to $d_0$ in the model $M$; and

7) $(Pr^*(n))d_n = d_{n+1}$ for all $n \geq 0$.

Processes are infinite sequences of assignments. If the interpretation of a program $Pr$ terminates, then the corresponding process is a sequence of assignments that is periodic and of period one after some finite bound. Such processes are called terminating.

We are now in a position to consider in a fairly precise setting what we might mean by the notion of a program satisfying or failing to satisfy our expectations. One of the things we do in actual practice in order to test for satisfaction is to run a program and see if the outputs we receive from these runs are what we expected on the given inputs. In other words we inspect the processes generated by the executions of the program and ascertain if these processes satisfy our requirements. We say that the program in question is successful if the processes it
generates meet certain requirements. We say that the program fails if the generated processes do not meet the requirements. The requirements against which processes are tested may be called goal properties.

A program Pr meets the goal property G in a model M = (D,I) relative to d₀ ∈ Assig(D) (briefly MGPr,d₀) if and only if there exists a process d₀,d₁,...,dₙ,... generated by Pr in M and this process has the property G. A program Pr meets the goal property G in a model M = (D,I) (briefly MGPr) if and only if for every d ∈ Assig(D), then MGPr,d.

There is an obvious parallelism between M ⊨ [P,d], where P is a formula of L, and MGPr,d where Pr is a program of PL. Similarly there is a parallelism between M ⊨ P and MGPr. The significant difference between the semantics of L and PL lies in the fact that in the former there is only one relation ⊨ between models and formulae assignment pairs or formulae while in the latter case there are possibly many such relations G. Intuitively we may capture the difference by saying that truth is essentially one while there are possibly many distinct goals that may be sound.

Nevertheless the analogy between the semantics of L and the semantics of PL may be exploited to yield the analogues of the notion of elementary classes of models, semantic entailment of programs, system, and algebra of systems that are relativized to goal properties. By these means many of the results available in the semantics of L can be imported with the appropriate emendations into the semantics of PL. The details of these constructions may be found in [1,2]. Here we shall merely indicate the principal results.

Let H(Pr) be the elementary class of a program Pr relative to the goal property of termination. That is, for G the property of termination of processes we let:

8) H(Pr) = { M | M model of L such that MGPr }.

The results obtained may be summarized as follows:

a) General results for arbitrary L and arbitrary commands in PL.

i. There exist logical connectives ∧ and ∨ in PL such that for any two programs Pr₁, Pr₂ of PL:

H(Pr₁ ∧ Pr₂) = H(Pr₃) = H(Pr₁) ∧ H(Pr₂) for some Pr₃ in PL:

and

H(Pr₁ ∨ Pr₂) = H(Pr₃) = H(Pr₁) ∨ H(Pr₂) for some Pr₃ in PL.

ii. The algebra of systems of PL is a pseudo-Boolean algebra.

iii. If L is incomplete then there exists a non-finitely axiomatizable system of PL.

b) Results that obtain if PL has only idempotent unconditional commands.

i. PL has exclusion negation.

ii. PL is compact.

iii. PL has finitary semantic entailment.

iv. The property of termination is complete in the sense that for every maximal system of PL there exists a model of PL and conversely.
c) Results that hold if $L$ is expressively complete (e.g., contains arithmetic) and PL has arbitrary commands.

i. PL has exclusion negation.

ii. The algebra of elementary classes of PL is isomorphic to the Lindembaum-Tarski algebra of PL and isomorphic to the Lindembaum-Tarski algebra of classical logic.

References


INTERACTIONS IN GENERAL SYSTEMS THEORY
Interactions in General Systems Theory

P. Zunde

The objective of the present research has been to study the problem of interactions within the framework of General Systems Theory, with applications to information systems. The research was carried out in various overlapped stages: a) development of a suitable definition of interaction; b) analysis of the selected definition leading to the development of a set of axioms and additional definitions; c) development of some theorems which may represent the basis for a theory of interactions in systems.

In this research special emphasis was given to finding meaningful relations between the concept of interactions and the concept of invariance. From those relations some possible suggestions leading to the decomposition of the system into subsystems are proposed.

Research in the area of interactions within the framework of General Systems Theory is at an early stage, and results are still far from conclusive. One of the first works dealing with the subject was by M. D. Mesarović in his paper "New Directions in General Systems Theory"[2]. Although the paper did not itself study the problem of interactions, the research related the concept of interaction to the concept of cohesiveness, previously developed by the same author. Mesarović said that a system is cohesive when, given a sequence of any output components, it is not possible to obtain as an output that sequence of objects, for whatever input sequence we choose. If this is the case in one system, then the system must have an internal structure which blocks the appearance of the sequence. The same paper extends the cohesiveness concept to two situations which define the so-called α-type and β-type.

In "Measure of Interaction in a System and Its Application to Control Problems" [3] the same author suggested an acceptable measure for the interaction between two sets of variables in a system and gave a methodology to get the measure by means of the cohesiveness type α and β. This paper offered an operational definition for the concept of interaction and also discussed a statistical approach to measure it. A characterization of zero and unit interaction is given and its application to linear systems. Mesarović showed that it is possible to arrive at necessary and sufficient conditions for the existence of unit interactions in those systems. The paper did not offer further generalization of the developments made.

R. Ashby in his paper "Systems and Information" [1] focused on the need to develop a rational way to simplification with the purpose of studying very complex systems. However, he also suggested that any developed simplification technique should be supported by a specific theory of communication within variables of the system so that our simplification does not become oversimplification, causing misleading results. The author realized the importance of discovering communication links among variables with the purpose of selecting the strongly interacting parts of the system from the noninteracting.
Mesarović Mathematical Theory of General Systems and Some Economic Problems [4] analyzed the concept of interaction as related to causality. In principle, the problem focuses in describing a causal ordering among the objects of the system, and after establishing formal relationships one has to investigate which system objects are causes and which are effects. According to the author, this is possible only if causality ordering results in properties that might be recognized in mathematical terms. From an intuitive point of view, it might seem reasonable to assume that a causal relation among two objects implies one-way interaction among those variables.

The same author also recognizes that a way to develop a causality ordering is to establish an external causality ordering. In this way, the analyst selects certain variables as inputs and other as outputs. Furthermore, the outputs can also be ordered, because outputs might depend directly on the inputs, or on other outputs. This ordering procedure is called the internal causality ordering in the system. Finally, some of the output objects at time $t$ might depend also on other systems objects at time $T$, $T < t$. This ordering is called time ordering causality.

The previous discussion assumes at least three kinds of interaction in a system: (a) input-output; (b) output-output, and (c) systems variables-output interactions.

Windelknecht in his book General Dynamical Systems [5] used and defined the term "uncoupled" for $T$-process. A $T$-processor is a collection of pairs of time functions $P \subseteq A^T \times B^T$; i.e., a time system. An alternative definition of $P$ is $P \subseteq (A \times B)^T$ or $P = \{ uv | v \in B^T \}$. A $T$-processor is uncoupled if and only if $u \in P^1$ and $v \in P^2 \Rightarrow uv \in P$ where $P^1$ and $P^2$ are the input set and output set, respectively.

This characterization says that a $T$-processor (a time system) is uncoupled if and only if every input function belonging to the input set can be paired with every output function belonging to the output set.
Definition of Noninteracting Systems.

a) Consider the system \( S \subseteq X \times Y \). System \( S \) is noninteracting if and only if
\[
S = X \times Y
\]
b) If the output space \( Y \) has only one element, we must have:
\[
Y = \{ b \} \quad S: X \rightarrow Y \quad \text{and}
\]
also \( S = X \times Y \). Then, by definition this is also a non-interacting system. Call it a "simple noninteracting system."

c) If in addition to the previous case, we have \( X = \{ a \} \), then \( S = X \times Y \). However we must rule out this case from the definition, because with only one input element and one output element we are not able to conclude interacting properties.

Note that \( X \) or \( Y \) might be any kind of objects; furthermore, they can even be sets of functions:
\[
S = X^T \times Y^T \quad \text{equivalent to } S = (X \times Y)^T
\]
as suggested in [5].

Lemma 1.
Every noninteracting system can be decomposed as the union of simple noninteracting systems.

Proof. Obvious.
\[
S = X \times Y \Rightarrow S = \bigcup_i f_i
\]
where
\[
f_i: X \rightarrow Y_i \quad \text{and } Y = \{ Y_i \}
\]

Lemma 2.
Every noninteracting system can be decomposed as the union of interacting systems (except the simple noninteracting system).

Proof. \( X, Y \) could be subdivided into different subsets each of which having more than one element.
\[
S = X \times Y \Rightarrow S = \bigcup_j f_j
\]
where
\[
f_j: X^j \rightarrow Y^j, \quad Y^j = \{ y_1^j, y_2^j \ldots \}
\]
The following diagrams give characterization of those lemmas for a simple case:

Invariant Spaces

a) Let $V$ be a set such that $V \subseteq X$ and also $V \subseteq Y$ and let $R$ be a binary relation $R \subseteq X \times Y$

$V$ is an invariant space under $R$ iff for $V \ a, \ a \in V$

where

$\{ aRb | a \in V \} = V.$

Consider the following definition:
b) Minimal Invariant Space:

If $V$ is an invariant space under $R$, and if in addition there does not exist a subset of $V$ which is also invariant under $R$, then $V$ is a minimal invariant space under $R$.

Example:

![Diagram](image)

$V = \{a, b\}$ is an invariant space under $R$.

$W = \{b\}$ is not an invariant space.

$U = \{a\}$ is an invariant space under $R$, and $U \subset V$.

The $V$ is not a minimal inv. space under $R$, but $U$ is a minimal invariant space under $R$.

Relation Between Non-Interaction and Invariance.

**Theorem 3**

1. If a system $S$ is noninteracting
2. and $Y \subseteq X$ ($X \subseteq Y$)

$\Rightarrow$ A minimal invariant space under $S$, is $Y$ itself. ($X$ itself).

**Proof:**

We must prove that $S$ has an invariant space and also that this invariant space is $Y$, minimal. $V = Y$ is clearly an invariant space under $S$.

Assume now that $W \subset Y$ is also an invariant space under $S$.

$\forall a, a \in W \Rightarrow a S \in W$.

However, as $S$ is noninteracting, there must exist $a S \in X$. Then $W$ cannot be an invariant space.

**Example:**

Let $X = \{a, b, c\}$, $Y = \{a, b\}$

$V = \{a, b\} = Y$ is an invariant space.

$W = \{a\}$ cannot be an invariant space.
Corollary 4

If $S$ is a noninteracting system, which has an invariant space under $S$ then the output space is a subset of the input space or vice versa.

$Y \subseteq X$ or $X \subseteq Y$

Theorem 5

Consider the system $R \subseteq \mathcal{O}_x \times \mathcal{O}_y$. If $X_1$ and $X_2$ form a partition of $\mathcal{O}_x$ and in addition $X_1, X_2$ are two invariant sets under $R$ then

$$R \subseteq X_1 \times X_1 \cup X_2 \times X_2$$

Proof. Obvious.

Note: If $V$ is an invariant space under $R$, $W \subset V$ is not in general an invariant space under $R$. Furthermore, $W$ is not, in general, an invariant space under the restriction $R/W$.

To see this point consider the following system:

$$R \subseteq X \times Y \quad X = \{x_1, x_2\}, \quad Y = \{x_1, x_2\}$$

$R = \{(x_1, x_2), (x_2, x_1)\}$

Clearly $X$ is an invariant space under $R$. Let $W = \{x_1\} \subseteq X$ and consider

$$R/W = \{(x_1, x_2)\}$$

Clearly $W = \{x_1\}$ is not an invariant space under $R/W$.

If $R$ is a noninteracting system,

$$R = X \times Y \quad R = \{(x_1, x_2), (x_2, x_2), (x_2, x_1), (x_1, x_1)\}$$

Let $W = \{x_1\} \subseteq X$

and then

$$R/W = \{(x_1, x_1), (x_1, x_2)\}$$

Evidently, $W = \{x_1\}$ is not an invariant space either under $R/W$.

As an immediate consequence of the previous theorems, we have that if $V$ is an invariant space under $S$, then the System $\hat{S}$ defined as

$$\hat{S} \subseteq V \times (Y-V)$$

is an empty system.

$$\hat{S} = \emptyset$$
Theorem 6

If \( V \) and \( W \) are two invariant spaces under \( S \), then \( V \cap W \) is also an invariant space under \( S \).

Proof:

\[
\begin{align*}
\forall a, a \in V \Rightarrow a \in S V \quad \forall a, a \in V \cap W \Rightarrow a \in S (V \cup W) \\
\forall b, b \in W \Rightarrow b \in S W
\end{align*}
\]

Theorem 7

If \( V \) and \( W \) are two invariant spaces under \( S \), then \( V \cap W \) is also an invariant space under \( S \), or it is empty.

Proof:

\[
\begin{align*}
\forall a, a \in V \Rightarrow a \in S V \text{ and } \forall b, b \in W \Rightarrow b \in S W
\end{align*}
\]

Let \( x \in V, x \in W \Rightarrow x \in S V, x \in S W = x \in S (V \cap W)

This theorem is illustrated in the following diagram:

\[
\begin{array}{c}
V \\
\downarrow \\
W \\
\end{array}
\begin{array}{c}
V \\
\downarrow \\
W \\
\end{array}
\begin{array}{c}
S
\end{array}
\]

\( a \in S (V \cap W) \). Assume there exist an image \( a \in S V \) but not included in \( W \). Then \( W \) would not be invariant, contradicting the hypothesis.

Theorem 8

If \( V \) is a proper subset of \( X (V \subset X) \), and, in addition, \( V \) is an invariant space under \( R \), then the system \( R \subseteq X \times Y \) is interacting.

Proof: By contradiction. Assume \( R \) is noninteracting; then \( R = X \times Y \). If the system has an invariant space, that invariant space has to be \( X \) and it is not possible to find a subset of \( X \) which is also invariant. (See Corollary 4). This contradicts the hypothesis that \( V \) is a proper subset of \( X \), which is invariant.
Practical Considerations

To find if a system $S$ is noninteracting, we could do the following:

a) Find an invariant space under $S$. Call it $V$.

b) If $V$ is a proper subset of either $X$ or $Y$, then $S$ is interacting.

c) $V = X$ or $V = Y$ (see Corollary 4), then the system $S$ is noninteracting

$$S = X \times Y$$

However, note that if the system does not have an invariant space, the system might be either interacting or not interacting.

For example, assume that any subset of the input space $X$ is not a subset of the output space $Y$. The system still could be interacting as shown below:

Let $X = \{x_1, x_2\}$

$Y = \{y_1, y_2\}$

$S = \{(x_1, y_1), (x_1, y_2), (x_2, y_1), (x_2, y_2)\} = X \times Y$ or

$S = \{(x_1, y_1), (x_2, y_2)\} \subseteq X \times Y$.

Independent Subsystems

Characterization of subsystems might be given by at least two ways. First assume that a system $S$ is given as $S \subseteq X \times Y$ one input space, one output space.

$$S \subseteq \{x_1, x_2, \ldots, x_n\} \times \{y_1, y_2, \ldots, y_p\}$$
As we have seen previously, certain subsets of X might or might not be related to subsets of Y. Furthermore, under the condition that a subset of X be also a subset of Y, S might have an invariant space under S.

The purpose here is to isolate from the system that or those subsets of X that are invariant under S or that do not interact with any other subset of Y.

Definition 9

Consider the System $S \subset X \times Y$

and let

$$P_{ij} \subseteq X_i \times Y_j \quad X_i \subseteq X, Y_j \subseteq Y$$

and

$$P_{hk} \subseteq X_h \times Y_k \quad X_h \subseteq X, Y_k \subseteq Y.$$ 

Then $P_{hk}$ and $P_{ij}$ are two mutually independent parts of S iff

a) $P_{ik}$, $P_{hj}$ are noninteracting

b) empty systems.

The previous definition is illustrated in the figure below:

The meaning of the above generalization is that whatever object we choose within $X_1$, as our input to $S$, we will never obtain as output the object $Y_P \in Y_2$. On the other hand, if we select as our input an element of $X_2$, we still could receive as output any element of $Y_1$, and then we cannot conclude that elements in $X_2$ caused the elements of $Y_1$ to exist.

Taking in mind the above considerations, we could say that the system $S$ has two independent parts, $P_{11}$ and $P_{22}$.
Definition 10

Consider the following System:

\[ S \subseteq X_1 \times X_2 \times \ldots \times X_n \times Y_1 \times Y_2 \times \ldots \times Y_p. \]

where system \( S_{ij} \subseteq X_i \times Y_j \quad i = 1, 2, \ldots, n, \quad J = 1, 2, \ldots, p \)

a subsystem of \( S \).

Evidently, we need to make a distinction between subsystem \((S_{ij})\)
and part \((P_{ij})\).

For example, let \( S \) be

\[ S \subseteq X_1 \times X_2 \times Y_1 \times Y_2. \]

a subsystem of \( S \) might be

\[ S_{1,2} \subseteq X_1 \times Y_2. \]

and a part of \( S_{12} \) might be

\[ P_{1,2} \subseteq X_1 \times Y_2, \text{ where } X_1 \subseteq X, \quad Y_2 \subseteq Y. \]

Basis For Decomposition Of a System

Let \( S \subseteq X_1 \times X_2 \times Y_1 \times Y_2 \)

We might assume that objects belonging to one of the output sets \( Y \)'s are caused by elements in one of the inputs sets taking one at a time, two at a time and so on.

During the following analysis, assume that there is noninteraction between inputs, noninteraction between outputs.

Consider the following cases dealing with the existence of elements \( Y_{2i} \in Y_2 \):

a) If elements \( Y_{2i} \) are caused by the presence of elements in \( X_1 \) only, we might say that \( X_2 \) does not interact with \( Y_2 \). Then

1. \( S_{2,2} = X_2 \times Y_2 \)

b) If elements in \( Y_2 \) require the presence of both, elements in \( X_1 \) and \( X_2 \), taken together, and if the presence of one of those inputs alone does not affect the output, then we might say:
Definition 11

Given the System $S$

$$S \subseteq X_1 \times X_2 \times \ldots \times X_n \times Y_1 \times Y_2 \times \ldots \times Y_p$$

Define the relation $R_{i,j}$ on $S$ as

$$(x_1, x_2, \ldots, x_i, \ldots, x_n, y_1, y_2, \ldots, y_j, \ldots, y_p) \iff (x_i, y_j)$$

or

$$R_{i,j}(S) = S_{i,j}$$

Next, define the following operation:

$$R_{i,j} \ast R_{k,l} = R_{i,k,j,l} \quad i \neq k, j \neq l$$

and

$$R_{i,j} \ast R_{k,j} = R_{i,k,j} \quad k \neq i, l = j,$$

$$R_{i,j} \ast R_{k,l} = R_{i,j,k,l} \quad i = k, j \neq l$$

In particular, if we have

$$S \subseteq X_1 \times X_2 \times Y_1 \times Y_2$$

then we must have:

$$S = R_{12,1} \ast R_{1,1} \ast R_{1,2} \ast R_{2,1} \ast R_{2,2} \ast R_{12,12} \ast R_{1,12} \ast R_{12,1} \ast R_{12,2} \ast R_{2,12} \ast R_{12,12}$$

(1)

where:

$$R_{12,1} \subseteq X_1 \times X_2$$

$$R_{1,1} \subseteq X_1 \times Y_1$$

$$R_{1,2} \subseteq X_1 \times Y_2$$

$$R_{2,1} \subseteq X_2 \times Y_1$$

$$R_{2,2} \subseteq X_2 \times Y_2$$

$$R_{1,12} \subseteq Y_1 \times Y_2$$
and
\[ R_{12,1} \subseteq (X_1 \times X_2) \times Y_1 \quad \text{etc.} \]
\[ R_{12,12} \subseteq (X_1 \times X_2) \times (Y_1 \times Y_2) \]

Note that in \( R_{12,12} \) we are considering the joint effect of having both inputs at the same time, upon the two outputs taking together.

If our purpose is to analyze the effect of objects in the input space on the objects of the output space, we might rule out from expression (1) all noninteracting subsystems.

**Invariance and Decomposition**

Consider the system \( S \subseteq X^T \times Y^T \), and let \( V^T \) be a subset of \( X^T \).

**Lemma 12**

1. \( V^T \) is invariant under \( S \). Then, functions in \( V^T \) map into \( W^T \subseteq V^T \subseteq Y^T \).
2. If, in addition, \( W^T \) is invariant under \( S^{-1} \), then \( W^T = V^T \).

**Proof:**

Assume function \( v \in V^T \), but not to \( W^T \). Then \( vS \in W^T \). As \( W^T \)
is also invariant under \( S^{-1} \), \((vS)S^{-1} \in W^T \Rightarrow v \in W^T \).

Then \( V^T = W^T \).
For $W_T$ to be also invariant under $S^{-1}$, $W_T$ has to be equal to $V_T$

Corollary 13

In that case, System $S$ can be represented as:

$$S \subseteq (X_T - V_T) \times (Y_T - V_T) \cup (V_T \times V_T)$$

Note that under the conditions of lemma 1 functions in $X_T$ but not in $V_T$, cannot have an image on $V_T$. Similarly, images on $Y_T$ but not on $V_T$, are not mapped under $S^{-1}$ on $V_T$. In other words, we can "decompose" our System $S$ into two disjoint systems.

Example

Consider the case of a low-pass filter, shown in the next figure:

In this system, $(S)$ high frequencies are filtered.

Let $X_T$ be the class of all periodic time functions. The output $Y_T$ is the class of all low-frequency time functions. Then $Y_T \subseteq X_T$ and is invariant under $S$. If we select a low frequency function $e(t)$ as our input to $S^{-1}$, $e(t)$ will map into a low-frequency function in $X_T$. Then $Y_T$ is also invariant under $S^{-1}$. Then, instead of selecting as our input space to $S$, all sets of periodic functions $X_T$, we might select just $Y_T$, the set of low-frequency functions.
If \( \forall u \in U, u \notin Y^T - V^* - U \) then \( u \in V^* U U \), and then \( V^* U U \) becomes an invariant space, of higher cardinality than \( V^* \). Then \( V = V^* U U \).

\( U \) is the residual space.

Illustration

**Case I.**

\( a) \ U \notin Y^T - V^* \), \( u \notin V^* \)

\[ X^T \rightarrow V^* \]
\[ Y^T \rightarrow V^* \]
\[ U \]
\[ X^T - V^* = U \]

\[ V = V^* = \{ V_1^* \}, \text{ a partition.} \]

\( b) \ U \notin Y^T - V^* \), \( \exists u, u \in V^* \)

In this case, the dot line makes \( U \) to be the residual space.

**Case II.**

\( a) \ U \subseteq Y^T - V^* \); \( \exists u, u \in Y^T - V^* - U \)

\[ V^* \rightarrow V^* \]
\[ X^T - V^* = U \]
\[ U \]
\[ Y^T - V^* - U \]

\[ V = V^* \]
b) \( U \subseteq Y^T - V^* \), \( \forall u, uS \nsubseteq Y^T - V^* - U \)

In this case, \( V^* U U \) is a maximal invariant space. Note that \( U \) by itself is not invariant but \( V = V^* U U \) it is. If \( U \) by itself were invariant, then \( U \) or a part of it should be included in \( V^* \). Then \( U \) is the residual space, and
\[
\check{V} = V^* U U.
\]

Relationship Between Minimal Invariant Spaces And Maximal Invariant Spaces

Definition 12

Let \( V^* = \{ V^*_i \} \) be the set of all minimal invariant spaces under \( R \) (a disjoint set). Let \( V \) be the maximal invariant space which contains \( V^* \): i.e., \( V^* \subseteq \check{V} \). Then, in general \( \check{V} = V^* U W \), where \( W \) is the set of all noninvariant spaces under \( S \), such that make \( \check{V} \) to be a maximal invariant space under \( S \). Call that set \( W \) the residual space of \( V \), under \( S \).

Our target is to define conditions under which \( W \) is the empty set. In other words, to find conditions for which a maximal invariant space is equal to the set of all minimal invariant spaces, \( \check{V} = V^* \) and thus, \( \check{V} \) becomes the partition of all minimal invariant spaces.

\[
V = V^* = \{ V^*_i \} \quad \text{a partition.}
\]

Conditions for \( V = V^* \).

Consider the system:
\[
S \subseteq X^T \times Y^T
\]

where
\[
V^* \subseteq X^T, \quad \text{Let } X^T - V^* = U \text{ as } V^* \text{ is the set of all minimal invariant spaces under } S, \check{V} = \check{V} \subseteq Y^T.
\]

Case I. \( \quad U \nsubseteq Y^T - V^* \). Then \( V = V^* U U \) would not be invariant. Then the maximal invariant space we can get is \( V^* \) if \( \forall u \in U, uS V^* \). Otherwise
\[
\check{V} = V^* U U
\]

Case II. \( \quad U \subseteq Y^T - V^* \)
II.A.

Consider the subset $Y^T - V^T - U$. If $\exists u \in U$, such that $uS \in Y^T - V^T - U$ then $U$ cannot be a residual space of $\tilde{V}$. Then

$$\tilde{V} = V^T$$

Minimal Invariant Space

A subset $V^T$ of the input space $X^T$ is minimal invariant under a relation $S$, iff there is no subset $W^T \subseteq V^T$ such that it is also invariant under $S$.

Maximal Invariant Space

A subset $V^T \subseteq X^T$ is a maximal invariant space under $S$, iff there is not any paper set $Z^T \subseteq V^T$ and $Z^T \subseteq X^T$, such that $Z^T$ is also invariant under $S$. Note that the following statement is not always true: "A maximal invariant space can be represented as a partitioned set of minimal invariant spaces." To illustrate, consider the following diagram, where 1, 2, 3 are time functions.

This is a counterexample.
Theorem 14

The collection of all minimal invariant spaces under S form a partition.

Proof:

Let $V_i^T$ be a minimal invariant space under S. Let $V^T = \{ V_k^T \}$. Consider $V_i^T$ and $V_j^T$, $i \neq j$. If $V_i^T \cap V_j^T = W^T \neq \emptyset$, then $W^T$ is also an invariant space under S (previous theorem) and the cardinality of $W^T$ is less than the cardinality of either $V_i^T$ or $V_j^T$ or both. Then $V_i$ or $V_j$, or both, are not minimal invariant spaces. This contradicts the hypothesis.

Illustration.


Conclusions

This research started with the development of definitions for noninteracting systems and invariant spaces; then, attempts were made to develop further concepts and relations within and between interaction and invariance. The success and applicability of those new concepts developed depends to a large extent on new developments in the area. However, we believe that the relationships dealing with the concepts of noninteraction and invariance, as well as the relation explored with respect to minimal invariance spaces and maximal invariance spaces, offer great potential for further development, mostly in their applicability to the decomposition of a system into subsystems.
References


INFORMATION AND COMPUTER SYSTEMS RESEARCH

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Structural Analysis of National Science Information Systems

D. H. Kraus, P. Zunde, V. Slamecka

Surveillance of the development of national science information systems in Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Yugoslavia, begun in 1966, was continued in 1971/72. Analysis of the materials received from these countries in late 1970 and early 1971, as a result of site visits to four of the countries (Bulgaria, Hungary, Poland, and Romania) in 1970 and as a result of correspondence, was completed in the spring of 1971. These analyses were synthesized with earlier reports and papers by the principal investigators [1-7,10-12] to form the basis for the book National Science Information Systems, A Guide to Scientific Information Systems in Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Yugoslavia [8]. The manuscript of the book was completed in the Fall of 1971 and submitted in photoready form to the M.I.T. Press. The book comprises nine essays: Development of Scientific, Technical, and Economic Information Systems in Eastern Europe; International Cooperation; The International Center of Scientific and Technical Information; Bulgaria; Czechoslovakia; Hungary; Poland; Romania; Yugoslavia. A current bibliography is appended to each of the essays. Each essay on the individual countries is accompanied by a directory of documentation and information centers in that country and a list of publications of the centers. In addition, there is an appendix of information received after the book had been prepared for publication, and a subject index.

After the book had been prepared for publication, a special study was made of the Hungarian information systems, with emphasis on libraries [9]. Advance copies of the book were received from the M.I.T. Press in late June 1972; the paper on Hungary is scheduled for publication in December 1972. The work on these two publications completed the project.

This research was prompted by the interest that U.S. leaders of the academic, governmental, and industrial communities evinced in nationwide information systems. When the research was begun (1966), the only well-developed national information systems were those of the socialist-bloc countries of Eastern and Central Europe, where such systems had been in operation since the late 1940s or early 1950s. Six countries with similar political and economic organization (a planned, socialist economy), but with different traditions, cultures, languages, and levels of economic development, were chosen for the study (Bulgaria, Czechoslovakia, Hungary, Poland, Romania, Yugoslavia). The research objective was to study the organizational structure of the information networks, the type and criteria of the planned services, the methods of information representation and structuring, the changes in the organization and policies of such systems, economic factors, and other factors that affected the design and implementation of the systems, as well as the kind and extent of cooperation among the information systems of the different countries. The results of the study were to be presented as English-language state-of-the-art reports on the information systems of the aforesaid countries, with the express purpose of aiding planners and designers of nationwide information systems in the United States.
Research on the information systems of these countries was begun in the Summer of 1966, based primarily on vernacular literature and correspondence with directors of information agencies in those countries. The objectives, organizational structure, administration, and operational methods of each national system were analyzed and the results were organized as a preliminary report on each country. These reports were completed by June 1967, and the report on a country was submitted to the leading national information center of that country in connection with site visits (Summer 1967) made to verify the preliminary conclusions, to assess the apparent effectiveness of the systems and services, and to obtain critical comments on the preliminary reports. Three of the countries (Hungary, Romania, Yugoslavia) returned written comments on the reports and the other three made verbal comments. The information agencies of these countries supplied additional literature. Final reports on each country, prepared on the basis of the new information, were completed by September 1968.

Surveillance of the information systems of the six countries was continued by monitoring the new literature and by correspondence with directors of the information agencies. A report [11] on cooperation among information agencies of the COMECON countries (which include the countries of our study) was published as part of the research.

In 1970 the M.I.T. Press agreed to publish an abridged and updated version of the reports. New site visits were made in 1970 to gain first-hand information on recent changes in the systems and to acquire new literature. Interviews were granted in four of the countries (Bulgaria, Hungary, Poland, Romania) and in Paris by a UNESCO expert on East European information systems. Extensive information was received from Romania, permitting the publication of a revised detailed report on the Romanian information system [6]. A special study was made of the Bulgarian library and documentation systems [7] and work was begun on the aforementioned book.

Quite early in the study it was realized that it would be difficult to assess the economic effectiveness of the national systems, because few budgetary data were made available to the researchers, and because of the inherent difficulties in simulating or conducting empirical studies of national systems. Therefore, the research here reported is devoted primarily to the organization of the national systems and is essentially a comparative description and analysis of the existing, developed systems and their evolution.

In the past twenty years, the national systems of the six countries have experimented with various organizational patterns, essentially involving the issue of centralization, decentralization, or a combination of the two. The approach to national information systems was nearly identical in all the countries of our study through the early 1950s, i.e., large national documentation centers were established with emphasis on technology and there was large-scale production of conventional documentation (bibliographies, abstracts, documentation cards, translations), with little regard for effectiveness or efficiency. In the 1950s documentation networks were established on several administrative and working levels: a national center of broad specialty (e.g., technology, agriculture, medicine), national subcenters for individual branches of science or technology, and lower-level information offices that served a single sponsor. These three levels of documentation centers were coordinated by administrative offices and formed the basis of the current systems, comprising
well-organized mechanisms for information transfer, at least within a network. The networks continued to operate on a documentation-for-documentation's-sake basis for several years. Toward the end of the 1950s and in the early 1960s, the whole policy of documentation and information came under official scrutiny and emphasis was shifted from documentation to information tailored to the individual need -- specifically, team research, the case system, and information analysis techniques were employed. This resulted in a change of duties and emphasis in centers on all three levels: information analysis was performed by high-level centers and routine documentation was shunted ever downward in the hierarchy. Eventually most of it will probably be done in the lowest level centers, while the branch centers occupy themselves with information analysis, and the highest level centers with research.

In the late 1940s and during the 1950s, the documentation centers (except in Yugoslavia) were supported entirely by state subsidies and their services were provided gratis. In the 1960s (Yugoslavia 1954), one by one, the countries began experimenting with partial support of the documentation and information centers, with an eye to making them self-sufficient. The change from gratis distribution to the sale of information services brought changes in the organization of such services. In the countries where subsidies were entirely or almost entirely withdrawn (Yugoslavia, Hungary), marginal operations perished and many allegedly vital services were discontinued for want of interest (e.g., retrospective bibliographies, some abstracting services). In Hungary other information operations burgeoned (market research and case studies), and information services again became concentrated in a few large specialized centers; this time, however, their survival depended and depends on effectiveness and efficiency. Czechoslovakia was headed in this same direction before the events of 1968.

Poland and Czechoslovakia, which have the most advanced and intricately structured information systems of the countries studied, are engaged in programs aimed at integrating all the information centers of their respective countries into a national system, with standardized information format and processing, in preparation for the development of national data banks. Bulgaria and Romania have experienced less radical changes in the organization and operation of their information systems and services. In Romania, from the beginning, information services have been concentrated in a relatively small number of large national specialized centers; documentation continues to hold a strong position among the services offered, and federal subsidies are still a mainstay of support for the centers. The Bulgarian system represents a mixture of federal support and the sale of services, with very close coordination of the nation's library and information systems, with several large national centers and with a relatively large number of subject-specialized (branch) and local information offices. It resembles Czechoslovakia and Poland in that respect. Yugoslavia's information services are fragmented and often competitive, with one large federal information center for science and technology and numerous smaller centers affiliated with republic governments or local industry. Yugoslavia is also trying to institute a national integrated information system, but the outcome seems less certain than in Czechoslovakia and Poland, because of the political makeup of Yugoslavia.
Although the development of documentation and information centers in the countries of our study has followed the Soviet lead in general, beginning in the 1960s the individual personalities of the countries began to show through strongly and one can no longer speak of them as a unit, although they retain some common features stemming from their earlier organization, their political situation, and the uniqueness of their language or languages (e.g., a hierarchical system in 4 of the 6 countries, dedication of the information program to the national economic and social plan, and proliferation of secondary publications).

Research on information and documentation problems and methodological guidance of related operations have been in the hands of the leading national center (technology) of each country from the beginning. These days branch centers, or their equivalent, are quite sophisticated; their contact with the national center is on a high level, and they guide the lower-level information offices in operational matters. In Czechoslovakia and Poland the national information center for science and technology has been relieved of routine information and documentation duties and is dedicating itself, in each case, to research on and the planning of a national, integrated information system, and to the coordination of the national program for education of information scientists.

Although information for technology continues to dominate the information programs of these countries, information for agriculture and medicine has played a moderate, but steady role since the early 1950s. Social sciences in general and education are gaining importance, as evidenced by events in Romania, where a major social-science information center was established in 1970, and where the mathematical and physical-science information center of the Romanian Academy was merged with the educational information center under the auspices of the Ministry of Education in 1971.

Superimposed on the national systems is a program of international cooperation in documentation and information. Gradually, despite difficulties imposed by language differences, lack of adequate thesauri, nationalism, operational differences, etc., the nations of our study have developed a system of information exchange and work-sharing in many areas of scientific and technological information through bilateral or multilateral agreements within COMECON. The ultimate development of such cooperation would appear to be the International Center of Scientific and Technical Information (est. Moscow, 1969), of which the countries of our study are members. This new center is designed to tie the information networks of the various countries to that of the Soviet Union and to each other through the development of data banks. Currently the member nations are concerned with standardization of data reporting, indexing, and classification; they are constructing thesauri and conducting information-science and systems research aimed at making the international data banks workable. Overtly, at least, it is intended that this international center will ultimately be coordinated with UNISIST. If this is realized, it will be the culmination of a general trend of the socialist-bloc countries from earlier isolation toward international cooperation in information and documentation, a trend critical for the six relatively small countries of our study, which are incapable, individually, of processing the increasing flow of information and of developing modern tools for such processing.
The most recent trends in the six countries (stronger in some countries than in others) are: (1) development of information analysis centers; (2) investigation of the means of creating an integrated national information system from the various existing systems and, eventually, of integrating this national system with an international system or systems; (3) emphasis on social science documentation and information; and (4) gradual mechanization and eventually (hopefully by the mid-1980s) automation of information-center and library operations.

References


In this research project the concept of control in computer-assisted instruction (CAI) was explicated by the development of a qualitative model of the instructional process, the subsequent design and implementation of an experimental CAI system, and the observation and analysis of student interaction with this system.

CAI is viewed as a dialogue between a student and a computer. In the qualitative model the student and the computer are described as hierarchically organized control systems. The dialogue between the student and the computer is assumed to occur at distinct levels. The dialogue concerns the subject matter, understanding of the subject matter, goals and strategies for attaining those goals, and the choice of a topic area at levels 0,1,2 and 3 respectively.

In accordance with the model, an experimental CAI system (GITIT) was designed and implemented on the Burroughs B-5500 with student interaction via a teletype terminal. GITIT provides the capability for either the student or the computer to control at levels 0,1 and 2. Control commands are provided whereby control may be shifted dynamically between the student and the computer.

GITIT has two modes of operation: discussion mode and tutorial mode. In discussion mode the student may ask any question or make any statement concerning the selected topic. In tutorial mode, GITIT administers a segment of instructional material called a module. A student may interrupt a module at any time either to place the system in discussion mode or to cause another module to be administered. He may later cause the machine to resume the interrupted module.

The data base for GITIT consists of a collection of short segments of programmed instruction called modules, and a list structure which supports a student computer dialogue concerning the subject content of the modules. A prescription is given for the generation of instructional materials to teach a set of consistent definitions. An algorithm for generating the list structure from a set of instructional modules and a specified technical vocabulary is included.

Observation of student performance on the system confirmed expectations based on prior research as to the variability of individual strategies and effectiveness in a learning task.

GITIT is adequate to support a wide range of learning tasks and is efficient with respect to computer processing time, memory utilization, and the preparation of instructional materials.
The findings of this research effort support the following conclusions:

1) The conceptual model of control which was developed provides a framework for describing and comparing existing CAI systems with respect to control issues.

2) The conceptual model of control served as a guide to the design of a CAI system with respect to (a) the following types of control: immediate control, control of a communication event, information control, procedural control, and the control of the topic area, (b) the commands required for each type of control, and (c) the data structure required to support such a system.

3) The data structure developed (a) supports a dual-mode CAI system, i.e., one in which either the student or the computer may control the information flow, (b) has a structure of sufficient complexity to support a wide range of learning tasks, i.e., rote learning, learning concepts in their interrelationship, browsing, etc., and (c) efficiently utilizes a hierarchical arrangement of computer memory such that there is an effective match between performance requirements and the speed and cost of memory.

4) A well-specified procedure was developed for generating the instructional materials required to teach a set of recursively defined definitions.

5) An algorithm is presented for developing a script to support student-computer discussion of the subject content of instructional modules.

6) Due to the modular design of the instructional materials and the fact that the links between modules are algorithmically generated, additions and modifications may be made without change to other modules.

7) The computer program for the CAI system is completely subject-matter independent, which permits the system to be used for teaching a wide range of subject areas.

8) The final CAI system proved to be efficient with regard to (a) the utilization of computer time, (b) the utilization of computer memory, and (c) the preparation of instructional materials.

9) Student performance on the system confirmed expectations based on prior research as to variability of individual strategies and effectiveness in a complex learning task.

10) The system permits the display of a wide range of learning strategies.

References

Delivery Systems for Self-Instruction


A view of the student as a willing learner, of the corps of currently practicing teachers as a valuable learning resource, and of education administrations as vendors of learning materials has led to the design and development of the "Audiographic Learning Facility (ALF)" [1,2].

This facility has been refined and expanded to include and support three modes of operation:

a) A Free-Standing Audiographic Media Development and Presentation Facility. In this mode, an audiographic recorder/player unit, Electrowriter transmitter, and VERB receiver are employed in the production, management, and presentation of learning materials within the bounds and resources of a local system as small as a single teacher serving a restricted student body. (An audiographic recorder/player unit is a stereo magnetic tape unit capable of recording synchronized speech and supporting line graphics as generated through an Electrowriter transmitter.)

b) A Centrally Administered Audiographic Media Development and Presentation Facility. In this mode, central responsibility for media development and availability introduces requirements for addressable learning units which can be identified from a menu of available units and requested for presentation and use.

c) A Centrally Administered Automatic (Computer-Based) Audiographic Learning Facility. This is the mode of operation of the objective prototype system whose assessment and exploitation is a major concern in this research. Through this mode of operation, computer controlled access to a body of learning materials can be monitored.

Work done under this project has led to funding by the State of Georgia of an experiment to evaluate the effectiveness of the free-standing mode of operation in a specific environment. This experiment includes ten teachers representing one elementary school and four secondary schools in four public systems and one post-secondary vocational-technical school.

Additional activities have included: the use of the free-standing summer institute for high school teachers in which 120 hours of formal lectures were presented under sponsorship of the CCSS office of the NSF; a two-quarter experiment in presenting an introduction to problem solving and programming via audiographic recordings in the free-standing mode; a one-quarter experiment in which a course in discrete mathematics was presented via audiographic recording in the free-standing mode.

These experiments have for a variety of reasons not been conducted in the kind of formal manner which would permit quantified analysis; however, progress to date very strongly supports the central contention that good and effective instruction can be presented via audiographic recordings in
a very large number of instructional environments where course content is compatible with explication in an essentially blackboard supported classroom.

The concept of the electronic delivery of learning materials from a centrally managed learning resource center brings about an immediate confrontation of the need for an index of contents in order to provide willing learners with a menu from which to choose in order to effect and manage their learning process.

This need for a menu introduces the problem of the "structure" of the media and ultimately the "structure" of knowledge and the relationships between these structures and learning processes. Thus, this research has been confronted by and is being addressed to the following problems:

a) An assessment of the viability of audiographic recordings as means of delivering instruction approximating the quality and content of what-is-happening-in-today's-classrooms.

b) An assessment of the viability of audiographic recordings for explicating approaches to learning in areas not compatible with a system such as ALF. (For instance, it is true that one has difficulty teaching Marine Biology in the absence of an ocean; however, approaches to confronting the subject and the acquisition of knowledge supportive of exploiting an ocean when it becomes available would seem applicable.)

c) An assessment of the relationship between learning goals, media structure, and behavioral objectives.

d) An assessment of the characteristics and problems of managing a major educational utility wherein learning materials can be stored, accessed, and used via telephone transmission.

e) A continued assessment of the loss or gain of ALF materials as contrasted with contemporary CAI.

Research to be conducted during the coming year will continue to aggregate data across independent experiments involving and exploiting the ALF.

Among the central concerns for this period is the relationship between learning and instruction. A central hypothesis in this concern is the idea that instruction is predicated on instructor control of media, objectives, and strategies; whereas learning involves increasing degrees of student control in these areas. Suppose that we accept the notion of an index of instructor control which is a function of media control (mc), desired behavioral objectives control (boc), strategy control (sc), and time (t); i.e.,

\[ I_{ic} = f(mc, boc, sc, t) \]

Likewise there is an index of learner control which is a function of the same set of variables

\[ I_{lc} = g(mc, boc, sc, t) \]
(Note: the variable boc in the function g might be better labeled learner objective control (loc) but for the time being this distinction is minimized if we assume a contract between learner and instructor such that loc and boc are by agreement synonymous.)

Under the notion of a contract, a learning experience $L$ might be characterized as

$$L = F(I_{lc}, I_{lc}, t)$$

A contract relationship might be characterized independent of time as follows

$$I_{lc} = 1 - I_{ic}$$

Thus for various strategies this relationship might be represented:

Thus under contract conditions the following three dimensional relationship exists

and a learning experience $L$ can be represented in terms of $I_{lc}$ as follows
Under conditions other than contract conditions such that learner objectives and instructor applied behavioral objectives are not identical (the most common case which separates education from course passing) the relationship is not so simple; it might be represented as follows:

A primary assumption of this research is that we can view a learning experience as being characterized by a transition from instructor control to learner control. Future research will be directed to explore the potential for compression of the time interval $t_{oa} - t_0$ through the development, refinement, and extension of an education system that will minimally deliver instruction at a level competitive with current practice while facilitating learning discoveries by the learner through the manipulation of the media. The intention of this research is therefore to determine the requirements of an educational system that has the dual features of an effective "delivery system" for instruction and a flexible "discovery system" for learning.

References
The objective of this project is an investigation and evaluation of very large digital mass memories and devices (of the order of $10^{12}$ bits) for storing and management of science/learning information.

Technical characteristics of large mass memory devices have been of interest to the Georgia Tech Science Information Center for some time [9]. Many surveys of the characteristics of mass memory devices have appeared in the literature [1,11]. This study has focused however, on the use of trillion bit memories, which have only recently become practical [3].

The first phase of the project was concerned with determining the state of the art of very large mass memory devices. This investigation reviewed current technology according to the following three approaches:

1. **Standard Storage Devices.** Common storage media were examined to determine their suitability for $10^{12}$ bit, on-line, memories. Storage media examined included semiconductor memories, ferrite-core memories, thin-film memories, and magnetic storage devices such as drums, disks, and tapes. For each media cost per bit, power consumption, size, and volatility were evaluated.

   Each of these evaluation criteria is important in considering the suitability of a storage medium for use in a trillion bit memory. Cost per bit (of the overall memory) is probably the most important factor to consider. It is desirable and practical to have a cost per bit range of approximately $10^{-4}$ to $10^{-5}$ $\$/bit. Very low power consumption is essential in order to avoid cooling problems. Very high recording densities are desirable to provide reasonable size (volumetric efficiency). It is not practical to use a volatile storage medium in view of the fact that long-term storage is one of the main roles of a mass storage unit.

   For common storage media it was concluded that only magnetic tape recording offered practical trillion bit on-line storage. Semiconductor, core, and thin film memories can be eliminated on the basis of cost per bit (all about 1$\$/bit). In addition power consumption and packing densities are unsuitable. Drums and fixed-head disks are also too expensive. Moving head disks approach the desirable price range; however, a $10^{12}$ bit disk memory using recording densities ($\sim 10^5$ bits/sq. in) would require $10^7$ square inches of recording surface.
Magnetic tape is probably the most widely used secondary storage medium, and is typically an off-line storage device. With $10^5$ bits/sq.in. data recording density, magnetic tape would provide a much better volumetric efficiency than drums or disks for $10^{12}$ bits of storage. Most magnetic tape systems are off-line storage and, with linear access methods, average access times are in the order of minutes. However, a magnetic tape memory with very high search speeds could be utilized for a $10^{12}$ bit on-line memory system.

2. Experimental Storage Devices. New, experimental digital storage techniques were examined. Among these techniques are laser recording systems, holographic memories, high density capacitor memory, and magnetic bubble, magnetic domain, and magnetic film storage devices. In terms of the parameters listed above, these new devices hold great promise for trillion bit memories. The current art however does not permit synthesis of large arrays of these devices.

3. Commercially Available Devices. The technical characteristics of three commercially available trillion bit memories were studied in detail. These were the IBM 1360 Photo-Digital Storage System [5,6], the Ampex Terabit Magnetic Memory [2], and the Grumman Data Systems Corp. Masstape [4]. Characteristics of these three systems are summarized in the table.

The second phase of this project was concerned with evaluating the practicality of trillion bit memories for actual use in a large-scale information delivery system. The Audiographic Learning Facility (ALF) [10] is such an information delivery system. A large-scale ALF system would put demands on a large digital storage unit which are quite unlike the demands of a computer central processor in its traditional use of mass storage. The difference is the sustained high speed information flow which an information delivery system requires. The ALF system strongly requires this high-speed, continuous information flow. Accordingly, a detailed design was attempted on a large-scale ALF system using very large digital memory.

The objective of ALF is the presentation upon request of any learning materials stored as graphics or speech in the facility's library. The presentation is to be made at the terminal which is the origin of the request. As many as fifty presentations may be proceeding simultaneously. Each presentation requires a sustained data rate of 40,000 bits/sec. Thus the system must be capable of maintaining a sustained data transfer rate of $2 \times 10^6$ bits/sec.
<table>
<thead>
<tr>
<th>SYSTEM CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMMERCIALLY AVAILABLE TRILLION BIT MEMORIES</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>IBMP 1360 Photo-Digital Storage System</th>
<th>Ampex Random Access Terabit Memory</th>
<th>Grumman Data Systems Corp. Masstape</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASIC STORAGE MEDIUM</td>
<td>Electro-Mechanical, Pneumatic, Photographic</td>
<td>Electro-Mechanical, Magnetic Recording</td>
<td>Electro-Mechanical, Magnetic Recording</td>
</tr>
<tr>
<td>SIZE OF BASIC STORAGE UNIT</td>
<td>1&quot; x 3&quot; x .007&quot; FILM CHIP</td>
<td>10.5&quot; tape reel with 4000' of tape</td>
<td>1/2&quot; magnetic tape</td>
</tr>
<tr>
<td>RECORDING DENSITY</td>
<td>$10^6$ bits/sq. in.</td>
<td>$10^6$ bits/sq. in.</td>
<td>$3 	imes 10^5$ bits/sq. in.</td>
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<td>$5 	imes 10^6$ bits/chip</td>
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<td>$4 	imes 10^7$ bits/cartridge</td>
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<td>32 chips/cell</td>
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<tr>
<td>MAXIMUM ACCESS TIME</td>
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<td>45 SEC</td>
<td>11 SEC</td>
</tr>
<tr>
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<td>$-10^{-4}$ $$/bit$$</td>
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90
To maintain such a high sustained transfer rate, it is necessary to sharply reduce the waiting times for access which cannot be overlapped with data transfer. This forces the transfer of large blocks of data for each random access. There is a limit, however, to the size of the blocks since the data must be transferred to an intermediate or buffer memory.

The Grumman Masstape unit would give the best performance, of the three commercially available systems which were studied, for a digital ALF system. This is because Masstape has the best random access characteristics. The Masstape system combines many small-capacity storage units (cartridges) with reasonable access time to any particular unit. The IBM 1360 also has small-capacity storage units (cells); however, to access a particular cell, that all must be moved pneumatically (and slowly) to the read station. The AMPLEX Terabit Memory has large-capacity storage units (transport). Access to any transport is rapid, but then it is necessary to wait a (long) search time to find the desired data record.

The digital ALF system that has been designed is shown in outline form in the accompanying diagram.
The conclusions of the detailed design study, described in forthcoming reports [6,7] are: (1) the cost of such a system would be about a million dollars; (2) a large buffer store of magnetic core memory and disk memory will be required since the Masstape (and to a lesser extent the disk) do not process true random access characteristics; and (3) even with large amounts of buffer memory, sophisticated queuing and rescheduling techniques will be necessary to maximize the effectiveness of such a system.

References


5. IBM Corporation. Systems Summary, IBM 1360 Photo-Digital Storage System.


This study is directed to the development and testing of algorithms for hardware processors designed to employ the new multilevel Q-graph approach to parsing. The algorithms developed will be tested in the programs of the closely related Structural Representation of English project as subroutines named GRAPAR and PST. The approach which has been adopted is motivated by the fact that Q-graph memory is currently estimated to be less than 2,000 bits, and by the fact that such small memory requirements permit the use of microcircuit memory as a viable alternative to core memory.

Research study has been conducted on the Q-structures (sequence of the symbols) of boolean expressions and algebraic expressions in computer languages to see how much complexity would be added to natural text structuring for such expressions to become acceptable in conversation. In view of technological developments, such a study has its applications in the development of hardware processors for artificial languages where the algebraic segments of different languages would share the same processor attached as a separate unit to the computer. The result of the study shows three structures that can be used as a basis for such considerations by giving a first look at the amount of complexity (or rather simplicity) by which such processors can be governed.

However, the role of the Q-graph for expressions or programs in various languages can be different than in the case of natural language. In artificial languages normally the classes of words are fixed—i.e., there is no difference between lexical and functional class. To make this completely certain, some artificial computer languages require strict respect for morphological marks of the classes of symbols or require declarations of the symbols: integers, subscripted variables, arrays, etc.

Q-graphs prove useful both in the role of acceptance measures for the program or expressions and in some cases in relaxation from the strict declarative rules where the same symbol might be used for more roles in the presence of other markers, especially the order of symbols. For example, if "I" is used as a nonindexed variable, it cannot be used also as an indexed variable in the same Fortran program.

The following three Q-graphs offer a pragmatic tool for study of positional markers, redundancies in symbolism and sensitivity to various relaxations. They are Q-graphs for Boolean expressions, algebraic expression, and a program where statements are given by their classes.
Figure 1 shows a Boolean expression as a recursive graph, where inside the parentheses is another Boolean expression.

Thus, for example,

\[ B = x_1 + \overline{x}_3 (\overline{x}_1 + x_2) \]

is a string

\[ + x + + + \overline{x} \rightarrow (+ \overline{x} + + x + +) \rightarrow \]

that is contained in the Q-graph shown in Fig. 1, since it is also \( B = \overline{x}_1 + x_2 \) contained in parentheses.

Thus

\[ + x + + + \overline{x} \rightarrow (+ B +) \rightarrow \]

is the path in Fig. 1 and also

\[ + x + x + \]

in the path in B.
Fig. 2 shows a Q-graph for the algebraic expression including a description of the classes represented by the nodes. Small circles are dummy nodes that serve only to simplify connection structure among real nodes of the graph.

Symbol E stands in place of the graph. Since it is used also as a node of the graph, the graph is a recursive graph as are also the algebraic expressions.

**Grammar of Algebraic Expressions**

(Acceptance graph, Q-graph for parsing of linearly written algebraic expressions)

N = numeral
V = simple or subscripted variable
f = function
x : = algebraic operations
( ) = syntactical markers

---

Fig. 2
The third Q-structure is shown as Fig. 3, below.
Symbols used in the Q-graph of Fig. 3 are classes of the statements that can be used in the program. The Q-graph is made for Fortran-type of a program, where eventual subroutines follow the main program. In analogy with natural language in which statements of the program are sentences and the symbols of the statements are words, the Q-graph shows the Q-structure of the text composed from the statements. Internal Q-structure of the sentences (syntax of the statements) is not considered at this point. (See: structure of an algebraic expression and structure of a Boolean expression).

Following are the symbols used for the classes of the statements:

- **L** - Label of the statement, in the same line as the following statement
- **N** - End of the statement, start of the next line
- **LET** - Execution of an expression ending with renaming the final value by given variable
- **CALL** - Call for a subroutine
- **I/O** - Input or output statement, like READ, WRITE, PRINT, etc.
- **DO** - DO-loop
- **CONT** - Dummy statement
- **DECL** - Declarative statement
- **GOTO** - Jump to given label or labels
- **IF** - Conditional statement
- **FUNN** - Function (if more than one statement, represents a subgraph not specified any closer in our text)
- **FORM** - I/O format
- **RETURN** - Return from the subroutine
- **END** - End of the program or subroutine
- **SUBNAME** - Headings of a subroutine, name, parameters, etc.

The Q-graph in Fig. 3 describes the order in which the statements may occur in the program. It is in a sense a grammar for the syntax of the text. Among the features of the grammar are:

1. Any format statement has to be labeled; There is no access to FORM, unless L is named.
2. Any statement following GO or IF must be labeled except for END. If however DECL or FORM follow GO or IF then the next statement after the last DECL or FORM must be labeled (left side of the graph).
3. Any statement other than GO or IF can be followed by any statement (right side of the graph) either labeled or not labeled among which also can occur IF or GOTO.
4. Subroutine part (lower half) has statements SUBNAME and RETURN that do not occur in MAIN (upper half).

5. CALL in the lower part shows that subroutines can be nested.

6. Subroutines cannot precede the main program.

7. Declarative statements can occur in any place of the main program (before END) or in any place in the subroutine between the SUBNAME and the END; however, always without a label.

It is the purpose for which a Q-graph is intended that determines its construction. The version in Fig. 3, for example, can be used for checking whether or not there is such an instruction in the program that cannot be reached during the execution because of improper labeling. On the other hand, if RETURN statements are omitted from a subroutine this would not be recognized. To guarantee that at least one RETURN statement has been used, the graph would have to be modified -- as shown for example in Fig. 4, where A is the subroutine part from Fig. 4 (without END and SUBNAME that does not contain RETURN node, while B is the same part that does contain RETURN as shown on Fig. 3. Also B has to enter into the node pointed to/from the circled C in Fig. 3. Thus, while certain general features of the programs written in different languages can be shown by corresponding Q-graphs, any final specific version has to be adjusted to a specific purpose of the particular Q-graph.
Our three examples of Q-graphs for algebraic and boolean expressions and the Q-graph for a program show that a processor built for Q-graph parsing of English sentences has good potential for various purposes by means either of extending or of exchanging Q-graph memory.

References


An Adaptive Microscheduler for a Multiprogrammed Computer System

J. M. Gwynn, E. M. Pass

The purpose of this research has been to study the concepts and methods of internal scheduling of digital computers and to propose a new model of internal scheduling designed to perform well in given environment types and with given task types. Computer simulation has been used to verify the proposed model in a specified environment against other internal scheduling methods and under various system measure functions.

This new model is adaptive in the sense that it modifies its actions to account for time variations in the composition of the internal task queue, and in their interactions.

Research by the current and other researchers has shown that the investigation of adaptive internal schedulers is quite rewarding because of the substantial gains in system productivity possible through fairly minor changes in internal scheduling philosophy. Thus, logical design was performed to develop an adaptive internal scheduling technique which would perform well in various environments and under constantly changing task structures and interactions.

In order to limit the scope of the research area for manageability, nature and interactions of the input tasks are not controllable by the assumed internal scheduler. Previous work (by Hoffman) showed such external scheduling also capable of semi-optimal handling by pre-scheduling techniques.

Within the limitations described above, system effectiveness measures have been defined which will allow the local optimization and global semi-optimization of the performance of the system with respect to various measure biases.

The development of the adaptive internal scheduler as proposed here has been detailed and documented. This involves the logical structure of the model representing the scheduler and how it interacts with its environment, the remainder of the computer system.

The detailed justification for the development of such a scheduler has been documented. Briefly, this documentation explains why the completed research results should be of interest not only in an academic, but also in a practical sense.

A set of general internal scheduler simulators have been developed to analyze the relevant situations chosen in this research. This task has been completed as far as general, existing, microschedulers are concerned. Three such simulators have been developed, as follows: a fast, coarse simulator to allow decisions to be made concerning the choice of schedulers without using large amounts of computer time for research; a slower, finer simulator to allow the investigation of...
certain attributes of processor allocation algorithms; and a slow, fine simulator to allow the detailed investigation of schedulers in general.

The remaining work is involved with implementing several other types of internal scheduler models, including roundrobin, first-come-first-served, fixed-formula scheduling, primarily on the fine simulator to permit the investigation required in this research.

In order to allow the environment to be realistically specified, data was gathered in such a manner that it is not biased and thus represents a real situation. For practical reasons, the B-5500 at Georgia Tech was chosen for this study. Methods have been developed and applied both for analyzing the workload statistically and for analyzing specific types of programs in detail to determine their dynamic resource needs. All that remains to be done here is to select a reasonable amount of raw data, analyze it, select a small number of prototypical jobs, analyze them, and construct the set of histograms required by the simulators to describe the workload and environment.

Once the preceding subtasks have been completed, the proposed internal scheduler will be evaluated against other classes of schedulers, including first-come-first-served, roundrobin, and others, the following system effectiveness measures: system revenue, component utilization, throughput, response time, system utilization, system cost and others.

The improvement in the techniques of resource allocation due to the proposed internal scheduler is not without its cost in terms of computer resources and time. Thus, for comparison purposes, the resource cost for each scheduler will be estimated and applied against its performance in terms of each effectiveness measure. By this means, the net gain for each scheduler may be measured.

References


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The past year's activity at the Information and Computer Science Laboratory has included participation in systems analyses of agencies in the government of the State of Georgia; work on a variety of applications in computer graphics and picture processing; development of an Algol compiler code evaluator; creation of a number of enhancements to PDP-8 system software and a PDP-8 simulator and assembler; and various other activities.

Systems Analyses of State Government. A project designed to study and reorganize computing in Georgia State government was directed by a member of the ICS faculty. This study involved a staff of over thirty professionals recruited from industry and government and covered all major areas of computing in government including the University System of Georgia. The recommendations of this study resulted in legislation which established a single agency for providing all computing services in Georgia state government with the exception of the Employment Security Division of the Department of Labor and those computers in the University System dedicated exclusively to instruction and research. Study findings were documented in a detailed final report [2] which received limited distribution and in a widely distributed summary report [3].

In addition, pursuant to the concept that State government operations comprise an ideal setting in which to effect real-world projects to provide graduate students a valuable experience, two major studies have been effected by ICS students under faculty direction. The first project addressed in detail the five major subsystems of the Department of Agriculture. Based on the findings of the subsystems study a comprehensive management information system has been designed and documented. All aspects of the study have provided operational input to the Department of Agriculture. The second project assessed the problems of processing the zero-based budget documents of the Budget Bureau and recommended four alternative systems approaches to expedite the information processing while building a data base on which to effect a management information system.

Computer Graphics and Picture Processing. Among a number of projects which utilized the PDP-8 computer, work in computer graphics has been particularly active. Utilizing programatically refreshed nonstorage display techniques, students developed a visual representation of a physical system (movable cursor-spring-projectile, with and without drag), simulated by known formulae. Particular effort was made in this project to provide realism to the resulting simulation, so that it would coincide with a human's instinctive impression of how the system should appear. One means necessary to accomplish this was to develop the program in assembly language which proved to be the only method efficient enough to refresh to the screen at a 40-frame per second rate and thus eliminate flicker from the display. Secondarily, a means to provide a variable amount of gravity and drag through input parameters was necessary for realism beyond perfectly elastic simulation. Finally, an unexpected situation to be dealt with involved the persistence of the images on the screen beyond their applicability to the pictorial simulation. Experimentation with the screen intensity settings helped to minimize this effect.
An interactive population study system based on the city's census tracts was developed, using graph-pen graphic and joystick cursor input, output displayed on a storage scope, and data stored digitally in mass on-line storage. The flexibility and utility of the system was captured by a unique form of documentation: single-frame motion picture equipment was used along with normal movie equipment to produce an exceptional photographic effect of animated and real-life motion images. An inherent motivation in this project was to demonstrate and capture photographically the potential of using automated means to manipulate large blocks of information easily and to be able to make intelligent decisions based on the results derived from the user-computer interaction.

In this situation, the graph-pen and joystick input devices were utilized to delineate sectors of the city into possible school districts. Based on a table of census tract information stored on magnetic disk, the program would then calculate various kinds of data for the user. For instance, a ratio breakdown by socio-economic level was a prime consideration for determining a balanced school system city-wide. Distance measurements were calculated automatically by the program, for evaluating possible bus routines and travel times. Proximity of the schools to the centers of the projected districts were also noted. In actual usage, the following occurred: an educated try would first be made; then, by working with the data obtained, further attempts would be made to optimize all criteria as much as possible. Interestingly, it was found that even an expert in the field found that his intuitive options were sometimes in error when confronted with the actual data presented.

A general-purpose interpreter was written to execute binary statements produced by the Edgrin graphics system. This new interpreter enabled Edgrin capabilities in user programs of any size or type. The Edgrin system is useful for display development as a stand-alone package, but its shortcomings such as limited storage capability, lack of subroutine call points, and undocumented source language, made it almost impossible to use in other sets of routines. The solution made use of the fact that punched paper-tape output could be derived from the Edgrin system in a known format; then, a separate machine language interpretive routine could be written and the two incorporated as a fixed display routine in any other routine or program written for the PDP8. The paper tape was translated, by an Edgrin subsystem program, to a binary tape which could be at the assembly language level, to any other (especially higher level) program. Basically, the interpretive package eliminated extraneous capabilities known to exist in Edgrin, and proved to be far more efficient in machine time. An increase in usefulness and machine speed were thus accomplished.

Work on a picture-processing application was begun which involved reducing analog graphic data through the A/D converter and displaying the results on the storage tube. Further work is progressing in this area.

Student work in analog plotter techniques has produced detailed representations of three-dimensional plots of algebraic functions on the on-line plotter to the PDP-8. Efforts to incorporate this capability with the other graphics equipment into a unified graphics system are taking place.
Algol Compiler Code Evaluation. An Algol Compiler code evaluator was written in the PDP-8 Algol developed in the ICS laboratory. Used in a compiler-writing course, the system augmented the student code for specific routines such as scan, a boolean compile, etc., with the additional code to generate program and compiled and executed together.

The evaluator was used as follows: students would punch a paper tape containing the code for the particular routine being studied; the paper tapes were then read into the PDP-8 reader and a program merged this information with previously developed code and the resulting program was passed to the Algol compiler; the compilation listing and execution output listing were then returned to the student with the paper tape. The system proved extremely useful due to the fact that a student could pinpoint his area of concentration and make use of previously developed routines or ones which he would develop in the future to supplement his current work.

PDP-8 System Software and Simulation. An undergraduate student has designed a number of useful enhancements to the PDP-8 system software. In particular, a log-on-and-off routine with a permanent log for utilization information; a unique batch controller using a HASP-like technique with cards from the reader or files from any system recognized device to control the system; and a program to call in the proper compiler automatically for compilation of a user program based on the program's system name and extension. These developments were recognized and published by the Digital Equipment Corporation's User Society [1] for world-wide distribution on demand. An auxiliary enhancement to the system was the acquisition of a BASIC package and a TECO editor.

The TECO editor on the PDP-8 was modified to be used with an Anderson-Jacobson correspondence terminal with upper- and lower-case capability. The resulting work was a text preparation method that can be used for producing high-quality typewritten material on any subject. Many uses have been found for this system: a secretarial aid in typing form letters; preparation of class handouts with minor changes; documentation of computer software and hardware configurations; etc.

A laboratory portion of a course was taught utilizing the PDP-8 system as a model [4]. A PDP-8 simulator and assembler were developed by students on a large computer using a higher-level language. Successful completion of the project not only gave the students an intimate knowledge of the PDP-8 system (more than would be derived by developing a program on the system itself) but also accrued other advantages: the students acquired systems programming experience dealing with machine-level hardware logic; they were able to operate a computer system in a typical small data processing environment through scheduled "hands-on" sessions; and they were able to apply programming principles and techniques learned in classwork to a useful problem situation.

Other Activities. Other activities at the ICS lab included the acquisition and operation of a large-scale computing facility and the addition of capabilities in support of the School's Audiographic Learning Facility.
As part of the laboratory development, the School of Information and Computer Science has taken over the management and operation of a large-scale Burroughs-5500 Computer System. The system is presently being utilized by students and faculty in coursework and research projects. A 24-hour timesharing service is being maintained, along with an 8-to-5 batch processing service. Utilization of this equipment is opening up many new possibilities for student involvement: for example, it is contemplated that students will be involved in the management of the B5500 facilities. During the initial operation an average of approximately 150-200 batch jobs per day have been processed, with a high of 300 jobs in one day. The batch runs are made with a standard handling system which performs an automated collating function to assure correct collection of output. The majority of the student work consists of Fortran and Algol compilations and executions, plus runs of a MIX simulator.

The two active data lines for terminals have been used fairly heavily, especially in the afternoon and evening hours, primarily on research projects involving graduate students. A limited amount of software development of system software and special-purpose user programs has been done. Extensive documentation of the overall progress of the operation of the B5500 system is being kept.

In the Audiographic Learning Facility controlled by the PDP-8, a number of useful capabilities have been added. A simulated time-of-day clock, using the machine's interrupt and internal clock features, provides second-to-second accounting capacity. Editing features have been added to decrease vulnerability to user-caused failures. Also, additional commands have been developed for various informative and control purposes.

Hardware changes have also been made to extend the system's capabilities and reliability. The line switching function which enables switching of output from any given tape recorder to any calling phone line has been completed and incorporated into the system. New data lines to detect any phone line condition, such as hangup, initial callup, etc., programatically have been installed. Work is in progress to replace phone company touchtone-ASCII converter data sets and to provide further tape recorder control functions.

References


3. Georgia Reorganization and Management Improvement Study.  
Data Processing Recommendations: Summary Report,  

4. Hooper, Charles.  A Method of Laboratory Instruction for Information  
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Computer Science), 1972.
EDUCATION IN THE INFORMATION SCIENCES
An Undergraduate Program in Information/Computer/Systems Science

The School of Information and Computer Science has recently been pleased to announce the establishment of a new undergraduate program leading to the degree of Bachelor of Science in Information and Computer Science.

The objective of this program is to provide a broadly based, comprehensive program of undergraduate education in the information, computer and systems sciences and professions. The program has two primary educational goals: education of professionals in the analysis, design and management of information, computer systems; and preparation for graduate work in the information, computer or systems sciences. If viewed as terminal education, the undergraduate program must impact to its graduate a set of marketable skills; if considered as a foundation for graduate work, the program must prepare him for scholarship. In order to sustain the multigoal function, a flexible program design is mandatory.

The undergraduate degree program which the School of Information and Computer Science has designed to harbor such a "power" is shown in Table 1. A total of 194 credit hours are required for graduation including 54 hours of electives. The required flexibility is accomplished by providing that 24 hours of these electives be taken in the Junior and Senior years in one of a relatively large number of "subject areas of concentration," to meet a variety of individual educational and professional objectives of students. Examples of the subject areas of concentration are:

- Computer Systems Design
- Programming Systems Design
- Management Information Systems
- Health Information Systems
- Numeric Computation
- Natural Language Processing
- Theory of Computing
- Systems Theory
- Artificial Intelligence
- Linguistics

The program design is highly hospitable to diverse multidisciplinary educational objectives. Its format permits students to include as free electives "minor" areas of study offered through other departments of the Georgia Institute of Technology.

The new undergraduate program of the School of Information and Computer Science is predicated upon a recognition of information science's responsibility for integrating technologies -- a recognition which has been a major theme in the history of information science education. The development of new independent academic programs such as this, whose primary objective is the advancement of and education in a unified body of knowledge relating to the theory, design and management of information processes and systems, is indicative of the remarkable degree of maturity which education in information/computer/systems science has attained in the first ten years of its existence.
### TABLE 1. INFORMATION and COMPUTER SCIENCE CURRICULUM

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a) With the consent of the School, these courses may be substituted by other empirical science courses relevant to the student's program.
b) Two of the following three courses shall be taken: P.T. 102, P.T. 104, P.T. 105. A maximum of 3 credits of Physical Training may be applied toward the B.S. degree.
c) Free elective courses, to be taken at any time during the course of study. If basic ROTC is selected to satisfy these six credit hours, it must be scheduled beginning the first quarter of the Freshman year.
d) May be substituted by ISyE 335.
e) Electives in the Junior and Senior year will include 24 credit hours in one of several areas of specialization recommended and approved by the School of Information and Computer Science.
BIBLIOGRAPHY OF PUBLICATIONS 1971/72*

Books and Doctoral Dissertations


Articles


* Includes books, dissertations, articles, technical reports and patent applications since July 1971.


Technical Reports


Patent Applications

Invention Disclosure NSF-71-22-GN-655, "Phase-Lock Flutter Compensator."
RESEARCH 1972/1973:
ANNUAL PROGRESS REPORT

School of
Information and Computer Science
NOTE

The GITIS series of technical documents and annual research reports which have been published by the School of Information and Computer Science on an irregular basis since 1969 will be discontinued at the conclusion of this year.

Beginning 1974, the School will introduce a new publication which will report regularly on research projects and other scholarly activities of interest to the academic and professional community of the discipline. Request for complimentary copies of the new publication should be addressed to Director, School of Information and Computer Science, Georgia Institute of Technology, Atlanta, Georgia 30332.
ACKNOWLEDGMENTS

The research activities described in this annual progress report for 1972-1973 were supported in part by the following grants: GN-655 from the Office of Science Information Service, National Science Foundation (Principal Investigator: Vladimir Slamecka); GN-36114 from the Office of Science Information Service, National Science Foundation (Principal Investigator: Pranas Zunde); GN-36079 from the Office of Science Information Service, National Science Foundation (Principal Investigator: Philip J. Siegmann); GZ-2628 from the Division of Education, National Science Foundation (Principal Investigator: Vladimir Slamecka); GK-36797 from the Division of Engineering, National Science Foundation (Principal Investigator: Thomas G. Windeknecht); LM 00147-01 from the National Library of Medicine, National Institutes of Health (Principal Investigator: Vladimir Slamecka); and a grant from the Department of Education, State of Georgia (Principal Investigator: Alton P. Jensen).

The School of Information and Computer Science gratefully acknowledges the support and assistance received from these research granting agencies and their staffs.
This document is the fourth annual research report of the School of Information and Computer Science, Georgia Institute of Technology. It covers the twelve-month period from July 1972 through June 1973.

As the largest graduate department of the Georgia Institute of Technology, the School of Information and Computer Science has an active research program whose scope encompasses selected areas in information science, computer science, and systems science, as well as engineering research in the design and evaluation of specific types of information and computer systems. The research program is broadly guided by the School's commitment to the long-range purpose and social objective of its discipline—to increase the cost-effectiveness of man's problem solving resources and professions, by the design and use of information processing automata and systems which assist his problem solving, decision making, and learning functions.

Within this general direction, the School pursues a research program in the theories of information, information processes and processors, and in mathematical systems theory. The applied research program continues to emphasize a spectrum of design and evaluation problems concerning science and learning information systems.

A significant component of the School's research resources is its Information Processing Laboratory, now equipped with three computer systems: a large, time-sharing Burroughs B-5500; a medium-scale PDP 11/45 configured for research in artificial intelligence; and a versatile minicomputer system (PDP 8/I), used in part to control the School's remote audiographic self-instruction system ALF. Several research projects have made use of other facilities available to the School, such as the IBM 370/158 computer system of the Atlanta Public Schools, and the GIPSY data management system at Emory University (under the auspices of the Graduate Programs in Biomedical Information and Computer Science, offered jointly by the School of Information and Computer Science and the Emory University School of Medicine).

Description of the academic programs offered by the School of Information and Computer Science, leading to the B.S., M.S., and Ph.D. degrees, is available in a separate brochure obtainable on request from the School.

VLADIMIR SLAMECKA, Director

Atlanta, Georgia
August 1973
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RESEARCH IN INFORMATION SCIENCE

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There are two central problems countenanced in this project. The first is concerned with the transmission and origination of knowledge in science. The second is concerned with the effect of information technologies and the implementation of various policies on the transmission and origination processes. Early in the project it was decided that some field of science would constitute a promising area for the study of information processes and processors. The factors on which this decision was based were: (1) there exists a body of data pertinent to the transmission and origination of knowledge in science; (2) a portion of this data is available in forms adapted to automatic processing; and (3) the importance of science to society and the relative ease with which both the formal processes and processors can be identified make the restriction of these studies to some science a reasonable choice.

The results obtained prior to the commencement of the past year may be summarized as follows:

a. A methodology for studying and describing quantitatively the phenomena of transmission and origination of knowledge in science was identified. The methodology is an adaptation of the genetic map construction techniques developed in classical genetics and the statistical techniques of population genetics. In the adapted methodology, concepts are the analogues of genes. They are viewed as stable factors inherited in the process of knowledge transmission. The origination of concepts is viewed as mutational events. The articles, monographs and other products transacted in the process of communication which are the surface expressions of concepts are viewed as the phenotypic expression of these concepts. The processes of transmission (e.g., as exemplified by the citation processes) are viewed as the inheritance mechanisms.

b. A concrete setting for testing and refining the adapted methodology was identified. Arrangements were made for accessing data banks that contain reference information and attendant indexing systems in the area of physics (the SPIN system). Programs were devised for accessing the relevant data and constructing maps. These programs are currently in use to perform the initial retrodictive experimental tests of the adapted methodologies. The programs developed are used for experimental tests of the analogy between the processes of gene transmission and mutations and the processes of conceptual transmission and innovation.

The results obtained during the past year may be outlined as follows:

a. A set of eight host markers were identified for the papers in the available SPIN collection. The markers were initially identified through the device of pooling together journals. A geographical marker whose two states are foreign and domestic was discriminated directly. Seven other
markers were obtained by considering the seven top categories of the SPIN classification and placing in one host range all of those journals which contained articles classified in a category with a frequency below a chosen threshold. The ensuing host range markers were tested for stability.

b. Two factor crosses of both configurations were identified within the SPIN collection for the mentioned host range markers. The recombination distances were computed. Twelve separate determinations of recombination distances for each pair of markers were made. Six of these determinations are for the cis-configuration and six are for the trans-configuration of the markers.

c. Statistical tests for the homogeneity of the computed recombination distances were made yielding a positive result. These tests also disclosed that there is a higher degree of homogeneity within each configuration. Thus perhaps there is a marker configuration effect whose nature we have not yet explored.

d. The results tentatively validate the proposed analogy and attendant adapted methodology.

Research in the immediate future will consist of: (a) identifying markers and refining the definition of the presently identified markers in order to obtain higher levels of marker stability; (b) testing for heterozigocity with respect to the selected markers; (c) investigating the configuration effect that is manifested in the data obtained; and (c) ascertaining the structural invariants of the set of recombination distances.

References

The objective of this project has been to determine the feasibility of using the lower predicate calculus as the principal formal mechanism for monitoring and bringing under operational control the coherence of abstracts for the purpose not only of assigning index terms to an abstract but also of providing a basis for question-answering.

The task of translating English tests into the lower predicate calculus with additions can be considered to consist of three areas. The first is how to extend the rules of formation of predicate calculus to provide sufficient syntactical structure to adequately represent the natural language structure of interest. The second is to determine the axioms and rules of inference for this extended system. The third area is to determine algorithms to translate into this system from the surface of the natural language text all the information necessary to make meaningful manipulations of the translated text.

Extension of the rules of formation has previously focused on two areas: the addition of specific quantifiers to capture more closely the natural language counterparts and the introduction of new categories of symbols. While the former do not appear to be essential but appear only to provide structures which are more convenient to our intuitions, the introduction of new categories of symbols (e.g., adverbs) appears quite significant and unavoidable.

The difficulty in efforts to determine the axioms for the extended systems center on the fact that the axioms for these systems are undesirably specific. We cannot, for example, put temporal operators such as "past" in the same category as modal operators such as "necessarily." Both operators have the same domain of sentences, but different axioms apply to each. This indicates the unpleasant possibility that descriptive axioms must be introduced for each temporal and for each modal operator to be used in the language.

In lieu of having a solution to this problem, we first tested the question of how much of natural language could already be translated into the predicate calculus without extending the axioms. An abstract was translated into the predicate calculus with tense and modality being represented as sentential operators. Besides the already recognized problems with adverbs and tense, it was evident that sentence adjuncts were quite significant in maintaining the connectedness of the abstract and that the translation may have atomized the structure too finely, thereby losing the identity of the text's topic.

Next, we considered a paper by Bohnert and Backer which dealt with the algorithmic translation from a restricted form of English to the predicate calculus. We applied their approach to the same abstract.
However, we modified their approach by using adjective plus noun constructions as primitive terms, adverbs plus verb as primitive predicates, special quantification symbols for plural terms, and predicates which accept sentences as arguments. The result was a better representation of the topic of the abstract, but the relation between terms in one sentence and those in another was obscure and the inability to disengage the adjectives and adverbs from the terms they modify left the representation less applicable than it would be if, for example, the same noun could be identified with or without the adjective.

For this reason, a third analysis was made using the results of the second together with adjectival and adverbial properties to determine what rules might be used to identify inter-sentential reference which was known to exist. Using the notion that the abstract discussed a set of individuals and that at least one individual must be referenced by each of two adjacent sentences, a more adequate representation was achieved. Clues as to which terms might refer to the same individuals included the use of deictics such as these and a comparison of properties attributed to the individuals by the terms in the text.

Analyses of other abstracts has emphasized the importance not only of such items as sentence adjuncts, tense, modals, deictics and properties attributed to the individuals by the terms in the text, but also of a special class of words which we call "metatext words." These words, e.g., process, method, and use, are extremely important to the coherence of an abstract, for they relate not only nouns but also descriptions of verbal activities.

Our previous research had shown that a major difficulty is that existing theories do not characterize those sequences of sentences which constitute discourses. Efforts in the fiscal year 1972/73 focused (1) on the problem of identifying the linguistic devices which contribute to the connectedness (or cohesion) and coherence of discourses and (2) on creating a formal theory of their use.

Cohesion can be defined as repetition; a sequence of sentences is cohesive if each sentence makes reference to something which is in some way related to something referred to in another sentence of the sequence (intersentential reference), and, moreover, there is not partition of the sentences of the discourse such that there is no intersentential reference between any of the sentences of one set of the partition and any sentences of any other set of the partition. Because linguistics have been concerned with sentences in which cohesive devices are used, even though "out of context," our identification of the syntactic devices used to establish cohesion is fairly complete. These devices include deictics, quantifiers, pronouns, word repetition, sentence adjuncts, sequencing, and logical reasoning; the intersentential reference is usually anaphoric.

Coherence, as a property of discourses, is a much more vague notion than cohesion. Involved are ideas such as topic, participant roles, theme, rationality, etc. Most significant, perhaps, is the notion that a coherent
discourse conveys a message, that at some point the interpreter will not only "understand" what has been presented but will also appreciate "why" it was presented. A coherent discourse must be cohesive, since the sentences of the discourse are related at least by their common reference to the message conveyed; indeed, cohesion can be considered a precondition for the judgment of whether a discourse is coherent or not—it would be inappropriate to consider the coherence of a discourse formed by joining two unrelated texts, even though each was coherent in its own right.

Coherence, because of the largely intuitive nature of our understanding, does not yet seem to be an appropriate topic for formal study. But, by formalizing cohesion, it may be possible in the future to sort out some of the questions which must be considered in evaluating a discourse for coherence, thereby leading to a firmer understanding of it. At the same time, formalizing our understanding of cohesion will guide linguists in the discovery of significant syntactic structures in language which cannot be readily discovered or characterized in the syntax alone.

For our initial exploration of this formalization, we considered a language based on a first-order predicate calculus with equality and an iota-operator. In addition to the usual logical constants, the primitive symbols included individual variables, individual constants, and predicate constants. The rules of formation were of the usual type. A discourse was represented by a finite sequence of sentences of this language. A model, $M$, consisting of a domain of individuals and an assignment function represented the context of a discourse.

Following Hintikka [1,2], all sentences had negation symbols driven as far inward as possible. This was to ensure that each variable was quantified in a unique manner. We used the following definition for cohesion: a discourse $S_1, \ldots, S_n$ is cohesive in a model $M$ if (1) for each $j > 1$ and for some $i < j$, there is a predicate constant occurring in $S_i$ which also occurs in $S_j$; (2) for each $j > 1$ and for some $i < j$, there is an individual constant occurring in $S_j$ which also occurs in $S_i$; or (3) there is an assignment function $A$ such that if all existential quantifiers are dropped from $S_1, \ldots, S_n$ yielding $S_1', \ldots, S_n'$, then $A$ satisfies each of $S_1', \ldots, S_n'$, and for every sentential formula $S_j$, $j > 1$, in which repetition does not occur through individual or predicate constants, there is an unbound individual variable $x$ occurring in $S_i$ such that $A(x) = f(c)$, where $c$ is an individual constant occurring in some $S_i$, $i < j$, or $A(x) = A(y)$, where $y$ is an individual variable occurring in $S_i$. Using this definition, we were led to the following results.

The sequence shown below would necessarily be cohesive in every model since the same predicate constant is used in both sentences:

$$(x)(\exists y)(Pxy \land Qyx),$$

$$(\exists y)(w)(Pw \land Svw).$$
The next sequence would be cohesive in some models.

\[(\exists x)(\exists y)(PxAQyARxy),\]
\[(\exists y)(\exists w)(HvALwAMvw).\]

To see it, though, we must look at the open formulas obtained by dropping existential quantifiers, since no predicate or individual constants are used in both sentences:

\[(PxAQyARxy),\]
\[(HvALwAMvw).\]

It is clear then that the discourse will be cohesive in any model in which any of the following formulas can be satisfied:

\[(PxAQyARxyAHxALwAMxw),\]
\[(PxAQyARwyAHyALwAHyw),\]
\[(PxAQyARwyAHvALxAMvw),\]

or
\[(PxAQyARwyAHvALyAMvy).\]

And, in general, the discourse will be ambiguous.

If \(f\) were one-to-one, i.e., there were no synonyms among the predicate constants,

\[(x)(y)((MxANy)\Rightarrow Rxy),\]
\[(y)(w)((HvALw)\Rightarrow Svw).\]

would be an example of a discourse which is not cohesive in any model, since we have not provided for cohesion through possibly known relations between predicates. In the more general definition, there is no sequence of sentences which is not cohesive in any model. And a more suitable definition of cohesion will, of course, allow for intersentential reference through relations between predicates.

Note that, given this notion of cohesiveness, not all sentences of a discourse have to be true in a given model for the discourse to be cohesive in the model. For example:

\[P\]
\[-P.\]

8
Since both an individual constant and a predicate constant are repeated, the discourse would be cohesive in every model according to the definition given, but, of course, not both sentences could be true. Moreover, it can be seen that the requirement that all sentences of the discourse be true in the model, in the traditional sense, would be too strong, making the notion of discourse no different than the notion of a set of sentences. Consider the following natural language discourse:

(1) There is a book on the table.
(2) The book is red.

It might be translated as follows:

(1') (\exists x)(\exists y)(\text{Book}(x) \land y = (\exists s)(\text{Table}(s)) \land \text{On}(x,y)),

(2') (\exists v)(v = (\exists w)(\text{Book}(w) \land \text{Red}(v))).

Since the same predicate occurs in both sentences, the discourse is cohesive in all models. However, sentence (2') will be true only in models in which there is exactly one book and it is red, while sentence (1') will be true in models in which there are many books. But, certainly, the natural language discourse would be considered both cohesive and coherent—even in situations in which there were many books, even many on the table.

The difficulty is that the intended interpretation of "the" in natural language discourse is not properly characterized by the iota-operator. Hiz [3] noted that many referentials in English do not make reference to anything outside the text, or more precisely, that they refer to what other phrases in the text would have referred to had these other phrases occurred in place of the referentials. Included in this process of indirect reference are many kinds of elliptical constructions, as when the second reference to an individual is made by repeating in the text part of the phrase which first made reference to the individual. For example:

(3) A wise king once ruled a fair country. The king . . .

or (4) There were both wise and foolish men. The wise knew . . .

or (5) There were both wise and foolish men. A wise one knew . . .

The restrictions on the quantifiers used in the elliptical phrases indicate that quantifiers are involved in this process. Indeed, they may be an integral part of the process, indicating when and how the indirect reference is to be made. For example, in the following discourse, the reference almost must be different between the first and second occurrence of "a king" for the discourse to be acceptable, although it is conceivable that the same individual is intended:

(6) A king rules this country. A king is wise.
Related to this is the notion of the "appropriate" use of cohesive devices, where the primary concern is the relationships existing between the use of various cohesive devices in discourse. In (6), if the same individual were denoted by both occurrences of "a king," the use of an existential quantifier in the second instance would be inappropriate, although the discourse would be cohesive according to the definition. Similarly, the use of "the" in the first reference to an individual in a discourse would be appropriate only if the individual was unique in the model.

From these considerations, we can conclude that the semantic notion of fundamental concern in relationship to cohesiveness is not truth in a model but satisfiability; the major objective is the determination of an assignment function for those terms in the discourse open to assignment which will satisfy certain constraints. A quantified expression, then, is not closed with respect to such assignments; rather, the quantifier indicates the nature of the constraint. If the constraints are appropriate to the context, both syntactic and semantic, the discourse will have an assignment under which it will be cohesive. Truth of discourses will have to be determined in relationship to such assignments.

Other devices by which cohesion is indicated in natural language discourse cannot be represented in the simple theory presented here. But they probably function in the same manner, constraining possibly assignment functions so that the discourse will be cohesive under those accepted. They include nominalization, tense, modality, and propositional attitudes.

Nominalization of verb phrases is a significant cohesive device in English, being a form of elliptical repetition in indirect reference. The usual method for representing a corresponding notion in logical systems is to provide variables which range over relations among individuals in addition to those ranging over individuals. Montague (1970) defines, as well, an abstraction operator which allows "naming" new predicates. Extension of the same technique would provide for the representation of nominalization of predicates in a manner more closely mirroring natural language, which is, in fact, fairly straightforward; the nominalizing affix marks the role with respect to which the nominalization is being made or it marks that the action itself is being named, while any other roles of interest are repeated. For example, possible nominalizations based on "John gave Mary a book" include: "giving," naming the action; "the giver," marking the agent; "the gift," marking the object; "the giver of the book," marking agent in the nominalization and repeating the object, etc. Correspondingly, nominalization of predicates in a logical system would have to indicate the argument position with respect to which the nominalization was being performed, while other terms of interest would have to be explicitly indicated. Note that if nouns are to be represented as one-place predicates, nominalized predicates will also be one-place predicates, regardless of the addicity of the predicate itself.

While the role of tense in cohesive discourse is not so clear, the following example illustrates its possible influence:
Here disagreement in tense overrides the nominalization of the agent role of the preceding activity so that the referent for "the giver" is not necessarily John. The discourse is apparently equivalent to:

(7) John gave Mary a book.
(8') A giver is usually thanked.
(9) But Mary never thanked John.

Change of tense in (8) to the past, though, changes the restrictions:

(7) John gave Mary a book.
(8") The giver was usually thanked.
(9) But Mary never thanked John.

In a similar fashion, shifts in modality or in propositional attitude in a discourse affect the possible assignments, in some cases requiring change in referents where otherwise they would necessarily be the same, in other cases affecting the truth value of propositions in the modals (e.g., "believed").

Some of these questions may extend beyond simple cohesion if the definition given above were to be accepted as adequate. However, as the first example illustrated, it appears that any extension of the notion of the truth of sentences to the truth of discourses will inevitably involve such questions. Alternatively, consideration of only cohesiveness, basically as defined above, without consideration of the semantics of discourse of some of the devices discussed, might prove uninteresting, there being little to distinguish the syntax or semantics of discourse from that of sets of sentences with some minor restrictions on admissible interpretations. Thus, the truth of discourses, as well as notions of equivalence of discourses and consequences of a discourse, would seem to be of fundamental interest in formalizing the syntax and semantics of cohesive devices.

Another notion of possible interest is the notion of "degrees of cohesion." Given a discourse, there may be many cohesive devices available, but in a given interpretation, not all of them may be used in a way which contributes to the cohesiveness of the discourse. The relative number of available devices contributing to the cohesiveness of the discourse can be considered an indicator of the degree of cohesiveness of the discourse. It should be noted that degree of cohesion is not related to coherence. A sequence in which each sentence was identical would presumably have an extremely high degree of cohesion; whether or not it would be coherent is another question altogether.
With this in mind, we have concluded that it would be best to create a new symbolic system in which to represent discourse and cohesive devices and to define a semantics for that system which would provide the intended interpretations for the cohesive devices represented.

Particular devices to be considered are: indirect reference, involving quantifiers, pronouns, nominalizations, and elliptical phrases; synonyms and antonyms (definitions); and tense, modality, and propositional attitudes.

Particular semantic notions of interest will be: cohesive discourse, true discourse, equivalence between discourses, consequences of a discourse, degree of cohesion, and appropriate use of cohesive devices.

On the basis of such formal considerations it should be possible to re-examine the feasibility of using a form of the lower predicate calculus in representing natural language discourse.

References


The chief concern of this research project has continued to center on the category of the indexical symbol, especially with respect to its internal complexification—a process which could conceivably mirror the beginning of grammar and thus the creation of language. Our final development of the internal coherency is treated below to the level of term complexity thus far attained.

We next propose propositional schemata and discuss their genesis. Finally, in connection with this development, we are at present examining the role of the German adverbs immer, wieder, oft in signifying the serial identity of recurring events.

Indexical Symbols: Category Coherency and Complexity. Our category contains the following set of ostensive semantic primitive terms:

\{THIS (IT), HERE (IT), NOW (IT), HENCE (IT), HITHER (IT)\} \hspace{1cm} (1)

The members of this set are values of idealized acts of ostension, abstracted from the set of English deictic elements that people in fact do use to point to concrete objects. The affix (IT) represents a free variable, so that the elements in (1) are in certain ways analogous to the iota quantifier of logic. The following table lists the intensional semantic feature uniquely proper to each of the elements in (1):

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>INTENSION</th>
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<tbody>
<tr>
<td>THIS (IT)</td>
<td>LOGICAL PROPER NOUN (LPN)</td>
</tr>
<tr>
<td>HERE (IT)</td>
<td>SPACE (SP)</td>
</tr>
<tr>
<td>NOW (IT)</td>
<td>TIME (TI)</td>
</tr>
<tr>
<td>HENCE (IT)</td>
<td>ORIGIN (OR)</td>
</tr>
</tbody>
</table>
| HITHER (IT)| TERMINUS (TER)        | (2)

Abbreviation of the intensional semantic feature is given in parentheses.

Interpretation of (1) and (2) as a matrix will provide us with a deeper insight into the subcategoricity of indexical symbolism, the property that is crucial to the genesis of the grammar of semantic structures.
The indexical symbols (IS) appear in rows, the semantic features (SF) in columns. A plus sign indicates the presence of a given intensional SF in an element of (1), a minus sign indicates its absence. The two submatrices along the diagonal have been boxed to emphasize their symmetry. Their significance will be discussed below.

Matrix (3) is initially best interpreted in terms of IS-SF equivalences. We propose the following such equivalences, each indexical symbol with its equivalent SF-tuplet.

- **HENCE (IT)** $\equiv <\text{OR}, \text{SP}, \text{LPN}>$  
  (4i)
- **HENCE (IT)** $\equiv <\text{OR}, \text{TI}, \text{LPN}>$
- **HITHER (IT)** $\equiv <\text{TER}, \text{SP}, \text{LPN}>$  
  (5i)
- **HITHER (IT)** $\equiv <\text{TER}, \text{TI}, \text{LPN}>$
- **HERE (IT)** $\equiv <\text{SP}, \text{LPN}>$  
  (6i)
- **NOW (IT)** $\equiv <\text{TI}, \text{LPN}>$
- **THIS (IT)** $\equiv <\text{LPN}>$  
  (7i)

Here we use angular brackets to set off the various SF-tuplets and the sign $\equiv$ to denote equivalence. We have italicized the SF's that prompt IS differentiation and duplication (or splitting).

While each element in (1) possesses an intensional SF proper to it alone, it becomes evident from (3)-(7) that there exists an ostensive semantic coherency among them, a coherency that can be expressed as ostensive semantic entailment (OSE). The significance of OSE is that the intensional semantic structure (SF-tuplet) of each implicans includes the intensional semantic structure of its implicate. Ostensive coherency can then be expressed by the following OSE schemata:
HENCE (IT) ⊸ HERE (IT); HENCE (IT) ⊸ NOW (IT)  
HITHER (IT) ⊸ HERE (IT); HITHER (IT) ⊸ NOW (IT)

and

HERE (IT) ⊸ THIS (IT)  
NOW (IT) ⊸ THIS (IT)

and

HENCE (IT) ⊸ THIS (IT)  
HITHER (IT) ⊸ THIS (IT)

Here the sign ⊸ denotes ostensive semantic entailment and is to be read as "ostensively semantically entails." Thus we propose the following OSE schemata, expressed in terms of levels of OSE depth, each level being a measure of ostensive semantic complexification of (1) and each being a representation of (1) as an internally structured whole.

OSE-LEVELS  (iii)  (ii)  (i)

(a) HENCE (IT) ⊸ HERE (IT) ⊸ THIS (IT) 
(b) HENCE (IT) ⊸ NOW (IT) ⊸ THIS (IT)  

(a) HITHER (IT) ⊸ HERE (IT) ⊸ THIS (IT)  
(b) HITHER (IT) ⊸ NOW (IT) ⊸ THIS (IT)

We offer three OSE-LEVELS: (iii) represents the greatest OSE depth, being the level of the most comprehensive entailment--the level of HENCE (IT) and HITHER (IT); (ii) represents the next comprehensive level--the level of HERE (IT) and NOW (IT); and finally, (i) represents the core implicate--the ostensive semantics of the LPN.

OSE schemata emerge upon substitution, within the SF-tuplets, of equivalent indexical symbols for their respective equivalent SF-tuplets. Substitution of THIS (IT) for its equivalent SF-tuplet gives us respectively:

HENCE (IT) ≡ <OR, SP, THIS (IT)>  
HENCE (IT) ≡ <OR, TI, THIS (IT)>

HITHER (IT) ≡ <TER, SP, THIS (IT)>  
HITHER (IT) ≡ <TER, TI, THIS (IT)>

HENCE (IT) ≡ <OR, SP, THIS (IT)>  
HENCE (IT) ≡ <OR, TI, THIS (IT)>  

HITHER (IT) ≡ <TER, SP, THIS (IT)>  
HITHER (IT) ≡ <TER, TI, THIS (IT)>

HENCE (IT) ≡ <OR, SP, THIS (IT)>  
HENCE (IT) ≡ <OR, TI, THIS (IT)>  

HITHER (IT) ≡ <TER, SP, THIS (IT)>  
HITHER (IT) ≡ <TER, TI, THIS (IT)>

HENCE (IT) ≡ <OR, SP, THIS (IT)>  
HENCE (IT) ≡ <OR, TI, THIS (IT)>  

HITHER (IT) ≡ <TER, SP, THIS (IT)>  
HITHER (IT) ≡ <TER, TI, THIS (IT)>

15
HERE (IT) \equiv <SP, THIS (IT)> \quad (6ii)
NOW (IT) \equiv <TI, THIS (IT)>
THIS (IT) \equiv <THIS (IT)> \quad (7ii)

We retain the equivalences here. Following substitution, semantic features still remain in (4ii), (5ii), and (6ii). The element THIS (IT) emerges as the base core semantics of indexical symbolism, being included in every other primitive element. It thus occurs as representative of the most primitive substantival. Despite its role as core implicate, however, THIS (IT) does not uniquely distinguish semantically any of its implicans. Indeed, we find that HERE (IT) and NOW (IT) each entails its own THIS (IT) implicate.

We next substitute the IS's of (6ii) for their respective equivalent SF-tuplets in (4ii), (5ii), and (6ii) and obtain:

HENCE (IT) \equiv <OR, HERE (IT)>
HENCE (IT) \equiv <OR, NOW (IT)> \quad (4iii)
HITHER (IT) \equiv <TER, HERE (IT)>
HITHER (IT) \equiv <TER, NOW (IT)> \quad (5iii)
HERE (IT) \equiv <HERE (IT)>
NOW (IT) \equiv <NOW (IT)> \quad (6iii)

Once again we retain equivalence. Only in (4iii) and (5iii) are there SF-reminders, OR and TER. These disappear upon substitution of HENCE (IT) and HITHER (IT), respectively. Such a substitution would lead to the collapse to one HENCE (IT) in (4iii) and one HITHER (IT) in (5iii), quite unlike the result in (6iii), where SP and TI continue to be differentiated. Space and time seem to play a very significant role in our OSE schemata, for they effect a splitting not only in THIS (IT), but in HENCE (IT) and HITHER (IT) as well. That is to say, they each demand their own THIS (IT) implicate; and, in turn (in their own role as implicate), they each require their own implicans. More on this later.

Let us now turn to a discussion of the symmetry of matrix 3. The symmetry within the two boxed submatrices along the diagonal (3) suggests that the items in each submatrix bear a very close relationship to one another. We take this relationship to be that of bi-entailment, such that we have:

HENCE (IT) if and only if HITHER (IT)
and
HERE (IT) if and only if NOW (IT)
whereupon we find it appropriate to conceive of the items in each of the submatrices as unitized symbols—composite in nature, created simultaneously, co-extensive in ostension—and thus best expressible as ordered pairs of the form:

\[
\begin{align*}
<\text{HERE (IT)}, \text{NOW (IT)}> \\
<\text{HENCE (IT)}, \text{HITHER (IT)>}
\end{align*}
\]

Brackets here set off the ordered pairs.

Let us now consider the significance of the submatrices when we interpret them in the light of composite, unitized symbols. As our initial task, we reduce the matrix in (3) to the two partial matrices:

\[
\begin{array}{ccc}
\text{LPN} & \text{<SP, TI>} & \text{OR} \\
\text{THIS (IT)} & + & - & - \\
<\text{HERE (IT)}, \text{NOW (IT)}> & + & + & - \quad (13) \\
\text{HENCE (IT)} & + & + & + \\
\end{array}
\]

and

\[
\begin{array}{ccc}
\text{LPN} & \text{<SP, TI>} & \text{TER} \\
\text{THIS (IT)} & + & - & - \\
<\text{HERE (IT)}, \text{NOW (IT)}> & + & + & - \\
\text{HITHER (IT)} & + & + & + \\
\end{array}
\]

The row-column format here is essentially that of (3). By pairing and thereby term-unitizing \text{HERE (IT)} and \text{NOW (IT)}, which are the symbols that differentiate (lla) from (lib) and (12a) from (12b), we also effect the collapse of the a-b doublets in each schema. Thus, matrices (13) and (14) reflect the process of ostensive composition, the process that brings about co-extensive ostensive representation by variant symbols. On the basis of (13) and (14), we can compositionally derive the following OSE schemata:

\[
\begin{align*}
\text{HENCE (IT)} \leftrightarrow \text{HERE (IT)} \leftrightarrow \text{THIS (IT)} & \quad \text{(lla)} \\
\text{HENCE (IT)} \leftrightarrow \text{NOW (IT)} \leftrightarrow \text{THIS (IT)} & \quad \text{(lib)} \\
\text{C} & \\
\text{HENCE (IT)} \leftrightarrow <\text{HERE (IT), NOW (IT)}> \leftrightarrow \text{THIS (IT)} & \quad \text{(15)}
\end{align*}
\]

and
Here the C-topped arrow denotes the operation of ostensive composition; the sign 0+ again denotes OSE. Space and time emerge here under the scope of a single entailed THIS (IT) as semantically bound and co-ostensively represented. This means essentially that HERE (IT) and NOW (IT), so paired and term-unitized, have the same referent, entail a composite THIS (IT) singlet and are entailed respectively by the same HENCE (IT) and HITHER (IT) singlets. Moreover, HENCE (IT) and HITHER (IT) each in turn become ostensively co-extensive as to space and time. They remain the elements, however, that keep (13) and (14) apart. As we will see below, pair HENCE (IT) and HITHER (IT) and (13) and (14) will collapse as will (15) and (16).

The OSE schemata in (15) and (16) reflect a shift in the symbol process from what we take to be the more concrete level of (11) and (12), simple implicans with its respective simple implicate, to a higher level of abstraction represented in the operation of ostensive composition. In the operation of composition, we seek to represent ostensively the regionalization of an object conjointly for space and time. The coherency of the category of the indexical symbols is thereby heightened; indeed, more so, when we realize that composition has its counter process in decomposition. Composition is thus reversible, but we do not return to the separateness evident in the dual schemata of (11) and (12). Rather we retain the coherency attained in (15) and (16). Thus, we do not have composition-decomposition operations of the form:

\[
\text{COMPOSITION} \rightarrow
\]

(11a)

(15)

(11b)

\leftarrow \text{DECOMPOSITION}

and

\[
\text{COMPOSITION} \rightarrow
\]

(12a)

(16)

(12b)

\leftarrow \text{DECOMPOSITION}
but rather composition-decomposition operation represented in schemata of the form:

$$\begin{align*}
C & \rightarrow \\
\left< (11a), (11b) \right> & \rightarrow (15) \rightarrow (17) \\
D & \\
C & \rightarrow \\
\left< (12a), (12b) \right> & \rightarrow (16) \rightarrow (18) \\
D & \\
\end{align*}$$

where (11a) and (11b) are coherently paired as are (12a) and (12b).

In (17) and (18) we have the following decompositional OSE schemata:

$$\begin{align*}
\text{HENCE (IT)} & \leftrightarrow \left< \text{HERE (IT)}, \text{NOW (IT)} \right> \leftrightarrow \text{THIS (IT)} \quad (17i) \\
D & \\
\text{HENCE (IT)} & \leftrightarrow \left< \text{HERE (IT)} \leftrightarrow \text{THIS (IT)}, \right. \\
\text{NOW (IT)} & \leftrightarrow \text{THIS (IT)} \left. \right> \\
\end{align*}$$

Here we have distributed the THIS (IT) over the ordered pair and obtain therein (9a) and (9b). We next distribute the HENCE (IT) over the ordered pair and obtain:

$$\begin{align*}
\left< \text{HENCE (IT)} \leftrightarrow \text{HERE (IT)} \leftrightarrow \text{THIS (IT)} \right>, \\
\left< \text{HENCE (IT)} \leftrightarrow \text{NOW (IT)} \leftrightarrow \text{THIS (IT)} \right> \\
\end{align*}$$

(17iii)

where we attain to a paired (11a) and (11b). We now have a coherent HENCE (IT) schema, relative to space and time.

The same obtains for HITHER (IT), so that we write:

$$\begin{align*}
\text{HITHER (IT)} & \leftrightarrow \left< \text{HERE (IT)}, \text{NOW (IT)} \right> \leftrightarrow \text{THIS (IT)} \quad (18i) \\
D & \\
\text{HITHER (IT)} & \leftrightarrow \left< \text{HERE (IT)} \leftrightarrow \text{THIS (IT)}, \right. \\
\text{NOW (IT)} & \leftrightarrow \text{THIS (IT)} \left. \right> \\
D & \\
\end{align*}$$

(18ii)
and attain to a coherent HITHER (IT) within the context of (1).

Our next move toward a higher coherency involves pairing HENCE (IT) and HITHER (IT), a move that collapses (15) and (16) to a single schema. Before we turn to this development, we must rewrite (17) and (18) as hierarchical ostensive systems. This amounts essentially to depicting all levels of composition and decomposition at one and the same time. This would be equivalent to a potential generative scheme.

At this point in our development of the ostensive semantic coherency of indexical symbols, we propose two higher-level, internally structured wholes for (1), each again with three levels, each reminiscent of and parallel to the OSE-levels of (11) and (12). Thus, for the HENCE (IT) OSE schema, we have:

OSE-LEVEL 3

\[
\langle \text{HENCE (IT)}^{iii} \leftrightarrow \text{HERE (IT)}^{ii} \leftrightarrow \text{THIS (IT)}^{i} \rangle,
\]

OSE-LEVEL 2

\[
\langle \text{HERE (IT)}^{ii} \leftrightarrow \text{THIS (IT)}^{i} \rangle, \quad \langle \text{NOW (IT)}^{ii} \leftrightarrow \text{THIS (IT)}^{i} \rangle^{2} \leftrightarrow
\]

OSE-LEVEL 1

\[
\langle \text{THIS (IT)}^{1} \rangle
\]

and for the HITHER (IT) OSE schema:

OSE-LEVEL 3

\[
\langle \text{HITHER (IT)}^{iii} \leftrightarrow \text{HERE (IT)}^{ii} \leftrightarrow \text{THIS (IT)}^{i} \rangle,
\]

OSE-LEVEL 2

\[
\langle \text{HERE (IT)}^{ii} \leftrightarrow \text{THIS (IT)}^{i} \rangle, \quad \langle \text{NOW (IT)}^{ii} \leftrightarrow \text{THIS (IT)}^{i} \rangle^{2} \leftrightarrow
\]
OSE-LEVEL 1

<THIS (IT)>¹

The triplets initially evident in (11) and (12) are identified here by the superior indexes iii, ii, i, in order of the original OSE-dominance. A new OSE triplet has been formed, the terms retaining the order of OSE-dominance typical of (11) and (12). There results here a complexified internal ostensive semantic coherency, due to the compositional pairing of HERE (IT) and NOW (IT). The original dual system of HENCE (IT), HITHER (IT), and THIS (IT), which we thought of initially as splitting, can be regarded as decomposition, the reverse process of composition. Anticipating our semantic generative schemata, we envisage (19) and (20) as underlying any possible generative schemes. We would attempt to establish equivalences where there are now entailments—this not only within levels but across levels as well.

One level of OSE complexification remains yet to be demonstrated, the pairing of HENCE (IT) and HITHER (IT), and with such a pairing the final collapse of (15) and (16). Such an achievement would establish the total unity of (1) as a completely structured whole.

We now combine (13) and (14) to:

LPN <SP, TI> <OR, TER>

| THIS (IT) | + | - | - |
| <HERE (IT), NOW (IT)> | + | + | - |
| <HENCE (IT), HITHER (IT)> | + | + | + |

The row-column format is again the same. The items in the boxed symmetrical submatrices of (3), both elements and features, are here paired and regarded as terms, albeit the most composite ones at that. The plus signs now appear along the whole of the diagonal and completely to one side of it, just as in (13) and (14).

With the move to total pairings, the elements continue to reveal the essential unity of (1) through their ultimate inclusion of the LPN semantic feature. Collapsing of like items in (15) and (16) follows the ordered pairing of HENCE (IT) and HITHER (IT), giving us the following final compositionally derived OSE schema:

HENCE (IT) ⊤<HERE (IT), NOW (IT)> ⊤THIS (IT) (15)

HITHER (IT) ⊤<HERE (IT), NOW (IT)> ⊤THIS (IT) (16)
The sign C again denotes the operation of composition. With (22), we attain to the greatest internal ostensive semantic coherency and co-extensiveness possible for the elements of (1). Coherency here extends as well to the counter operation of decomposition. Let us now turn to it.

Decomposition of (22) in turn becomes coherent, such that we have:

\[
\langle \text{HENCE (IT)}, \text{HITHER (IT)}\rangle \circ\!
\langle \text{HERE (IT)}, \text{NOW (IT)}\rangle \circ\!
\text{THIS (IT)}\rangle
\]

\[
\langle \text{HENCE (IT)} \circ\!
\langle \text{HERE (IT)}, \text{NOW (IT)}\rangle \circ\!
\text{THIS (IT)}\rangle,
\langle \text{HITHER (IT)} \circ\!
\langle \text{HERE (IT)}, \text{NOW (IT)}\rangle \circ\!
\text{THIS (IT)}\rangle
\]

\[
\langle \text{HENCE (IT)} \circ\!
\langle \text{HERE (IT)}, \text{NOW (IT)}\rangle \circ\!
\text{THIS (IT)}\rangle,
\langle \text{HITHER (IT)} \circ\!
\langle \text{HERE (IT)}, \text{NOW (IT)}\rangle \circ\!
\text{THIS (IT)}\rangle
\]
Schema (22ii), the initial decompositional format of (22i), is in reality a composite of (17i) and (18i), this being noted at the left-hand margin. The latter thus stand interrelated under the final pairing of HENCE (IT) and HITHER (IT) in (22). Schema (22iii) corresponds then to a composite schema, relating (17ii) and (18ii), while (22iv) is a composite representation of (17iii) and (18iii). The composite schemata of (17) and (18) corresponding to the various decompositional schemata of (22) are indicated, as noted above, in the left-hand margin.

We can now propose the most complex coherent ostensive composition-decomposition hierarchical system, representing the complete internally structured intracategoricity of (1). Here we have:

OSE-LEVEL III

\[
\begin{align*}
&\langle \langle \text{HENCE (IT)}^{iii} \mapsto \text{HERE (IT)}^{ii} \mapsto \text{THIS (IT)}^{i} \rangle, \\
&\text{HENCE (IT)}^{iii} \mapsto \text{NOW (IT)}^{ii} \mapsto \text{THIS (IT)}^{i} \rangle^{3} \mapsto \\
&\langle \text{HERE (IT)} \mapsto \text{THIS (IT)} \rangle, \\
&\text{NOW (IT)} \mapsto \text{THIS (IT)} \rangle^{2} \mapsto \\
&\text{THIS (IT)}^{1} \rangle, \\
&\langle \langle \text{HITHER (IT)}^{iii} \mapsto \text{HERE (IT)}^{ii} \mapsto \text{THIS (IT)}^{i} \rangle, \\
&\text{HITHER (IT)}^{iii} \mapsto \text{NOW (IT)}^{ii} \mapsto \text{THIS (IT)}^{i} \rangle^{3} \mapsto \\
&\langle \text{HERE (IT)} \mapsto \text{THIS (IT)} \rangle, \\
&\text{NOW (IT)} \mapsto \text{THIS (IT)} \rangle^{2} \mapsto \\
&\text{THIS (IT)}^{1} \rangle^{III} \mapsto
\end{align*}
\]

OSE-LEVEL II

\[
\langle \langle \text{HERE (IT)} \mapsto \text{THIS (IT)} \rangle, \langle \text{NOW (IT)} \mapsto \text{THIS (IT)} \rangle^{II} \mapsto
\]

OSE-LEVEL I

\[
\langle \text{THIS (IT)}^{I} \rangle
\]

Schema (23) reveals the tripartite structured whole underlying the category of the indexical symbol as represented by the items of (1). Its coherency is expressed in OSE rules, its complexity is reflected in the THIS (IT) singlets and their interrelatedness within and across OSE-levels.

The category so internally complexified is essentially a generative scheme. Beginning with the core semantic THIS (IT), it is possible to decompose it into its various OSE-levels, raising it in the process to a semantics equivalent to its former implicans, again within and across OSE-levels, so
that ostensive semantic entailment transforms to ostensive semantic equivalence (OSEQ) on the various levels. (For a detailed explanation of the generative scheme, see the section on natural language in Research 1970/1971: Annual Progress Report, School of Information Science, Georgia Institute of Technology.)

Primitive Propositional Schemata. We propose the following two primitive propositional schemata:

\[ \text{THIS (IT) IS THIS (IT)} \] \hspace{1cm} (24)

and

\[ \text{THIS (IT) IS NOT THIS (IT)} \] \hspace{1cm} (25)

with (24) the positive identity schema, (25) its negation. Schema (24) results from an attempt to ostend with an ever-decreasing time \((t)\) modulus between ostensions. An ostensive stutter string is thus initially obtained, having the form

\[ \ldots, \text{THIS (i)}_{t_1}, \text{THIS (i)}_{t_2}, \text{THIS (i)}_{t_3}, \ldots, \]

which transforms to a serial identity of the form

\[ \ldots \text{THIS (i)}_{t_3} \text{ IS THIS (i)}_{t_2} \text{ IS THIS (i)}_{t_1} \ldots \]

Identity abstracted and generalized gives us (24). Any two such identity lines that do not merge (that is, that cannot be set in a one-to-one ostensive correspondence) transform to (25). Interestingly, in the transformation (25) we witness the collapse of the respective identities to terms in the negation:

\[ \text{THIS (i) IS THIS (i)} \rightarrow \text{THIS (i) IS NOT THIS (j)} \hspace{1cm} (26) \]

\[ \text{THIS (j) IS THIS (j)} \]

awaiting expansion in accordion-like fashion, if necessary. For example, one might imagine \(\text{THIS (i) WHICH (i) IS THIS (i) IS NOT THIS (j) WHICH (j) IS THIS (j)}\).

Given the negation schema of (26), it is now possible to complexify the second \(\text{THIS (IT)}\) element according to the potential generative scheme inherent in (23).

The German Adverbs "immer," "wieder," "oft." The development of the notion of the ostensive stutter string identity prompted an awareness on our part of the operation of memory in language creation. This led us to a study of the German adverbs \(\text{immer, wieder, oft}\) in their role as "memory-identity" markers. (For our interest in German adverbs, see the section entitled
"On the German Locative" in Research 1969/1970: Annual Progress Report, School of Information and Computer Science, Georgia Institute of Technology.) These adverbs indicate that language has a way of demonstrating and symbolizing the operation of man's memory as it manifests itself in his recording of states of affairs he perceives occurring in time and in some measure recognizable as identical. Such adverbs presuppose man's being able to store in memory the symbolic representation of events, to recall them when prompted and to judge them identical in some acceptable way to events that are presently occurring. Thus, one cannot think of these adverbs as time specifiers internal to and bounding the event, but rather as identity markers of a special type.

These adverbs are extremely interesting manifestations of how language monitors and correlates past and present events. In this sense, they appear to have a strong pragmatic dimension of meaning.

Reference


An Empirical Approach to Menetic Phenomena of Natural Language

C. R. Pearson

In this project, laws concerning the meaning of words in natural language that are extant in the literature have been analyzed and systematized by using a Language For Meaning that was developed specifically for this purpose. The data and assumptions upon which these laws are founded were re-examined whenever this became necessary for analyzing the import that a given law has for developing a theory of meaning (menetic theory) of natural language; otherwise, additional analysis was deliberately held in abeyance until purported menetic theories are available for evaluating the importance of the given law. By systematizing known laws, new laws of meaning are likely to be discovered in the areas which have not been adequately investigated in the past.

An improved menetic representation for natural language words will be proposed within the framework of contemporary linguistics and especially generative semantics. This should contribute greatly to the discovery of new linguistic laws, and should also offer guidance in selecting the best possible avenues for future menetic research in the fields of linguistics and information science.

This research approaches menetic phenomena of natural language as an empirical science and attempts to evaluate the bounds placed on a satisfactory theory by the empirical laws of meaning for individual words which the theory is intended to explain and by the philosophic requirement determined by our conventions about what we mean by explanation and how we go about it.

The first part of our research is concerned with the empirical and philosophic requirements for a theory of meaning for natural language, and is an evaluation of the empirical data found in the literature. A language for talking about menetic phenomena has been developed, using a methodology derived from the *Meaning of Meaning* by Ogden and Richards. In this part of the research we catalog the principal senses of the word "meaning," and develop the notion of "symbol" which forms a base of the language of meaning. The important observation is also made that the eight senses of "meaning" bear a remarkable similarity to the eight components of a symbol. Further, eight dimensions of symbolic term processes are distinguished, and language itself is defined.

This language is then used to analyze the many menetic laws that have been observed. These have never been cataloged before and so this in itself is a vital contribution to menetic theory. In the philosophy of scientific methodology, the role of laws is clearly seen to determine the design of theory. For this reason it is rather remarkable that these laws have never been assembled in one list before. No claim of completeness can be made. The list developed in this project can only be a beginning of what is in itself a gargantuan task.
The laws have also been analyzed for their validity, and the data on which they are based were examined. An attempt has been made to place them in logical relationship with the other laws, and the implication of each law for menetic theory has been assessed.

One of our principal conclusions is that menetic theory must predict eight components of word meaning. Several relationships between these components are determined by menetic laws found in the literature, but it is apparent that many more relationships exist, and there should be laws governing these as well. With this different viewpoint, we will take a new look at menetic data and attempt to discover and formulate what are thought to be some of the additional regularities not mentioned in the literature.

Finally, the questions of menetic representation for linguistics and the internal structure of symbolic themes in semiotics will be analyzed.

References
Q-parser is a program for parsing English sentences using the so-called Q-graph described previously in [2,3,4].

Originally, the Q-graph was regarded as a finite graph; the most recent development, however, has been the transformation of the Q-graph into a recursive graph. By virtue of this development three features have been added to the characteristics of the Q-parser: (1) the parser directly reflects the recursive character of English sentences; (2) the number of nodes in the Q-graph has been kept small; and (3) the flexibility of the parser has been increased in that manipulation of the grammatical rules can be made by changing the configuration of the Q-graph.

Following is an example of recursion of the noun phrase in the case where a prepositional phrase is the noun modifier. Symbol NP is used for a subgraph of the Q-parser for a complete noun phrase. Symbol NP_s is used for a simple noun phrase that does not contain any prepositional phrase PP. Connector (a) is the parser's alternative for the case where PP does not follow NP_s. Thus, noun phrase

\[ + NP \to \Xi \to NP_s \to PP \]

(1)

where

\[ + PP \to \Xi \to \text{preposition} \to NP_s \]

(2)

from where

\[ + NP \to \Xi \to NP_s \to \text{preposition} \to NP_s \]

(3)

Structure NP_s (simple noun phrase) is contained twice in NP, yet in the Q-parser there is only one structure NP_s that is used recursively (as the need occurs and as many times as necessary).

The flexibility of the Q-parser derives from the fact that all parsing rules are contained in the Q-graph. The same program that parses the sentence compares lexical classes of the words (and possible functional classes derived from the lexical classes before parsing begins) with the nodes of the Q-graph in search of a match. If a match is found between the class of the node of the Q-graph and one of the anticipated classes of the word, then the next node (and the next word) are compared. If no match can be found, an alternative word class is tried for both the previous word and the graph-node.

Because it is graph-independent, the program does not interfere with the rules of the grammar. Therefore, incorporation of strings other than English sentences or phrases is possible by augmenting the Q-graph. The
Q-graph thus allows the parsing of sentences used in various areas of science and various cultural environments.

Following is an illustration of the use of the program for parsing English sentences used in the area of Boolean algebra. Consider for example the sentence:

"Expression \( f \equiv x_1 + x_2x_3 \) is a good example of an expression containing prime implicants only." (4)

In our last report we showed the subgraph that parses Boolean expressions [6]. If the subgraph is used as a part of the Q-graph, the use of the Q-parser is extended to the area of Boolean expressions embedded in natural language [7].

Since the Q-graph is input data for the Q-parser program, the modification of the Q-graph (augmentation, reduction, etc.) does not affect the program. It is the user that controls the grammar of the parser, directing the grammar toward his particular needs.

The output of the Q-parser has been augmented by a transformation which, using the features of recursive subgraphs, transforms the sentence into tree structures. The current program prepares a sentence diagram for later text structuring purposes.

The above sentence (5) would be outputted as the syntactic pair structure shown in Fig. 1.

---

Fig. 1 thus shows an example of mixed grammars: an English sentence which embeds a Boolean expression. (The syntactic pair structure in Fig. 1 has been modified so that it can be used as a substructure of the syntactic structure of a whole text. It therefore differs slightly from a classical syntactic pair structure.)
Since the Q-parser also outputs alternative parsings in the case of an ambiguous sentence, more tree structures are also outputted.

The program for the Q-parser has been completed, along with appropriate program documentation. In addition, the output of the syntactic pair structure is currently being tested.

Class Transformation Problems in Text Structuring. Text structuring is a process that transforms a given text from its linear string form into a structural form. Among the possible structures which can result from the structuring process is a form called the syntactic structure of the text. It is a structure in which intrasentence relations IR are given by syntactic pair structure and in which the extrasentence relations ER are given by a referential mechanism that can be described by a context-independent rule.

Examples of simple ER are:

1. Repetition of the word:
   "The brown table in my room. . . . The table is old."

2. Use of a pronoun:
   "The brown table in my room. . . . It is an old piece."

The situation becomes more complex when reference is made to other classes than the class "noun." Pronominalisation is a transformation that provides a grammatical vehicle for references that require noun form, where the referrand is not a noun. For example: "Eva talked so much. Her talkativeness was . . . ."

If ER references are to be represented as structural relations, it is necessary to be aware of the transformations of the functional classes. There is a need for transformational mechanisms from any class to any other functional class, such as for example noun ↔ adjective, noun ↔ verb, etc. There are indeed transformations that are used less frequently. For example it is possible to talk about "the book on [preposition] the table" or about "the preposition on" [transformed into the noun class as the name of a preposition] or about "the on-ness [nominalized preposition on] of the preposition on" (whatever that means).

An example of the adjective ↔ noun transformation is the following two-sentence text called structure S:

"Matrix M is called incidence matrix. The incidence is the result of operation OP."

Fig. 2 shows the syntactic structures of both sentences. The double line shows the extrasentence relation given by the same "deep structure" meaning that has been surfaced in this case as an adjective in one sentence and as a noun in the other one.
It is important to know the class of "incidence" in the structure S: Thus, if structure S is to be transformed into one sentence such that A in sentence SA is to be substituted by B from SB, then B has to be adjectivalized since it is to be substituted for an adjective. "Incidence" as a noun is the same string as "incidence" as an adjective. However, SB forms an equivalence between "incidence" as a noun and the noun-phrase on the right side: incidence $\equiv$ result of operation OP. The noun phrase "result of operation OP," if adjectivalized, must form a different string. Since it contains a noun modifier (i.e., "of operation OP") it cannot be used in front of the modified noun as was the case of the adjective "incidence" formed from a single word.

An acceptable form is the relative clause:

"... that is the result of operation OP"

which can be used as adjectival:

"matrix M is the name of the matrix that is the result of operation OP."

Let ADJ$_1$ be an adjectival and N$_1$(ADJ$_1$) be the noun form of ADJ$_1$. Then the substitution for ADJ$_1$ by N$_1$(ADJ$_1$) transforms the string

$$\rightarrow \text{ADJ}_1 \rightarrow \text{N} \rightarrow \text{rest of sentence}$$

into the string

$$\rightarrow \text{N} \rightarrow \text{that} \rightarrow \text{N}_1(\text{ADJ}_1) \rightarrow \text{rest of sentence}$$

(with proper transformation of the nominalized verb of the substitutend); for example:
"The red \( (ADJ_1) \) house \( (N) \) is expensive" (compare with 5).

"Red" (noun) means to have a color with short wave length \((N_1(ADJ_1) = \text{substitutend})\) (7)

where according to (6) there is

"The house \( (N) \) + that + "has a color with short wave length \((N_1(ADJ_1))\)" + is expensive. \( (8) \)

Though the explanation of what "red" means is given as "noun" described by "noun phrase" (7), the transformation noun + adjectival (achieved by relative clause) allowed the surfacing of the description of "red" in adjectival form and its substitution for the adjective "red."

The following theorem is a basic theorem for both the creation and use of the syntactical structures of a text. (Others have also been under investigation.)

**Def. 1** (Preservation of syntactic structure by substitution). Syntactical structure of a sentence is said to be preserved by substitution \( T \) iff \( T \) does not change the structure of the rest of the sentence and the substituend has the same relation to the sentence as was the relation of the substituee.

**Def. 2** (Zero semantic substitution). Substitution \( T \) is said to be zero semantic substitution if \( T \) preserves (Def. 1) the structure of the sentence \( S \) and the substituend is pronounced to be semantically equivalent with the substituee.

Examples of zero-semantic substitution would be substituting a name by its definition or giving a name to an object described by a noun-phrase of \( S \) and substituting the name for it. Also, many examples can be found in so-called ad hoc agreements between speaker and listener.

**Substitutional Theorem (Form 1).** To preserve syntactical structure of the sentence any substituend must have the same functional class as the substituee.

**Another Form of the Substitutional Theorem (Form 2).** To preserve the meaning and proper grammatical form of a sentence, any substituend must assume the functional class of the substituee.

Form 2 is a necessary condition for zero-semantic substitution. To become zero-semantic substitution the interchanged elements must be still semantically equivalent (Def. 2).
Rephrasing of a Given Text. After a syntactical structure of the text has been created, with respect to both IS and RS, the text can be rephrased by different parsings of the structure into trees that can be converted back into strings called sentences.

The class transformation problem which remains to be solved is that which exists when the parsing of the structure requires a change of class due to the rigid syntactical rules for formation of a single sentence. It has been shown in the previous section that under certain conditions a need for the transformation of the functional class occurs—when for example two sentences are joined into one sentence (e.g., (5,6,7)).

Planned Continuation of the Research. Given the syntactical structure of a text, our interest has been focused [1] and will remain focused in the future on the problem of finding rules and formulating theorems that govern such parsings of the text structure in order to allow the rephrasing of the whole text, so that it will in turn be possible to derive different sentences with extrasentential references different than in the original text while the content of the original text will be maximally preserved.

References
Computer Model of Concept-Based Grammar

D. E. Rogers, R. vanWolkenten, T. V. Gayle

The purpose of this project has been to provide insight towards synthesis (e.g., indexing and automatic abstracting) of information in natural language form. A concept-based grammar can be considered to begin with either (a) all semantics applicable to the expression to be generated or (b) only some minimum amount of semantics, the remainder being specified by the choice of rules to be applied. The rules are of two types, conditionals, which test the state of a given data element for the selection of a set of rules, and imperatives, which transform a data element.

The following specify the data elements considered by the rules:

**Primitives:**

- **T** = set of terminal characters.
- **N** = set of nonterminal characters.
- **Names** = categories to which strings of characters or sets of strings of characters may belong.
- **Concepts** = senses which can be associated with strings of characters or sets of strings of characters.

**Atom:**

An atom of the grammar is an ordered triple \([A, B, C]\), where

- \(A \in (T \cup N)^*\).
- \(B = a \text{ set of names which apply to } A \text{ before the application of any rules of the grammar.}\)
- \(C = a \text{ set, possibly null, of concepts which apply to } A \text{ before the application of any rules of the grammar.}\)

**Primitive Item:** A primitive item of the grammar is an ordered triple \([A, B, C]\) where \([A, B, C]\) is an atom or

- \(A \in (T \cup N)^*\).
- \(B = a \text{ set of names.}\)
- \(C = a \text{ set of concepts.}\)

**Item:** An item of the grammar is an ordered triple \([A, B, C]\), where

- \([A, B, C]\) = a primitive item or
- \(A \in \{\text{items}\}^*\)
- \(B = a \text{ set of names.}\)
- \(C = a \text{ set of senses.}\)

Both of these grammars dealt with roles, analogous to the "deep-structure" cases exemplified today in the work of Fillmore [2]. Study of cases as
discussed by Panini and of English word-formation as presented by Bloomfield provided further insights into a particular category of devices operating to connect sentences in texts. Words in this category we have called, for lack of a better term, metawords. These are words such as "process," "method," "duration," etc., which are generally excluded from consideration in machine analyses because they are not indicative of content. Our most recent investigations have aimed to show, though, that these words are indicative of the roles in which topics discussed by a document are being considered. And, moreover, when retrieval is based on both topic and role, greater relevancy should be expected.

Roles are marked primarily by the grammatical structure of the linguistic expressions, as when we distinguish agent, object, or instrument in terms of the structure of the sentence. Fillmore [2] discusses this aspect of grammatical structure in some detail. Thus, for example, in "yesterday, John hit the nail with the hammer," "with" marks the instrumental case while grammatical structure marks the agent, object, and temporal cases, or roles. But, such roles can be marked explicitly, as well, through the use of metawords including "agent," "object," "use," etc. Thus, we could say: "An act was performed by John. This was the hitting of the nail. John used a hammer. The time of the act was yesterday." Here, it can hardly be said that the grammatical structure and function words indicate the roles of agent, instrument, and the time of the activity "hit," yet these roles are clearly specified. "Act" marks the action and alerts the reader to the possibility of entities being described which fall into the roles associated with actions. "Performed by" is a metaword identifying agent and relating it to the action. "Used" is a metaword marking instrument. And "time" obviously marks the temporal slot.

No one would use such a cumbersome method to express the simple proposition of this example. However, as we shall see in the analyzed text below, when the action being described is complex, involving many component actions, each with different agents, different objects, etc. and each fulfills a different role with respect to the action or situation being described, then the use of a single sentence is at least inconvenient. Add a desire to make some additional comments about each of the components, and the grammatical structure of a single sentence becomes practically inadequate. Instead, we use many sentences and metawords to mark the roles of the entities in the situation being described.

Initial investigation has indicated the categories and roles shown in Table 1 to be frequently referred to through the use of the metawords shown or through grammatical structure. The table is not supposed to be complete, merely representative.

The names of the divisions are, of course, metawords themselves. It can be seen that there are two main classifications, entities and activities. Within entities we distinguish different kinds of things that can be talked about as distinct elements such as count entities, mass entities, situations, propositions, etc. Within activities, we distinguish the roles involved such
| **Activities** | procedure, study, experiment, event, method |
| **Action:** | conduct, do, act, produce, make, create, examine, study, prepare, form |
| **Role:** | |
| **Actors:** | |
| **Instigator:** | author, causer |
| **Agent:** | doer |
| **Beneficiary:** | |
| **Object:** | |
| **Instrument:** | use, aid, method, employ |
| **Location:** | area, place, locale |
| **Goal:** | objective, purpose |
| **Result:** | outcome, product, effect |
| **Time:** | |
| **Duration:** | during, while |
| **Cause:** | reason, be due to, be responsible for |
| **Obstacle:** | interfere |
| **Anti-obstacle:** | over-come, support, depend, protect |

| **Entities:** | |
| **Abstract:** | concept, entity |
| **Count:** | thing, object, number, individual, group, flock, herd |
| **Mass:** | substance, material |
| **Measure:** | rate, prevalence, quantity, variance, trend, amount, value |
| **Relation:** | |
| **Activity:** | (see above) |
| **Proposition:** | fact, case |
| **Situation:** | story, event, experiment, study, experience, program |
Table 2

LOWRY'S METHOD:

P1, S1: entity: activity
  instrument of activity: determine
  object: protein

P4, S6: instrument of activity: estimate
  object: protein

PROTEIN:

P1, S1: object of activity:
  instrument: determine
  Lowry's method

P1, S4: object of activity:
  agent or instrument: protect
  sulfhydryl reagents, especially dithio-erythritol and 2-mercaptoethanol

P3, S5: object of activity:
  unspecified role: test
  sodium hydroxide concentration

P4, S1: instigator of result:
  that similar to visible absorption
  spectrum

P4, S6: object of activity:
  instrument: estimate
  Lowry's method

P4, S8: object of activity:
  increase

P4, S10: agent or object of activity:
  precipitate

P5, S5: agent of activity:
  object: produce
  absorption spectrum

P6, S1: object of activity:
  instrument: estimate
  Lowry's method

P8, S1: object of activity:
  instrument: determine
  Lowry's method
  sulfhydryl, disulfide reagents, and potassium ions
Table 2. Continued

SULFHYDRYL:

P1, S3: agent of activity: produce
object: interferences

P1, S4: agent or instrument of activity: protect
object: sulfhydryl groups of proteins
object of activity: protect

P4, P-title: agent of activity: interfere

P5, S2: entity: situation

P5, S4: object of activity: show effect
agent: tartrate

P5, S5: agent of activity: give
object: color

P8, S1: agent of activity: interfere
activity is obstacle to activity: determine
object: protein
instrument: Lowry's method

P8, S3: agent of activity: yield
object: color
### Table 2. Continued

**DISULFIDE:**

<table>
<thead>
<tr>
<th>P1, S3: agent of activity:</th>
<th>produce interferences</th>
</tr>
</thead>
<tbody>
<tr>
<td>object:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P4, P-title: agent of activity:</th>
<th>interfere</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>P5, S3: Accompaniment of activity:</th>
<th>appear interfere</th>
</tr>
</thead>
<tbody>
<tr>
<td>or agent or instrument of activity:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P5, S4: object of activity:</th>
<th>show effect tartrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>agent:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P5, S5: agent of activity:</th>
<th>give color</th>
</tr>
</thead>
<tbody>
<tr>
<td>object:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P8, S1: agent of activity:</th>
<th>activity is obstacle to activity: determine protein Lowry's method</th>
</tr>
</thead>
<tbody>
<tr>
<td>activity is obstacle to activity:</td>
<td>determine protein Lowry's method</td>
</tr>
<tr>
<td>object:</td>
<td>object: instrument:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P8, S3: agent of activity:</th>
<th>yield color</th>
</tr>
</thead>
<tbody>
<tr>
<td>object:</td>
<td></td>
</tr>
</tbody>
</table>

**POTASSIUM:**

<table>
<thead>
<tr>
<th>P1, S3: agent of activity:</th>
<th>produce interferences</th>
</tr>
</thead>
<tbody>
<tr>
<td>object:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P1, S5: instrument of activity:</th>
<th>develop column chromatography</th>
</tr>
</thead>
<tbody>
<tr>
<td>object:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P6, P-title: agent of activity:</th>
<th>interfere</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>P6, S1: location of activity:</th>
<th>estimate protein Lowry's method</th>
</tr>
</thead>
<tbody>
<tr>
<td>object:</td>
<td>instrument:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P6, S2: agent of activity:</th>
<th>be responsible for interference</th>
</tr>
</thead>
<tbody>
<tr>
<td>object:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P6, S4: agent of activity:</th>
<th>interfere</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>P6, S5: location of activity:</th>
<th>determine</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>P8, S1: agent of activity:</th>
<th>interfere</th>
</tr>
</thead>
</table>

| P8, S1: activity is obstacle to activity: determine protein Lowry's method |
|-----------------------------------------------|------------------|
| activity is obstacle to activity: determine protein Lowry's method |
| object: instrument: |

<table>
<thead>
<tr>
<th>P8, S5: agent of activity:</th>
<th>produce a white precipitate</th>
</tr>
</thead>
<tbody>
<tr>
<td>object:</td>
<td></td>
</tr>
</tbody>
</table>
as instigator, agent, object, obstacle, etc. It is possible that a third category should be represented, that of relations. They seem to be on a par with both activities and entities, and the roles involved cannot be easily associated with those of activities. But there seem to be few metawords to identify those roles.

We next wanted to consider two questions. First is whether, given some indexing terms, we can find in the text marks, including grammatical structure and metawords, which will categorize the roles in which those index terms occur. Where appropriate, we will be considering those roles which are in relation to roles of other indexing terms; roles associated with the category entities will not be so restricted. Second, we want to consider whether the determination of such roles can contribute to greater precision in document retrieval. As an illustration, we analyzed an article which appeared in Analytical Biochemistry, "Interferences by Sulfhydryl, Disulfide Reagents, and Potassium Ions on Protein Determination by Lowry's Method" [6].

Since many indexing systems are based on title alone, and in view of the fact that the title of this article is particularly representative of its content, we took as index terms the following words and phrases from the title: "sulfhydryl," "disulfide," "potassium," "protein," and "Lowry's method." In fact, "reagents," "interferences," and "determination" may also occur in some indexes of the article, e.g., the B.A.S.I.C. index of the Biological Abstracts. However, it is anticipated that such terms would generally be dropped in any index system based on document (as opposed to title) analysis. Moreover, the title would not be expected to mark the roles of the indexing terms. For example, the article might have been entitled "Sulfhydryl, Disulfide Reagents, and Potassium Ions and Protein Determination by Lowry's Method."

The procedure that was used is as follows. Given an occurrence of an index term in the document, its environment was examined to determine what roles were assigned to that index term by grammatical structures and/or metawords. At the same time, other roles and index terms associated with that occurrence were recorded. The result of this analysis is given in Table 2.

As an illustration of how some of these results were obtained, let us consider the index term "Lowry's method." There are four occurrences of the index term in the document. To begin with, we observed that insofar as the index term includes a metaword, "method," we can immediately identify it in every occurrence both as an instrument in some activity and as an activity itself. We make use of an additional convention, that is to say in that the index term occurs as an argument in a relation as opposed to its occurring in a role of some activity, we say that it is identified as an entity in the indicated category. In this case, it is identified as an entity which is a procedure, i.e., in the category activity, as in sentence 1 of paragraph 1 "Lowry's method for protein determination is a routine procedure . . ." So that now we have that "Lowry's method" is an activity, it is an instrument with respect to some other activity, and, moreover, that it is identified in
the document as an entity which is an activity. We can say, as well, that because of the occurrence of the index term in the nominal phrase "Lowry's method for protein determination," that it is the instrument of the activity "determine" whose object is "protein."

The second occurrence of the index term "Lowry's method" is in sentence 6 of paragraph 4, "... did not permit the estimation of proteins by the Lowry method." There we have, through the grammatical structure of the sentence and through the fact that "method" identifies instrument, that "Lowry's method" is an instrument in the activity "estimate," the object of which is "proteins."

As a further illustration, we can consider occurrences of "protein." It also occurs in the first sentence of the document in conjunction with "Lowry's method," wherein it acts as an object of the activity "determine," the instrument being "Lowry's method." But, in other occurrences of "protein," we find that its role is not pertinent to the central theme of the document. Thus, for example, in sentence 6 of paragraph 4, "... did not permit the estimation of proteins by the Lowry method," "protein" occurs either as the agent or the object (the ambiguity resulting from the use of "of") of the activity "precipitate." However, this is not directly related to any of the other index terms.

From the information tabulated in Table 2, we obtain the information of Table 3 by considering first those occurrences of index terms in roles related to roles of other index terms and second those occurrences of index terms in which they are marked as entities. Other occurrences are ignored.

For example, let us consider the index term "protein." In Table 2 we see that it occurs in paragraph 1, sentence 1 as the object of an activity whose instrument is another index term, "Lowry's method." We therefore include it in Table 3, indicating only the index term "protein," the role object of the activity "determine." Since "Lowry's method" will be tabulated in Table 3 on the basis of its own occurrences, it will not be included here. In paragraph 1, sentence 4 "protein" occurs as object of an activity "protect." We have as agent or instrument "sulfhydryl reagents." Therefore, since "sulfhydryl" is an index term, this occurrence of "protein" is included in Table 3. Since the role is the same we merely add the new activity "protect" under "protein." In paragraph 3, sentence 5 "protein" occurs as object of an activity "test." However, in this case there is no other role specified which includes other index terms. Therefore we ignore this occurrence. In paragraph 4, sentence 1 "protein" occurs as an instigator of a result "that" which has the relation "similar to" to "visible absorption spectrum." However, again, there is not the occurrence of another index term. Therefore, this occurrence of "protein" is ignored. In paragraph 4, sentence 6 "protein" occurs as the object of the activity "estimate" with the instrument "Lowry's method," an index term. Therefore we add this new activity "estimate" to Table 3 under "protein." The remaining occurrences of protein in the discourse provide no new information in that all the activities are the same or else they do not involve roles in which other index terms occur.
Table 3

<table>
<thead>
<tr>
<th>LOWRY'S METHOD:</th>
<th>entity: activity</th>
<th>instrument of activity:</th>
<th>determine</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROTEIN:</td>
<td>object of activity:</td>
<td></td>
<td>determine</td>
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<td></td>
<td></td>
<td></td>
<td>protect</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>estimate</td>
</tr>
<tr>
<td>SULPHHYDYL:</td>
<td>agent or instrument of activity:</td>
<td>protect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>entity: situation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>obstacle to activity:</td>
<td></td>
<td>determine</td>
</tr>
<tr>
<td>DISULFIDE:</td>
<td>obstacle to activity:</td>
<td></td>
<td>determine</td>
</tr>
<tr>
<td>POTASSIUM:</td>
<td>location of activity:</td>
<td></td>
<td>estimate</td>
</tr>
<tr>
<td></td>
<td>obstacle to activity:</td>
<td></td>
<td>determine</td>
</tr>
</tbody>
</table>
Table 3 provides an unusually consistent statement of the content of the
document in that by considering the 'intersection' of activities to which
the various index terms are related we get only "determine." Based on the
roles expressed, we obtain "interferences of sulphydryl, disulfide, and
potassium in determination of protein by Lowry's method," which gives
virtually the same relationships among the index terms as did the original
title.

The above discussion strongly indicates that, given index terms, roles can
be identified. The degree to which equally meaningful results can be
obtained consistently is not clear; the selected article did have several
good features from the point of view of this approach.

The effective use of Table 3 for retrieval will depend on the user's ability
to identify the role or roles as well as the topics he is interested in.
Some examples will illustrate possible interactions. First, we can assume
the user desires information on protein determination and that he has no
specific methodology in mind. For such a query, we would suggest that he
enter the retrieval system seeking "protein" marked as an entity and object
of activity "determine" (or synonym). Moreover, if the index system permits
it, we would seek "determine" marked as an entity of type activity. The
justification for this is that for an article to properly discuss the deter-
mination of protein it should discuss the properties of proteins. Thus, one
expects to find occurrences of "protein" in sentences such as "Since protein
is a such-and-such group, . . ." whereby it would be marked as an entity.
At the same time, we want a document which talks about the entity, the
activity "determine." Given such a query then, the article analyzed here
would not be retrieved--at least with the expectation of being highly
relevant--since the index terms do not occur in the appropriate roles.

For a second example, let us consider a user who is interested in learning
something about "Lowry's method." In this case the query would be repre-
sented by the index term "Lowry's method" in the role entity. Because
"method" is a metaword which marks both activity and instrument of an activ-
ity, we expect to find all occurrences of "Lowry's method" related to some
other activity. In particular, this article could be retrieved on the basis
of "Lowry's method" marked as an entity in Table 3. However, because other
roles are marked and filed by index terms for this article with respect to
the other activity and they are not filed for the query, we may anticipate
that it might be too specific for this query.

However, as a third example, if the searcher were interested in "substances
which interfered in Lowry's method," we would expect this article to be
extremely relevant in that (1) it deals with "Lowry's method" and (2) the
role obstacle of an activity, in which "Lowry's method" is used, is filed.
Correspondingly, if the user were specifically interested in "sulphydryl
reagents," "disulfide reagents," or "potassium ions" in relationship to
"Lowry's method" or "protein determination," there would be no question in
retrieving this article.
We have assumed throughout this discussion that the method of selecting the indexing terms is known. However, given such indexing terms, an analysis is possible which will explicitly show the relationships expressed between such indexing terms in the document. Moreover, given knowledge of such roles and their relationships, greater precision is possible.

Summary of Planned Continuation of Research. Clearly, the analysis performed above is in no sense a product of a well-specified set of rules. Further research is needed in three areas: (1) the determination in greater detail of the roles, or meta-categories, that exist and the relationships that exist among them; (2) the more complete investigation of the ways in which these relationships are marked in text; and (3) the precise determination of how knowledge of these roles can be combined with content indicators such as index terms to improve precision in retrieval. Further research is needed into concept-based grammars in order to explore and appreciate more fully problems in representation of natural language in formal systems, as, for example, in the work on the translation of English text into the lower predicate calculus with additions, described elsewhere in this Annual Report.

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Abstract Digital Computers

L. Chiaraviglio, J. R. Horgan, R. C. Roehrkeasse

The central problem of this project has been to articulate a mathematical model of digital computers and to study the principal properties of these machines and their processes in a precise algebraic setting. We envisage this to be the core task of a unified theory of computation that is capable of dealing with the concrete modern paradigm of computation. The accomplishment of this task contributes to the stated general objectives by providing an encompassing theory to cover the present and ever-increasing range of information phenomena that are the manifestation of our expanding use of digital computers.

Work prior to 1971 characterized an abstract digital computer as an algebra and investigated its theory of morphisms and representation. The details of this work may be found in [3].

The results obtained in this project during the year 1971/72 fall into two groups:

a. The extant theory of recognizers (automata) has been embedded in the algebraic theory of abstract digital computers. For each class of automata in the hierarchy of recognizers (finite state, pushdown store, linear bounded Turing machines, and their non-deterministic counterparts) an abstract digital computer has been constructed which captures all the computations of the machines in the class up to changes of state, head positions and tapes. Abstract digital computers are algebras and it has been shown that the theory of morphisms for these algebras is sufficient to recapture the hierarchy of automata.

b. The extant theory of degrees of unsolvability has been embedded in the algebraic theory of abstract digital computers. For each class of functions of a given degree an abstract digital computer has been specified which computes the function of that class. It has been shown that the theory of morphisms for these abstract computers is sufficient to recapture the hierarchy of degrees.

The mentioned results constitute a test of the adequacy of the proposed theory of abstract digital computers. The proof of the sufficiency of the theory to house the principal aspects of the extant mathematical theory of computation is evidence for the adequacy and universality of the theory.

Details of the embedding of the theory of recognizers in abstract digital computers may be found in [4,5]. Details of the embedding of the theory of degrees of unsolvability in abstract digital computers may be found in [1].

The results obtained in this project during the year 1972/1973 may be summarized as follows:
a. Automata of the hierarchy of recognizers were construed as unary algebras whose carriers are the sets of configuration and whose operators are the configuration functions. These unary algebras together with a time set that is isomorphic to the powers of the operators form autonomous discrete time systems associated with the automata. Morphisms between time systems have been shown to recapture the ordering of the hierarchy.

b. Abstract digital computers were shown to give rise to autonomous discrete time systems. The relations between automata and digital computers were exhibited through the morphisms between their respective time systems.

c. A theory of morphisms based on the time systems of digital computers was shown to entail that morphisms between abstract digital computers need not preserve the structure of the set of states of the computers that is inherited from the structure of the set of contents of its addresses. The importance of this result is that it gives a formal justification to the notion of general purpose computers.

d. The identification of the computational procedure of digital computers via their underlying isomorphic automata was shown to entail that the structure of the set of states of the digital computers is uniquely specified by their control functions.

Details of the results outlined above may be found in [6].

References


Investigations Into the Pattern Processing Capabilities of Tessellation Automata

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It has been only very recently that the theoretical areas of computer science (automata theory, computability, etc.) have been applied to real-world problems (e.g. the correctness of programs, the complexity of computations, etc.). We hope to continue this endeavor by showing how a newly emerging branch of automata theory—tessellation automata—can be applied to the area of pattern processing. We hope to gain insights into pattern recognition, pattern generation, and pattern classification through the discovery of the properties of these automata.

Through the interaction of theory and practice, new and meaningful formalisms emerge, and the present investigation is no exception. We are presently studying the properties of sequential versus parallel processing in tessellation automata, this being inspired by the articles of Rosenfield and Pfaltz on digital picture processing [7]. Our study has brought about the formulation of a new kind of tessellation automaton, what we call a mixed mode tessellation automaton. (This is a tessellation automaton capable of parallel and sequential processing. Such a machine is called a parallel (sequential) tessellation automaton when it is not capable of sequential (parallel) processing.) Our results so far concern the various properties of this machine. We have also continued our efforts in elucidating the properties of combinatory tessellation automata, which were discussed in a previous report.

In our previous research efforts, we found that all recent theoretical studies of tessellation automata have been concerned with those particular finite state automata in which the neighborhood structure is spatially independent and fixed for all time, and in which the choice of the local state transition function to be applied to a particular cell is independent of the position of that cell in the array, though it may be temporally dependent. It therefore was of interest to consider tessellation automata in which the above properties do not hold. Thus, we addressed ourselves to the question of whether any advantages and/or insights accrue from formulating a not necessarily finite state tessellation automation in which the neighborhood structure of, and the choice of the local state transition function to be applied to, a given cell at a particular time, depends on the total configuration at that time and the relative position of the cell in the array.

We answered this question in the affirmative by formulating numerous individual, locally controlled tessellation automata of this latter type, each one of which can simulate a wide class of other tessellation automata, including all those with the above uniformity properties. Thus, we found the existence of many tessellation automata, each one of which can be said to be universal with respect to a large class of other tessellation automata, including virtually all those in which previous investigators have had a theoretical interest. For these universal tessellation automata, we also demonstrated the fact
that numerous construction of initial configurations, whose evolution through
time are meant to embody some calculation or construction, can be done in an
effective manner, which is certainly not the case with those automata previ-
ously studied. Thus, instead of being given a tessellation automaton and a
procedure, and asking oneself whether the former is capable of carrying out
the latter, we have, in many cases, a method for effectively constructing an
initial configuration for one of our newly formulated tessellation automata,
whose evolution through time embodies the execution of this procedure.
Hence, these newly formulated tessellation automata are also universal in
the sense of not being procedure bound; that is, not being overly sensitive
to the type of procedure which it is to carry out. This is not to say that
previously formulated tessellation automata are all procedure bound, but
that some tessellation automata were designed to accomplish one task—such
as the reproduction of patterns—and that it is not clear what else they can
do.

During the past year we have accomplished the following:

a. Demonstrated that any mixed mode tessellation automaton can be
simulated by a sequential tessellation automaton.

b. Exhibited a sufficient condition for any mixed mode tessellation
automaton to be capable of being simulated by a parallel tessellation
automaton.

c. Defined the notion of strict equivalence between parallel and se-
quential processing in a mixed mode tessellation automaton of finite extent
and exhibited a necessary condition and a sufficient condition for this
equivalence to hold. We have also exhibited a sufficient condition for this
equivalence to hold in terms of a property resembling Dijkstra's "deadly
embrace."

d. Defined the notion of weak equivalence between parallel and sequen-
tial processing in a mixed mode tessellation automaton of finite extent and
exhibited a necessary condition for this equivalence to hold.

e. Demonstrated the power of combinatory tessellation automata.

Our past year's research effort may be outlined in somewhat greater detail
as follows:

Section I: Mixed Mode Tessellation Automata. The material in this section
was influenced by Rosenfeld and Pfaltz [7], where the relationships between
sequential and parallel processing of two-dimensional pictures are examined,
each picture being represented by a finite grid, each point of which is
associated with a state. We generalize their ideas to that of a mixed mode
tessellation automaton, which differs from previously studied tessellate
automata in that the local transformations may be applied sequentially,
rather than in parallel. We then concentrate on conditions under which two
main types of mixed mode tessellation automata, namely the \textit{parallel} and \textit{sequential} tessellation automata, can simulate all the others.

\textbf{Definition 1.} For \( n \geq 1 \), an \( n \)-dimensional \textit{mixed mode tessellation automaton}, \( TA \), is a 4-tuple \(<A, Z^n, \Sigma, \Pi>\), where

1. \( A \) is a finite, non-empty set of states.
2. \( Z^n \) is the set of \( n \)-tuples of integers. For \( \xi \in Z^n \), we call \( \xi \) a cell of \( TA \). The set \( CON = \{ g | g : Z^n \rightarrow A \} \) is called the set of configurations of \( TA \).
3. \( \Sigma \) is an ordered \( r \)-tuple of elements of \( Z^n \), for some \( r \geq 1 \), and is called the \textit{neighborhood index} of \( TA \). Suppose \( \Sigma = \langle \gamma_1, \ldots, \gamma_r \rangle \). Then, for \( \xi \in Z^n \), \( \langle \xi + \gamma_1, \ldots, \xi + \gamma_r \rangle \) is called the \textit{neighborhood} of \( \xi \).
4. \( \Pi \neq \emptyset \), called the set of \textit{global array transformations}, is a finite subset of \( CON \cup CON \) which is the union of \( \Pi_p \), the set of \textit{parallel} global array transformations, and \( \Pi_s \), the set of \textit{sequential} global array transformations, defined as follows:
   a. Suppose \( \rho \in \Pi_p \) and let \( c \in CON \). Then \( \rho(c) = c' \in CON \), where, for some \( \sigma \in A^{(AP)} \), called a \textit{local transformation}, we have, for each \( \xi \in Z^n \), that \( c'(\xi) = \sigma(c(\xi + \gamma_1), \ldots, c(\xi + \gamma_r)) \). \( c' \) is called the \textit{successor configuration} of \( c \) with respect to \( \rho \). Thus, we have that the state of a cell in a successor configuration of \( c \) is a function of the states of the neighborhood of that cell in configuration \( c \).
   b. Suppose \( \rho \in \Pi_s \) and let \( c \in CON \). Then \( \rho(c) = c' \in CON \), where, for some \( \sigma \in A^{(AP)} \) and \( \tau \in (Z^n)^\omega \) for \( \tau \) 1-1 and onto, called a \textit{trajectory}, we now define \( c'(\xi) \) for \( \xi \in Z^n \):
      \[ For \ 0 \leq i \leq \tau^{-1}(\xi), \ define \ c_i^{(\xi)} \in CON \ as \ follows, \ c_0^{(\xi)} = c \]
      \[ For \ 0 \leq k \leq \tau^{-1}(\xi) - 1 \text{ and } \xi \in Z^n, \]
\[
\begin{align*}
\hat{c}_{k+1}(\xi) &= \begin{cases} 
\sigma_p\left(c_k(\xi)(\xi_1^k, \ldots, c_k(\xi)(\xi_r^k)) \right) & \text{if } \xi = \tau_p(k) \\
\hat{c}_k(\xi) & \text{otherwise}
\end{cases}
\end{align*}
\]

Then, \(c'(\xi) = c(\rho^{-1}(\xi)) \)

c' is also called the *successor configuration* of c with respect to \(\rho\). The trajectory indicates the sequential order in which we process the cells of \(\mathbb{Z}^n\), and we have that the state of a given cell in a successor configuration of c is a given cell in a successor configuration of c is a function of the states of the neighborhood of that cell in configuration \(c^*\), where \(c^*\) differs from c only in that we update the states of all cells processed before the given one.

If \(\Pi_p = \emptyset\), then TA is called a *sequential* tessellation automaton, while if \(\Pi_s = \emptyset\), then TA is called a *parallel* tessellation automaton.

We now formalize the notion of simulation of one tessellation automaton by another (see A. R. Smith (2)):

**Definition 2.** Let \(G = <A, \mathbb{Z}^n, \Sigma, \Pi>\) and \(G^* = <A^*, \mathbb{Z}^n, \Sigma^*, \Pi^*>\) be two n-dimensional mixed mode tessellation automata. For \(t, q \geq 1\), we say that \(G^*\) *simulates G in t/q times real time*, if there are effectively computable injective mappings \(\Delta: \text{CON} \rightarrow \text{CON}^*\) and \(\Gamma: \Pi^q \rightarrow \Pi^q\), such that, for any \(c \in \text{CON}\) and \(\langle \rho_1, \ldots, \rho_q \rangle \in \Pi^q\), we have,

\[\Delta(\rho_1(...(\rho_1(c))...)) = \rho_t^*(...((\rho_1^*(\Delta(c)))...),\]

where \(\langle \rho_1^*, \ldots, \rho_t^* \rangle = \Gamma(\langle \rho_1, \ldots, \rho_q \rangle)\). If \(t = q = 1\), we say that \(G^*\) simulates G in *real time*.

We now introduce another important concept.

**Definition 3.** Let \(TA = <A, \mathbb{Z}^n, <\gamma_1, \ldots, \gamma_r>, \Pi>\). Suppose \(\xi \in \mathbb{Z}^n\) and \(\rho \in \Pi_s\). We now define what we call the *type of cell \(\xi\) with respect to \(\rho\)*, denoted by type \(T_{\xi, \rho}\), as follows:
Let $\tau_\rho$ be the trajectory which determines $\rho$. Let $S_0 = \{\#\}$, and, for $i \geq 0$, let $S_{i+1} = S_i \cup S_\rho^i$. For $0 \leq j \leq \tau_\rho^{-1}(\xi)$, we define $e_j(\xi) : Z^n \to S_j$.

(Thus, $e_0(\xi)$ is the constant function which maps $Z^n$ into $\{\#\}$.) For $0 \leq k \leq \tau_\rho^{-1}(\xi) - 1$ and $\xi \in Z^n$, we define

$$e_{k+1}(\xi) = \begin{cases} 
<e_k(\xi+\gamma_1), \ldots, e_k(\xi+\gamma_r)> & \text{if } \xi = \rho(k) \\

e_k(\xi) & \text{otherwise.}
\end{cases}$$

Then, type $\epsilon_{\xi,\rho} = \frac{e(\xi)}{\rho^{-1}(\xi)}$.

(Note that type $\epsilon_{\xi,\rho} \in S_1$.) It is seen that type $\epsilon_{\xi,\rho}$ indicates in what manner the next state of cell $\xi$, with respect to the transformation $\rho$, depends on updated information. That is, it indicates whether the states of the neighborhood of $\xi$ have been updated and if so, how.

We now state the main theorems of this section.

**Theorem 1.** Let $\Sigma_{\rho} = <A, Z^n, \gamma_1, \ldots, \gamma_r, \Pi>$. For each $\rho \in \Pi_s$, suppose $|\text{type } \xi_{\rho,s} \in Z^n| < X_0$. Then there is a parallel tessellation automaton, $PTA$, which simulates $TA$ in real time.

**Theorem 2.** Let $\Sigma_{\rho} = <A, Z^n, \gamma_1, \ldots, \gamma_r, \Pi>$. Then there is a sequential tessellation automaton, $STA$, which simulates $TA$ in 2 times real time.

**Section II: Strict Equivalence of Parallel and Sequential Processing.**

Several recent research efforts are aimed at strengthening the theoretical understanding of parallel and sequential modes of picture and pattern processing. Rosenfeld and Pfaltz [7] have shown that any picture transformation that can be accomplished by a series of parallel local operations with Moore neighborhood index can also be accomplished by a series of sequential local operations with Moore neighborhood index, and conversely; but the local operations may be different for the two types of processing.

In this paper we concentrate our investigation on the equivalence of parallel and sequential local operations of arbitrary neighborhood index in arbitrary dimensions, where the local operator is the same for both modes of processing. Tessellation structure is the paradigm in which we conduct our study.
Let TS be an n-dimensional tessellation structure. Let NI, the neighborhood index of TS, be an ordered r-tuple, r ≥ 1, of elements in TS. Suppose NI = (e₁,...,e_r). Then for cell i in TS, (i+e₁,i+e₂,...,i+e_r) is called the neighborhood of i. An array of k number of cells in this n-dimensional TS will be denoted as L_n,k. For simplicity, we will consider the one-dimensional case as no generality will be lost by doing so. L₁,k will be written as L_k. For any neighborhood index, (e₁,...,e_r), a local transformation f operated on cell i has the following form:

\[ f(c(i+e₁)_t,...,c(i+e_r)_t) + c(i) \]

where \( c(i)_t \) represents the content of cell i at time t. Since we only consider those f's that take one time unit to complete the execution, we will omit the time subscript. Local operations will only be applied to the cells in L_k, but the cells outside of L_k may still be elements of the neighborhood of a cell in L_k.

**Definition 1.** Given an L_k array in one-dimensional TS, a local transformation f is said to be in sequential mode over L_k if it operates on one cell at a time in some sequence (e.g., left to right) over every cell in L_k. This sequence will be referred to as the trajectory, \( τ \), of f. Let Seq_τ(f)L_k denote the sequential mode of operating f over L_k, with respect to the trajectory \( τ \), just once.

**Definition 2.** A local transformation f is said to be in parallel mode of operation over L_k if it operates on every cell in L_k simultaneously. Par(f)L_k will denote the parallel mode of operating f over L_k once.

**Definition 3.** Let C(L_k) denote the contents of the k cells of L_k. C(L_k) is sometimes called a configuration of L_k. Given any local transformation f, Par(f) is said to be strictly equivalent to Seq_τ(f), Par(f) ≡ Seq_τ(f), iff for any C(L_k):

\[ C(Par(f)L_k) = C(Seq_τ(f)L_k) \]

**Definition 4.** Let A be the set of finite states in TS; that is, C(i), the content of cell i, ranges over A. Given any neighborhood index, (e₁,...,e_r), for cell i, a local operation f is said to be independent of the neighbor j, where \( j = i + e_k \) and \( 1 < k < r \), iff, for all a,...,a_{k-1}, a_{k+1},...,a_r ∈ A,

\[ f(a₁,...,a_{k-1},a,a_{k+1},...,a_r) = f(a₁,...,a_{k-1},a,a_{k+1},...,a_r) \]

for all \( a,\hat{a} \in A \).

This cell j is also called an independent neighbor of i with respect to the function f.
Definition 5. Let \( C(L_k)_{t_0} \) be an initial configuration of \( L_k \) at time \( t_0 \). Let \( C(L_k)_{t'} \) be the configuration of \( L_k \) at time \( t' \), \( t_0 < t' \leq t_0 + k \), which resulted from the sequential mode of processing \( f \) via trajectory \( \tau \). Let \( H \subseteq L_k \). If every cell \( i \in H \) is such that the local transformation \( f \) has been applied to it between the time \( t_0 \) and \( t' \) then \( H \) is said to have been preprocessed at time \( t' \). We will omit the time specification since it is quite obvious.

Now we will show the necessary and sufficient condition for \( \text{Par}(f) \equiv \text{Seq}_\tau(f) \). We will arbitrarily pick the trajectory \( \tau \), left-to-right, for \( \text{Seq}_\tau(f) \); the important thing is that we need to fix one specific trajectory. Remember that we are only concerned with the case where both \( \text{Seq}_\tau(f) \) and \( \text{Par}(f) \) are restricted to operating over \( L_k \) once.

**Theorem 1.** Given a local operation \( f \), \( C(L_k) \), and a fixed neighborhood index in TS, \( \text{Par}(f) \equiv \text{Seq}_\tau(f) \) if for any sequential application of \( f \) on a cell \( i \in L_k \) all the preprocessed cells included in the neighborhood of cell \( i \) are independent neighbors of cell \( i \) with respect to the operation \( f \).

**Corollary 1.** \( \text{Seq}_\tau(f) \equiv \text{Par}(f) \) for any local transformation \( f \) if the neighborhood of any cell \( i \) contains only the cell \( i \) itself.

Similarly, even if the neighborhood structure is larger than one cell but the local transformation \( f \) is such that it really depends only on the content of the cell that is being processed then we will have \( \text{Par}(f) \equiv \text{Seq}_\tau(f) \). Let us refer to \( f \)'s of this type as the pseudo-single neighbor functions or PSN functions. Any identity map for neighborhood structure of more than one cell is an example of PSN functions.

A "Mutually Destructive" Condition. We propose a special condition and illustrate it through the relationship between the trajectories of \( \text{Seq}_\tau(f) \) and the resulting instances where \( \text{Seq}_\tau(f) \equiv \text{Par}(f) \). Note that for any \( L_k \), \( k \)-finite, there exists \( k! \) trajectories for \( \text{Seq}_\tau(f) \). Out of the \( k! \) possible trajectories, if at least one trajectory can be chosen such that for each application of the local operation \( f \) on a cell \( i \), throughout \( L_k \), all the cells in the neighborhood of \( i \) are either non-preprocessed or independent of \( f \) then \( \text{Seq}_\tau(f) \equiv \text{Par}(f) \). As an example, consider the following case of a binary state alphabet one-dimensional TS with the neighborhood structure of any cell \( i \) as \( ((i-1),(i),(i+1)) \). Let the local function be defined as:

\[
\begin{align*}
f(1,0,0) & \rightarrow 1; \quad f(1,0,1) \rightarrow 1; \quad f(x,y,z) \rightarrow 0 \text{ otherwise.}
\end{align*}
\]

Choose the trajectory of \( \text{Seq}_\tau(f) \) to be the one from right to left in a consecutive order. For this
trajectory, the only preprocessed cell in the neighborhood of any cell \( i \) is cell \((i+1)\). But cell \((i+1)\) is independent of \( f \). Thus by Theorem 1 we have \( \text{Seq}_T(f) \equiv \text{Par}(f) \). The obvious question is whether we can always find such a favorable trajectory \( \tau \) for \( \text{Seq}_T(f) \).

Next we illustrate a condition where no matter which trajectory \( \tau \) is chosen for \( \text{Seq}_T(f) \), \( \text{Seq}_T(f) \) can never be made equivalent to \( \text{Par}(f) \). Again, consider the same TS as above, and define the local function \( f \) as:
\[
\begin{align*}
f(0,0,1) & \to 1; \\
f(1,0,0) & \to 4; \\
f(x,y,z) & \to 0 \text{ otherwise.}
\end{align*}
\]
Let the initial configuration \( C(L_4) \) be 1001. Everything outside of \( L_4 \) is 0's. So \( C(\text{Par}(f)L_4) = 0110 \). No matter which trajectory \( \tau \) we pick for \( \text{Seq}_T(f) \), we would have to process the two cells initially containing the zeroes in some order. However, in this case, processing any one of the two cells first will cause the content of that first processed cell to change, and thus the later processed one can never attain a 1. Therefore \( C(\text{Seq}_T(f)L_4) \neq 0110 \), and thus \( \text{Seq}_T(f) \neq \text{Par}(f) \).

The above-mentioned condition reminds one of a different, but similar, situation called the "Deadly Embrace" condition proposed by Dijkstra [2]. Since the nature of the problem here is such that processing any one of the two cells first will result in an unfavorable consequence for the latter, we will call it the "Mutually Destructive" condition. Hence if a mutually destructive condition exists, no trajectory \( \tau \) of \( \text{Seq}_T(f) \) will give us \( \text{Seq}_T(f) \equiv \text{Par}(f) \).

Given a TS and a fixed neighborhood structure certain local functions will give rise to the mutually destructive condition while other local functions will not as demonstrated above. Let us denote the class of local functions for which there exists a trajectory for \( \text{Seq}_T(f) \) such that \( \text{Seq}_T(f) \equiv \text{Par}(f) \) as the class \( \text{LF} \). Certainly, for any \( f \in \text{LF} \) the mutually destructive condition can not occur. Two earlier mentioned local functions, the constant function and the PSN functions, are obvious members of \( \text{LF} \).

Let \( N(i) \) stand for the neighborhood of cell \( i \). Then \( k \in N(i) \) will denote that cell \( k \) is in the neighborhood of cell \( i \).

**Definition 6.** Cell \( k \) is said to be a **related neighbor** of cell \( i \) iff there exists a chain of cells \( q_1, q_2, \ldots, q_n \) such that \( q_1 \in N(i), q_j \in N(q_{j-1}) \) for \( 2 < j < n \), and \( k \in N(q_n) \).

**Definition 7.** Let \( \prec \) be a precedence relation as defined by Ashour [1]. Thus \( a \prec b \) means that \( a \) is processed before \( b \).

Suppose for a given \( C(L_k) \) and a specific neighborhood structure we are told that cells \( i \) and \( j \) in \( L_k \) are such that cell \( i \) is a related neighbor of cell \( j \). This implies that there is a chain of cells \( q_1, q_2, \ldots, q_n \) such that \( q_1 \in N(j), q_m \in N(q_{m-1}) \) for \( 2 < m < n \), and \( i \in N(q_n) \). If we want the
contents of cells $i$ and $j$ after $\text{Par}(f)$ to be the same as the contents of the same two cells after $\text{Seq}_t(f)$, for any $f$, then our first attempt might result in picking a trajectory $\tau$ for $\text{Seq}_t(f)$ where the sequence of processing is $i < q_1 < q_2, \ldots, < q_n < i$. This does not guarantee our desired result, for it is possible that $i \in N(q_1), q_{m-1} \in N(q_m)$ or $q_n \in N(i)$. Thus we should pick a trajectory for $\text{Seq}_t(f)$ where no cell is a related neighbor of a cell that is to be processed after it. Now, suppose that we are further given the following conditions:

i. cell $i$ is a related neighbor of cells $q_1, q_2, \ldots, q_n, i$ but not vice versa.

ii. cell $q_m$ is a related neighbor of cells $q_{m-1}, \ldots, q_1, i$ for $1 < m \leq n$ and no cell $q_m$ is a related neighbor of any cell $q_p$ where $p > m$.

iii. cell $j$ is not a related neighbor of any of the cells $q_1, \ldots, q_n, i$.

In this case the trajectory which specified the order of processing as $i < q_1, \ldots, < q_n < i$ will guarantee that no preprocessed cell is included in the neighborhood of any cell that is being processed. Thus the resulting contents of cells $i, q_1, \ldots, q_n, i$ after $\text{Par}(f)$ will be the same as that after $\text{Seq}_t(f)$ for any $f$. A pictorial example for the two-dimensional TS is shown below.

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The neighborhood structure for cell $i$ is $\boxed{i}$. $L_{2,5}$ is specified by the cells $(2,2), (2,3), (3,3), (4,3)$ and $(4,4)$ as marked. The arrows indicate
the trajectory for \( \text{Seq}_{\tau}(f) \), and cell \((2,2)\) is a related neighbor of cell \((4,4)\).

**Theorem 3.** Given \( C(L_n,k) \) and a specific neighborhood structure. If there exist two cells \( i \) and \( j \) in \( L_n,k \) such that cell \( j \) is a related neighbor of cell \( i \) and cell \( i \) is a related neighbor of cell \( j \), then there is a possibility for the "mutually destructive" condition to occur for some \( f \).

**Theorem 4.** Given \( C(L_n,k) \) and a specific neighborhood structure, a sufficient condition for \( \text{Seq}_{\tau}(f) = \text{Par}(f) \) for any \( f \) is that there exist no two cells \( i \) and \( j \) in \( L_n,k \) such that they are related neighbors of each other.

A Weaker Relationship. Let us relax the criteria for equivalence and consider a weaker relation.

**Definition 8.** For any \( C(L_n,k) \) and a local transformation \( f \), define for \( m,n \) positive integers

\[
\text{Par}^m(f)_{L_{n,k}} = \frac{\text{Par}(f)\text{Par}(f)\ldots\text{Par}(f)}{m\text{-times}}_{L_{n,k}}
\]

\[
\text{Seq}^n(f)_{L_{n,k}} = \frac{\text{Seq}_{\tau}(f)\text{Seq}_{\tau}(f)\ldots\text{Seq}_{\tau}(f)}{n\text{-times}}_{L_{n,k}}
\]

**Definition 9.** Given a local transformation \( f \), \( \text{Par}(f) \) is said to be \( R \)-related to \( \text{Seq}_{\tau}(f) \), \( \text{Par}(f) \cap \text{Seq}_{\tau}(f) \), iff for any \( C(L_n,k) \) there exist \( m,n \) positive integers such that

\[
C(\text{Par}^m(f)_{L_{n,k}}) = C(\text{Seq}^n(f)_{L_{n,k}})
\]

We might mention that for \( m = n = 1 \), \( \text{Par}(f) \cap \text{Seq}_{\tau}(f) \) reduces to \( \text{Par}(f) \equiv \text{Seq}_{\tau}(f) \). It is easy to see that the sufficient condition for \( \text{Par}(f) \equiv \text{Seq}_{\tau}(f) \) also holds for \( \text{Par}(f) \cap \text{Seq}_{\tau}(f) \); just consider the case where \( m = n \) for \( \text{Par}(f) \cap \text{Seq}_{\tau}(f) \).

**Theorem 5.** Given a local transformation \( f \), if \( \text{Par}(f) \cap \text{Seq}_{\tau}(f) \) then if one of the \( \text{Par}(f) \) or \( \text{Seq}_{\tau}(f) \) is not one-to-one then the other can not be an identity function.

**Section III. Statement of Main Theorem on Combinatory Tessellation Automata.** The universal generalized tessellation automata we formulate in this study will be of denumerable state size, finitely variant in neighborhood structure, of
neighborhood bound 2, and neighborhood deterministic. The non-uniformities which do exist, though, are of a particularly simple kind, as will presently be made clear. The class of generalized tessellation which these belong is called the class of combinatorial generalized tessellation automata. The formulation of them utilizes various n-dimensional generalizations of pure combinatorial logic. Just as combinatorial logic can be viewed as a syntactic manipulation of strings of symbols, these generalizations of it can be viewed as a syntactic manipulation of arrays of strings of symbols. To be more specific, the state set of a combinatorial generalized tessellation automaton will consist of some subset of the well-formed formulas (wffs) of some formal system, and the transition from one configuration to another will entail the "movement" and/or "combination" of various of these wffs.

**Main Theorem.** There exists an n-dimensional generalized tessellation automaton \( G\# = <S\#, E\#, n, a\#, \beta\#> \) which is of denumerable state size, finitely variant in neighborhood structure, of neighborhood bound \( Z \), and neighborhood deterministic, and which is such that, if \( G = <S, E, n, a, \beta> \) is of countable state size, finitely variant in neighborhood structure, finitely variant with respect to transitions, of finite neighborhood bound \( \delta \), configurationally uniform in neighborhood structure, configurationally uniform with respect to transitions, and transitionally effective, then \( G\# \) simulates \( G \) in \( \delta + 3 \) real time. In addition, if \( G \) is neighborhood deterministic and transition deterministic, then \( G\# \) uniformly simulates \( G \) in \( \delta + 2 \) times real time.

**Some Properties of \( G\#:**

1. \( G\# \) is not transitionally effective.

2. \( G\# \) has no Garden-of-Eden configurations. Let \( c\# \in \text{CON}\# \). Let \( \gamma\# \in \text{INP}\# \) be such that \( \gamma\#(i) = "I" \) for all \( i \in Z^n \). Then, there is a \( c \in \text{CON}\# \), such that \( \tau_{\gamma\#}(c) = c\# \).

3. Let \( c\# \in \text{CON}\# \) be such that \( \{i|j \in Z^n \text{ and } c\#(j) \neq "I"\} \) is finite. Let \( \gamma\# \in \text{INP}\# \) be as in 2 above. Then, there is an \( m \geq 0 \) and a \( c \in \text{CON}\# \), \( \{i|j \in Z^n \text{ and } c(j) \neq "I"\} \) being a unit set, such that \( m\#(c) = c\# \).

**Future Work.** The further development of the project will require completion of the following tasks:

1. Formulate a comprehensive theory of combinatorial tessellation automata.

2. Find a necessary and sufficient condition for a mixed mode tessellation automaton to be capable of being simulated by a parallel tessellation automaton.

3. Examine other notions of equivalence between parallel and sequential processing in mixed mode tessellation automata.

4. Formulate a comprehensive theory of the "speed" of parallel versus sequential processing in mixed mode tessellation automata and eventually
expand this into a general theory of computational complexity with respect to tessellation automata.

5. Examine the notion of the convergence of patterns with respect to parallel and sequential operations in mixed mode tessellation automata.

6. Formulate other kinds of tessellation automata and examine their properties. The notion of one tessellation automaton driving another seems to be a fruitful area of research. This is where the neighborhood index and/or the local transformation of a cell of one machine depends in some way on the behavior of the other machine.

References

The object of this study has been to ascertain the fundamental logics of information processing, and the central problem countenanced is to articulate appropriate logics for the appraisal of plans and programs. The task has two principal components: first, that of ascertaining the range of processes that are the interpretation or meanings of plans or programs; second, that of ascertaining the morphology and transformational syntax of plans and programs.

The results obtained in this project during the past year may be summarized as follows:

a. The states of the universe in which plans or programs are to be interpreted are assignments of variables to entities in the domains of the referential interpretations of the goal languages. The goal languages are languages in which the goals that are to be attained by the execution of plans or programs are stated. The only restriction that is universally placed on such goal languages is that they are declarative extensional languages. Pairs of formulae of the goal languages are the goals to be attained by the execution of programs. The first element of the pair is the initial condition to be satisfied by the initial state of the execution. The second element of the pair is the terminal condition that is to be satisfied by some nth state of the execution and thereafter. A generalization of this concept of goal is obtained by considering sequences of formulae of the goal languages. Thus processes are sequences of assignments in the realizations of goal languages.

If GL is a goal language, M = (D,I) is a realization of GL where I is an interpreting function that assigns structures and elements of D to the constants of GL, and Assig(M) is the set of all functions that map the set V of variables of GL into D, then any sequence s, a function from the natural numbers into Assig(M), is a state of a universe UM in which plans or programs that are relative to GL are to be interpreted. Such an interpretation is called a programmatic model of the plans or programs.

If G = (G₁,G₂), G₁ and G₂ formulae of GL, is a goal, and H(M,G₁) and H(M,G₂) are the assignments in a realization M that satisfy G₁ and G₂, respectively, then we say that a process s is bound by G in M if and only if s(o) is in H(M,G₁) then there is an n such that for all m ≥ n s(m) is in H(M,G₂). A process s bound by G in M may be thought of as succeeding in attaining the goal G. Two processes are equivalent in M if they are bound by the same goals. In other words the processes co-succeed in M.

In general, then, the logic of appraisal of plans and programs has to characterize the morphology and transformational syntax of a binary predicator "≡" such that if P₁ and P₂ are two programs and it is a theorem that P₁ ≡ P₂,
then the processes that are associated to \( P_1 \) and \( P_2 \) by their interpretation co-succeed and conversely.

\[ \text{b. The interpretations of plans or programs are viewed as complex structures consisting of: (1) the realizations } M = (D,I) \text{ of a goal language } GL; (2) a referential interpreting function } IP \text{ of program terms; (3) an allocation function } A \text{ that maps the variables of } GL \text{ into positions of the tree of constructions of program terms; (4) a representation function } R \text{ that maps elements of } D \text{ into the set of program terms; and (5) a processing facility } F \text{ that transforms program terms into program terms. We assume without loss of generality that programming variables are taken from the set } V. \text{ The quintuplet } (M,IP,A,R,F) \text{ is a programmatic model of plans or programs relative to a goal language } GL. \]

Suppose \( P \) is a program with variable \( x_1,x_2,...,x_n \), then the process \( s \) generated by a program \( P \) in a programmatic model \((M,IP,A,R,F)\) relative to an assignment \( d \) in \( \text{Assig}(M) \) is given by: (1) \( s(o) = d; \) (2) if the allocation of \( x, A(x) \) is a position in the construction of the term \( F^n[(R(d(x_1))/x_1,R(d(x_2))/x_2,...,R(d(x_n))/x_n,P)] \), then \( (s(n+1))(x) \) is the interpretation, \( IP \), of this term relative to \( s(n) \), else (3) \( (s(n+1))(x) = (s(n))(x) \).

A program \( P \) succeeds in attaining a goal \( G \) in a programmatic model relative to some assignment if and only if the process generated is bound by \( G \). Two programs are semantically equivalent if and only if the process generated in every programmatic model co-succeed.

\[ \text{c. Present-day programming languages have an incomplete syntax. To the usual morphology of programming languages we may add a binary predicator } "\text{=}" \text{ which when appropriately infixed between programs will yield a new category of signs that we may call assertions. To this morphology we append suitable assertions as axioms and at least two rules of transformation: a rule of substitution that allows the appropriate substitution of terms for variables in assertions and a rule of transitivity. These two rules together with the assertions that are axioms characterize the set of assertions that are theorems of the expanded programming language.} \]

A processing facility \( F \) for such an expanded programming language will be said to be admissible if and only if for every program \( P \) it is a theorem that \( F(P) \equiv P \). A processing facility \( F \) is said to be a reduction if and only if if \( P_1 \equiv P_2 \) is a theorem then there exist \( m \) and \( n \) such that \( F^n(P_1) = F^m(P_2) \). Two theorems that relate the transformational syntax of expanded programming languages \( PL \) to their programmatic semantics are as follows:

**Theorem 1.** If \( PL \) is an expanded programming language, \( GL \) a goal language that contains the morphology of \( PL \), and \( P_1, P_2 \) are programs that are semantically equivalent for all programmatic models with admissible processing facilities, then \( P_1 \equiv P_2 \) is a theorem of \( PL \).

**Theorem 2.** If \( PL \) is an expanded programming language and \( P_1 \equiv P_2 \) is a theorem of \( PL \), then \( P_1, P_2 \) are semantically equivalent for all programmatic models with a reduction facility.
The first theorem is a semantic completeness theorem which holds for a restricted set of goal languages and a restricted set of programmatic models. The second theorem is a soundness theorem that is not restricted with respect to goal languages but has a strong restriction on processing facilities.

Details of the above consideration are found in [1].

References


The goal of this work has been the development of a systematic approach to the recognition and description of pictures by computer.

At the commencement of the project, existing paradigms for picture recognition were reviewed and found to be inadequate for many picture recognition tasks. However, several authors have proposed a more powerful paradigm for picture recognition in order to overcome some of the inadequacies of existing paradigms, and based on the work of these authors and on knowledge gained from an analysis of the inadequacies of the existing paradigms, a new paradigm for picture recognition has been developed. The evaluation of the paradigm is accomplished through its application to several interesting picture recognition problems.

The receptor/categorizer paradigm for picture recognition was found to be of little use when analyzing complex pictures where structure and interrelationships among the picture components are important factors. The syntactic paradigm also was found to have serious limitations. In particular, problems involving (1) ambiguity of shape, (2) non-pictorial paraphrase, (3) non-ideal data, and (4) multistability in perception are, in general, characteristic of those cases in which techniques based on the syntactic paradigm are found to be inadequate. Other techniques for picture recognition which do not fall within the receptor/categorizer or syntactic paradigms are ad hoc and heuristic, and hence of little value for other than their intended applications.

It was found that the underlying causes for the failure of the syntactic paradigm to apply to certain recognition problems are the use of extensional (versus intensional) class descriptions and an inability to utilize contextual information. The new paradigm, therefore, was developed in such a way that contextual information could be explicitly utilized and recognition could be performed based on the implicit use of intensional class descriptions. The paradigm provides a general model whereby many problems previously unsolvable by the receptor/categorizer or syntactic paradigms can now be solved. This new paradigm is termed a paradigm for semantic picture recognition, or in short, the semantic paradigm. It was so named because it provides a procedure by which the "semantics" of a picture can be exhibited. That is, the use of the semantic paradigm permits the exhibition of relations and properties of a non-pictorial kind which describe the event depicted by the picture "syntax."

The semantic paradigm can be informally described as the following procedure: first, a primitive description is constructed of the scene depicted by a picture. This description is a function of the information processor's sensory and preprocessing facilities. Secondly, a set of "rules of inference" is constructed which can be thought of as the information processor's body of knowledge of the world. Each of these rules is an independent
entity, whose application to a scene description may result in the inference of new properties and relations. Recognition is implicit in the process of applying these rules since the result is a scene description in which objects are described in terms of properties which are found to hold for them, and relations between objects are exhibited.

The contribution that this paradigm makes is fairly straightforward. It presents a very concrete structure for the programmer to follow in approaching a recognition problem. This structure is such that the universal aspects of any picture recognition problem are isolated from the problem-dependent aspects. Thus, the programmer is freed from the task of developing a completely ad hoc program which is difficult to debug and modify. The problem-dependent aspects of the program are succinctly contained in the set of rules of inference which can be rapidly expanded or modified by the programmer to develop a solution for the particular recognition task.

The semantic paradigm has been shown to be a valuable contribution to the field through its successful application to problems that heretofore were unsolvable using the existing paradigms. In particular, the following four problems were considered.

1. For a problem involving ambiguity of shape, a hypothetical world "W" was described in which the recognition task was to distinguish objects having the same shapes but belonging to different classes. For example, world W contains air-filled balloons, gas-filled balloons, solid balls, and egg-shaped lead blobs. Depending upon the context in which an object is found a classification decision can be made which could not be made by analyzing only shape. For example, balloons usually look like balls, but at times, balloons might be supporting a weight which would give them the shape of lead blobs. The explicit use of contextual information through the semantic paradigm provided a solution to this problem.

2. For a problem involving non-pictorial paraphrase, the problem of recognizing (the function performed by) electrical control circuits was considered. It is shown that an infinite variety of circuits could perform the same function, and hence belong to the same class. Thus, existing paradigms were found to be completely inadequate. The semantic paradigm, however, provided the necessary structure to solve this problem.

3. For a problem involving non-ideal data, an attempt was made to recognize features such as hair, eyes, eyebrows, nostrils, and the mouth in grey level pictures of human faces. Although this problem cannot be solved using existing paradigms, an ad hoc solution has been given (Kelly, 1970). The semantic paradigm, however, proved to provide a more straightforward and flexible solution.

4. Lastly, a problem involving multistability in perception was investigated, namely, that of attempting to recognize the object in a picture of a reversible (Necker) cube. It was found that the semantic paradigm solution produced the multistable behavior encountered by human beings.
That is, first the cube is "seen" from one aspect, and then the figure appears to reverse, or in the case of the semantic paradigm, the previous scene description is replaced by a new scene description, which is then replaced by the old description, etc., indefinitely.

A more detailed description and evaluation of the semantic paradigm can be found in [1].

References


Adaptive Scheduling of Computer Tasks

J. M. Gwynn, E. M. Pass

This research has been aimed at the design and testing of an adaptive microscheduler which assigns the resources of a time-sharing computer system so as to approach optimality with respect to some externally prescribed criterion. The scheduler bases its assignments on history taken from the performance of tasks in the system and corrects itself when the predictions deviate from observations.

The scheduler is of a general goal-seeking type and is able to move toward optimality with respect to any externally imposed criterion whose optimization can be specified in terms of resource utilization histories.

The Burroughs B-5500 was chosen as the computer system on which to test the adaptive microscheduler. Simulation was to be the means of comparison of the adaptive microscheduler with several prototypical microschedulers, including the B-5500's own scheduler, and simulators were written in SIMULA for the UNIVAC 1108 to represent the behavior of the B-5500 TSS/MCP with various different prototypical microschedulers. The B-5500 TSS/MCP simulator was validated by comparing actual Georgia Tech runs with simulation runs using the B-5500 microscheduler. Data monitored over a long period was distilled into a data base usable in the simulation runs. Thus, the data collected would be representative of the actual Georgia Tech workload and, hopefully, representative of a college or university environment.

During the past year, the adaptive microscheduler was designed and a simulator was written in SIMULA for the UNIVAC 1108 to reflect the behavior of the adaptive scheduler in the B-5500 TSS/MCP. A description of the microscheduler and the results of comparing with various prototypical microschedulers under several measures of system effectiveness are presented in some detail below.

Operation of Adaptive Microscheduler. The general goal of the adaptive microscheduler is to attempt to maximize the general systems effectiveness measure (GSEM) through maximizing the local systems effectiveness measure (LSEM) at each decision point. It does this through evaluating the predicted values of LSEM obtained by tentatively assigning the requesting tasks to the requested resources, then actually making the assignments which maximize the LSEM. The prediction of new LSEM values is based partially upon exponential estimation based upon previous values of system variables and partially upon the difference between the most recent predictions and actual values (the correction). At certain intervals the prediction process may be parametrically adjusted in order to adapt to changing conditions in the environment in which the microscheduler is operating.

System Effectiveness Measures. The global system effectiveness measure is too general to use directly as a decision tool for a microscheduler. Thus
a local system effectiveness measure (LSEM) is required to be defined. It would ideally be of the nature that optimizing it at each point in time would be equivalent to optimizing the GSTM for the entire period. This is, however, unfeasible for a dynamic, unpredictable, nonanticipatory system because it is not possible at a given point in time to make the decision which is known to be correct at some later point in time. All that can be done is to make the apparently best decision at each point in time at which a decision must be made, hoping that worst-case situations will not occur.

The LSEM's used in this study are all defined to be the weighted sum of certain system and task parameters evaluated at each instant in time at which a decision must be made. By proper choice of the parameters and weights, optimizing an LSEM on an instantaneous basis may be made equivalent to a suboptimization of a given GSEM over a longer time interval. The better the decision function of the microscheduler is, the better the value of the GSEM which is realized, ignoring the possible additional resource load of the microscheduler.

The specific global (and local) system effectiveness measures considered in this research are presented in Table 1. Note that the LSEM's are all dependent upon resource utilizations only. Thus they are all effectively computable from recent and historical information, and no future information such as task completion time is required. Other system effectiveness measures could be considered by defining the corresponding LSEM's.

The construction of the LSEM for a given environment is quite important since it links the desired operation of the microscheduler to management's goals for the system. Certain goals may very well be conflicting. For instance, faster turnaround is in conflict with increased CPU utilization; the former is proportional to the decrease of instantaneous CPU usage whereas the latter is directly proportional to total CPU usage. Thus the relative coefficients of these terms must be adjusted to conform to management goals to resolve the conflict.

The decision, then, can be made in the manner described earlier in this section using the task LSEM predicted values for the next time interval to determine which requesting task is to receive use of each resource next.

Trends in System Performance. The microscheduler must be able to detect trends in system performance in terms of values of LSEM, its terms, and the attributes of the task in execution. It is necessary to minimize the resource requirements of the microscheduler in order not to negate the gains made by the improved microscheduler. Thus, prediction techniques must rely on small numbers of relevant variables to predict new values.

There is a long-term class of data, statistically describing the environment and current set of tasks; there is the short-term class, reflecting averaged values over some much shorter period of operation; then there is the instantaneous class detailing the most current values of the system and task
Table 1. System Effectiveness Measures

<table>
<thead>
<tr>
<th>Name</th>
<th>GSM (Overall)</th>
<th>LSI71 Term (Instantaneous)</th>
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</thead>
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<tr>
<td>THROUGHPUT</td>
<td>(tasks/unit time)</td>
<td>(I/O usage)/(core usage)</td>
</tr>
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<td>(CPU usage)</td>
<td>(CPU usage)</td>
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<td>(I/O usage)</td>
<td>(I/O usage)</td>
</tr>
<tr>
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<td>(1 - (queue handling time) / (swap in time))</td>
<td>(CPU usage) / (swap in time)</td>
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<tr>
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<td>(1 - idle time)</td>
<td>(1 - (CPU usage) + (I/O usage) + (core usage))</td>
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<td>COST</td>
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<td>((3.14*(CPU usage) + (4*(I/O usage)) + (8*(core usage))))</td>
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Table 2. B5500 Workload Analysis

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variables. These three classes of values enter into trend detection and prediction in the microscheduler of this research.

Because, at a given instant in time, averaged values of system and task variables gathered more recently are better predictors of near-future values than are less recent values, short-term averages must be weighted so that recent values carry more weight than less recent values (Denning, 71). The concept of weighted moving averages is the basis for certain techniques which have been developed to track changing patterns of demands in inventory control and operating systems (Burroughs, 72, Denning, 71, Wulf, 69).

Exponential estimation is a convenient class of weighted moving averages for computation in that it does not require the keeping of large tables of historical data for each resource of interest in order to facilitate prediction. It has the capability to adjust to change, but its rate of response can be adjusted dynamically and parametrically. This parameter is normally referred to as APPHA, but for the purpose of this research it will be known as A.

The formulae used in the predictor portion of the adaptive microscheduler may be summarized as follows:

1. \( AV(T2) = (A \times V(T2)) + ((1-A) \times AV(T1)) \)
2. \( CT(T2) = AV(T2) - AV(T1) \)
3. \( NT(T2) = (B \times CT(T2)) + ((1-B) \times CT(T1)) \)
4. \( PV(T2) = AV(T2) + (NT(T2)) \)

where

\( T1 = \) previous time  
\( T2 = \) current time  
\( AV = \) average value  
\( V = \) current value  
\( CT = \) current trend  
\( NT = \) new trend  
\( PV = \) predicted value  
\( A = \) first-order estimation parameter  
\( B = \) second-order estimation parameter

and time between applications (\( T2 - T1 \)) is assumed constant.

To correct for variable time of application of prediction, equations 1 and 3 must be corrected as follows:

\[
G(T3) = \left[ \frac{F(T2) - F(T1)}{T2 - T1} \times (T3 - T1) \right] + F(T1)
\]

\[
F(T3) = \min(1.00, \max(0.00, G(T3)))
\]
where $F$ is AV or NT,

$$
T_3 = \text{current time}
$$

$$
T_2 = \text{such time that "interval of application" would have been constant}
$$

$$
T_1 = \text{previous time.}
$$

Given that $T_0$ equals time before previous time, then $(T_1 - T_0)$ equals $(T_2 - T_1)$. If $T_3$ is between $T_1$ and $T_2$, the above equation for $F$ forms a linear interpolation formula, and if $T_3$ is greater than $T_2$, it forms a linear extrapolation formula. Initially, times zero and the first time of application are taken as $T_0$ and $T_1$, respectively. In case the extrapolation leads to a resource utilization not between 0.00 and 1.00, it is corrected to the nearer extremity.

These equations form a second-order, exponentially smoothed system which remains open to new information. The correction for variable time of application is not found in the literature, but significantly improves the predictive powers of the method. Assuming that values at some initial point in time may be specified, the equations can then be iteratively applied to provide new predicted values $(AV(T))$ and new trend values $(NT(T))$ at each later point in time at which a prediction is required.

This construction provides an almost built-in correction mechanism. If the predictor is consistently under or over-estimating the value of a variable, a corrector may be applied to modify the parameters $A$ and $B$ of the exponential estimator to make the microscheduler a little more responsive or to decrease the time application interval to make it a little more accurate. In case the predictor is performing badly, over- and under-estimating values, the parameters $A$ and $B$ should be modified to make the microscheduler more stable. Thus the predictor-corrector portion of the microscheduler acts as a homeostatic stabilizer to the microscheduler, allowing the adaptivity to handle changing conditions, but also stabilizing the process.

The process as used in this research is quite simple, as it must be. Separate $A$'s and $B$'s are maintained for every task in the mix and for every facility of the system capable of being assigned to or used by the tasks. When a task enters the mix, its $A$'s and $B$'s are set to predetermined initial values, and the task's historical information is set to values to reflect the predicted initial normalization usage of the critical resources. Thenceforth, whenever the predictor-corrector process is activated to predict a new value for a task/resource usage combination, the historical information and more recent information are available to allow the effective prediction of a new LSEM value for a task.

The exact nature of this corrector algorithm is environment-dependent; however, experiments were performed to determine the best manner in which to perform the correction in the environment of this research. It was determined that the best manner in which to perform the correction in this environment is represented by the following:
Compute difference between predicted value for task/resource usage and actual value.

If difference is greater than threshold, check signs of current difference and previous difference.

If they have different signs, the process is oscillating and must be more stable by relying more heavily on historical information; if A is not already at its lower limit, it is decreased by DA (defined extremely); otherwise, if B is not already at its lower limit, it is decreased by DB.

If they have the same sign, the process is not responsive enough to new data and must be made more responsive by relying more heavily on more recent data; A and B are increased in an analogous manner to that described previously.

Using the most recently computed values for A and B, and regardless of other tests, predicted task/resource usage value is generated and used to compute a predicted LSEM value; since the times between applications are variable, linear interpolation is used to take this into account in the prediction process.

**Explanation of Workload Analyses.** Table 2 presents a workload analysis produced by using the simulator mentioned earlier to analyze various micro-schedulers, under various system measures, using data drawn from the Georgia Tech B-5500 workload. The various microschedulers are represented by the columns of the tables, and the various global system effectiveness measures (GSEM's) considered are represented by the rows. For each microscheduler/GSEM combination, there are two numbers. The first is (the value of the GSEM) divided by (the value of the GSEM for the adaptive microscheduler), and the second is the value of the GSEM. In the comparison column, the first column represents the improvement realized by the adaptive microscheduler over the best competing microscheduler, and the second represents the improvement over the worst. As mentioned earlier, the adaptive microscheduler of this research performed quite well, in comparison with other microschedulers, under a variety of system effectiveness measures.

**Conclusions.** The design of the adaptive microscheduler of this research was motivated by the work of many other researchers. Each of them reported studies of resource utilization in digital computers. In most cases, specific resource scheduling methods were considered, such as the following: complete-history (Stevens, 68, Sherman, 72); round-robin (Baskett, 70, Schwetman, 70, Sherman, 72); foreground-background (Rehmann, 68); reward-penalty (Marshall, 69, Eisenstein, 70); moving-average (Denning, 70); random-guess (Sherman, 72); FIFO (Sherman, 72); pre-emptive (Sherman, 72); policy-driven (Berstein, 71); load-adjustment (Wilkes, 71); exponential-smoothing (Wulk, 69, Ryder, 70, Sherman, 72); stochastic-estimation (Eisenstein, 70); heuristic (Ryder, 70). In a few cases, the researcher attempted to develop methods which would predict near-future resource utilization and, accordingly, schedule the tasks' resource allocation (Eisenstein, 70,
Sherman, 72, Wilkes, 71). All of those predictors were fixed-formula, non-adaptive, fixed-parameter methods, normally attempting to optimize the use of only one resource.

In contrast, the microscheduler of this research is adaptive in terms of changing its parameters in response to the error committed in the last prediction. Furthermore, this method is second-order in its exponential estimator, a technique chosen to make more accurate predictions and to be less susceptible to noise. Since the time of prediction will, in general, not be evenly spaced, a linear correction is applied to attempt to predict more accurately. To our knowledge, this correction for uneven time steps is not considered in the literature but proves quite effective in this research. The improved prediction formulae contribute to the success of the adaptive microscheduler. Moreover, all three of the most critical resources (CPU, I/O, and core of the system and environment at hand) are treated, rather than only one.

The literature lacks any general methodology for effecting microscheduler improvement for a variety of systems effectiveness measures. This research provides a general method of using resource utilization predictions to attempt optimization with respect to various measures of system effectiveness, even though a different formula using the predictions may be required for different measures.

References


Our research on a hardware processor for natural language (in particular, for English) is closely related to a parallel research project on the structuring of English text. The basic first step in this respect has been the development of an English-sentence parser which we call the Q-parser, because the grammar used for parsing is contained in a directed graph called a Q-graph. A comparison between the anticipated functional classes of the words of a given sentence is made against the graph, and whenever a successful graph is formed such that the classes of the words in an entire sentence match the classes of the nodes in the graph, then parsing is complete. The method finds all parses of the sentence. (For a more detailed description of the algorithm, see [1-3] and especially the references given in [1].)

Our design has been generalized during the past year to reflect a fresh approach to parsing using a recursive Q-graph. The concept of the recursive Q-graph and its implementation in the program called Q-graph Parser facilitate program modularity (where by "modularity" we mean the independence of one part of the program from other parts); the concept is reflected very strongly in our hardware design, where single parts of the hardware work asynchronously, leaving room for further modification or updating of the concept without harming the remaining parts of the processor.

Our effort was limited to the parsing problems of sentence analysis because it is the most advanced part of our research and provides reasonably firm ground for identification of hardware components, requiring little circuitry other than standard elements such as core memory, read-only memory and pushdown store.

Though our research in text structuring was also successful in analyzing the transformation from a parsed sentence to a syntactical pair structure, and partially to the syntactical structure of the whole text, these features have not been incorporated into the hardware of the language processor.

Elements of Hardware Structure. The hardware structure of the processor for parsing English sentences is shown in Fig. 1. Following are the four basic components:

1. CM Core memory that stores all possible functional classes (lexical classes and other possible classes).

2. ROM Read-only memory that is asynchronous memory producing classes of the front nodes of the Q-graph. It contains the grammar for parsing. Modification of ROM allows for the substitution of an alternate grammar.

3. PDS Pushdown store that stores parameters of recursion under which the ROM operates.
Fig. 1. Hardware Structure of the Processor
START

Next word $W_i = W_{i+1}$

No more "next word"; end of sentence

Output the parse

First class of the word $W_i$

Next class $L_i^k = L_i^{k+1}$ of the word $W_i$

Next class $L_i^k = L_i^{k+1}$

No more "previous word"; beginning of sentence

END

1

SYN

Back up one word; start from the last used class of the backed up word $i = i-1$

2

No match for $L_i^k$ class

CM

3

Match

Fig. 2. Flowchart for CM
4. MATCH Control operation that delegates control of the process to ROM or CM, depending on whether or not a match has been found between the L-class (class of the word of the sentence) and G-class (class of the node of the Q-graph in ROM).

Processor Core Memory. Processor core memory is represented by box CM in Fig. 1. In the hardware, it is an element that has its own function, described by an algorithm the flowchart of which is shown in Fig. 2. It contains possible functional classes of each word of the sentence that form initial conditions (data) of the processor.

Of various possibilities for actual implementation, the following seems to be the most attractive. The capacity C is chosen so as to contain two full lengths of a sentence—e.g., assuming that the length LS of the longest sentence is 50 words, the capacity will be $C = 2^{LS} \times 5 = 500$, where the factor 5 is a constant representing (with a safety factor for average distribution) the number of functional classes in which a particular word can function in the given sentence.

The memory contains two sentences at the same time, one (S1) that is being currently analyzed and another one (S2) that is being loaded into the memory, word by word and in the time intervals, in which MC is not used for the processing (marking for the match). CM is used in a circular fashion, such that (S2) is loaded immediately succeeding S1 and that when the capacity is reached the loading continues from the first address. The modular use of CM allows for more effective utilization of the space, so that one sentence can be longer than 50 words if the previous or succeeding sentence is shorter. Three registers are necessary in such a case to store the first, middle and last addresses for identification of the space occupied by S1 and S2 (not shown in our diagrams).

Read-Only Memory ROM. Read-only memory, ROM, permanently stores the Q-graph that represents the grammar for parsing. The Q-graph is a directed graph where each node represents one functional class called G and the pointers to the front neighbors, called the line of the table representing the Q-graph.

One class after the other is retrieved from the same line of ROM and matched with L-class in the box Match (Fig. 1) until there is a match. The process is asynchronized (to the other parts of the processor) and continues until one of three things happens:

1. Match is reached (3), in which case the search is stopped. Matched node in the line contains the address of the line where its front nodes are stored. ROM then finds the new line and waits for the signal from CM to start the search.

2. End of the line without match (2), in which case the search stops. Pushdown store is used to retrieve the next line for search (which is one of the previously used lines that will be tried for match with different L-class than before). When new line is inserted from PDS, ROM waits for the starting signal from CM.
Fig. 3. Flowchart for ROM
3. **Special symbol in the line is reached**, in which case pushdown store PDS is used for storing or retrieving parameters of recursion, depending on the kind of symbol. Search activities of ROM are interrupted and resumed after PDS activity is finished.

It is assumed that response time of ROM is much shorter than response time of CM.

The algorithm that governs the activity of ROM is shown in Fig. 3. Input START represents the start of the analysis of the first word, where the initial address of the first node of the graph has to be inputted. From that time, each next line is found individually from the interval process. Input SYN on the other hand is a synchronization signal that coordinates the activity of CM and ROM. It informs ROM when to start the search of the line that has been prepared for matching.

**Match of the Classes.** When matching of L-class and G-class is in progress, two things can happen:

1. **The match is made**; i.e., the functional class of the word L is assigned to the word and the next word is going to be tried. Memory CM has to store which of the classes has been matched and then retrieve the next word, starting with its first class: \( i = i+1 \), where \( L_i^1 \) is the first class of the new word \( W_i \). ROM will stop the search and in a new line given by the pointer attached to the matched class.

2. **The match has not been made**; i.e., the control remains in ROM activity and the search for match continues.

**Characteristics of the Design.** The following features are emphasized in the design:

1. **Exchangeable ROM.** Memory ROM has its own algorithm, controlled by MATCH box, in cooperation with PDS. Different features of the parsing process can be reached by an exchange ROM:
   1.1 Different speed of parsing by rearrangement of the Q-graph hierarchy or recursive characteristics.
   1.2 Different grammars by changing the graph for experiments with parsing grammars.
   1.3 Augmentation of the power by incorporating auxiliary subparser, e.g., for parsing algebraic expressions, logical expressions (see our reports (1),(2)).
   1.4 Since ROM works asynchronously with the rest of the system, improvements requiring a redesign of the concept or change in the implementation can be made without affecting the rest of the system (except for the change in response time from ROM).
2. The core memory (actual core matrix) of the CM box is assumed to be ordinary core memory with no special response time. The faster the better—otherwise, it works asynchronously with the rest of the system. The algorithm from Fig. 2 is built into CM by additional hardware to the cores. Considering response time of the core memory in retrieving one word as one time unit, then the number of accesses per one sentence can be from 10 to 100,000-ths of units. The estimate comes from all possible fully made paths through the graphs; thus, 50-word sentence, with 3 classes/word on the average, gives $50^3 = 125,000$ units—where, however, the claimed advantage of Q-parser is that it substantially reduces the number of paths since most of them are interrupted long before they reach full length. Our estimate is that on the average the upper level will not often exceed more than a few thousand units. One or two hundred units will more likely serve for an average sentence.

3. It has been assumed that loading and unloading of the input or analyzed sentence is done by a program that handles the whole text for the computer, where the sentence analyzer is controlled by an instruction of the main program.

References


RESEARCH IN SYSTEMS SCIENCE

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The study of general dynamical processes is the logical development of basic system theory structures and properties within axiomatic set theory. Over a period of years, a rather extensive collection of studies of relevant concepts and structures has been built up within a certain common set-theoretic formalism. The purpose of the present research is to continue the development of the theory of general dynamical processes in two specific directions; namely, (i) to unify and expand the existing theory of stereotype voting groups (as an example of the important system structure of "an evolving society of individuals"); and (ii) to introduce within the established set-theoretic formalism an axiomatic formulation of computing processes including the elementary theory of recursive functions and sets, unsolvable problems, and abstract computability.

Results to date include the following:


b. A study of ways to generalize some system theoretic results concerned with coupling of states first discovered in the special case of a theory of stereotype voting groups.

A voting group is a collection of individuals who take a sequence of votes (yes or no) on some issue. A stereotype voter is a member of a voting group whose vote at any time \( t + 1 \) is completely determined by the votes of some or all of the members at time \( t \). A stereotype voting group is a voting group containing only stereotype voters.

Human beings admit a number of obvious stereotypes as voters in voting groups. Consider the following examples:

(i) Votes as his friend did last time.

(ii) Votes as the majority did last time.

(iii) Votes as the minority did last time.

(iv) Always votes the same way.

(v) Always votes the same way unless no one else agrees, in which case he changes his vote.

(vi) Alternates his vote between yes and no.

(vii) Votes as two other voters did last time provided they agreed; otherwise, votes as he did last time.

(viii) Votes as the majority of a certain subgroup did last time.
All of the above voting behaviors are examples of what we previously defined to be stereotype voters.

Granted that stereotype voters are at best an approximation to the behavior of real voters, how does a given "mix" of stereotype voters function as a group trying to make a decision? It strikes us that human voters are close enough to stereotype voters to make this question interesting. Thus, we proceed with a mathematical model.

Let us assume we have n-voters in the group. Let 0 represent a "no" vote and 1 represent "yes." We can represent any collective vote of the group by an n-tuple (called the state)

\[ x(t) = x_1(t)x_2(t)...x_n(t) \]

where

\[ x_i(t) = \begin{cases} 
0 & \text{if the } i\text{th voter votes "no" at time } t \\
1 & \text{if the } i\text{th voter votes "yes" at time } t 
\end{cases} \]

Here, of course, \( t = 0,1,2,\ldots \). Given the behavior of each (stereotype) member of the group, the subsequent vote is clearly a function of the present vote only; i.e.,

\[ x(t+1) = f(x(t)) \]

The next-state function \( f \) is finite here and, hence, may be represented conveniently in tabular form. Let us take an example.

Suppose we have the following group of five stereotype voters:

- #1 votes constant.
- #2 votes yes if either #3 or #4 or both did last time; otherwise, no.
- #3 votes as #4 did last time.
- #4 votes as #3 did last time.
- #5 votes as #2 and #3 provided they agreed last time; otherwise, constant.

For this group, the tabular representation of the function \( f \) becomes as follows:

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In the form of a transition graph, this data becomes:
By inspection, we see a steady-state of sorts is always reached. Steady-state can be unanimous agreement, voter #1 opposing the rest of the group, or a three-to-two or a four-to-one split in which voters #3 and #4 (aping each other's vote) continually change their votes oppositely. An initial minority often prevails in steady-state here (see initial states marked *). Indeed, in one case, the vote of #3 initially chooses between a unanimous no vote in steady-state or a three-to-two split of yes (see +).

Stereotype voting groups offer simple, but fertile and interesting, examples of coupled dynamical systems in discrete time. Earlier, an extensive effort was made to develop a suitable theory of the behavior of such groups. In [7], the basic model of stereotype voting groups is given and illustrated with examples. In [1], Chan has rather completely analyzed the problem of manipulation of voting groups by an information media (such as an opinion pollster publishing erroneous results) under the assumption the voters are stereotype. It was shown (i) there are six "natural" classifications of voters corresponding to manipulatability; (ii) the manipulatability of a group is completely determined by the mix of voter-types present; (iii) when manipulation is possible, it can always be accomplished in two or three simple steps; and (iv) a computer algorithm exists for determination of a manipulation strategy. Fortunately, human voters are not perfect stereotype voters and no real information media has access to the information required by Chan's algorithm. However, his results are yet of considerable practical interest.

Hegner [3] has considered stereotype voting groups of "threshold" voters. A threshold voter is one who votes "yes" next time iff the number of current "yes" votes in a certain subgroup of voters (uniquely assigned to this voter) exceeds a certain threshold. While not all stereotype voters are threshold ones, threshold voting groups form a very large class. In [7], a quite complete analysis is given of pointwise, local, and global stability for threshold voting groups and the concept of state reduction (a very important concept practically) is developed. In a separate study, a program was written for the analysis of small voting groups by digital simulation.

Within the context of stereotype voting groups, some important system theory concepts arise and can be explicated. The fact that each voter's next vote is explicitly a function of the present votes of the members of the group renders the group behavior "deterministic," no matter how large the group might be. Dynamical processes such as stereotype voting groups are often too large to be tractable when modeled carefully. Thus, we become interested in subprocesses in general, and decomposition into subprocesses in particular.

In certain kinds of subprocesses, we lose determinism: If A is the set of voters in a subgroup, let Â be the set of voters that the members of A base their next-votes on. Clearly, if Â ⊆ A, the subgroup is self-contained in a dynamical sense, i.e. determinism is not lost. In other words, given the initial state of the subgroup, the entire future behavior of all subgroup members is completely determined. Such a subprocess of a dynamical process
is classically called closed. An open subprocess is evidently one generated by a subgroup \( A \) where \( A \not\subseteq A \). For such a subprocess, the original simple kind of determinism is lost. In the previous example, \( \{1\} \), \( \{2,3,4\} \) and \( \{3,4\} \) generate closed subprocesses whereas \( \{5\} \), \( \{2,3\} \), etc. generate open ones.

Subprocesses can interact (i.e., influence each other) or not. There are three basic cases. If \( A \) and \( B \) represent disjoint subgroups of a voting group, \( B \) influences \( A \) provided \( \text{\( A \cap B \neq \emptyset \)} \), i.e., some member of \( A \) bases his vote in part on some member of \( B \). We have

(i) noninteraction if \( A \) does not influence \( B \) and \( B \) does not influence \( A \).

(ii) one-way interaction if \( B \) influences \( A \) while \( A \) does not influence \( B \).

(iii) two-way interaction if \( A \) and \( B \) influence each other.

In the example, \( \{1\} \) and \( \{2,3,4\} \) are noninteracting; \( \{2,3,4\} \) are noninteracting; \( \{2,3\} \) and \( \{5\} \) have one-way interaction; and \( \{3\} \) and \( \{4\} \) have two-way interaction. A decomposition of a voting group is a partition into closed subgroups. In such a partition, the subgroups are pairwise noninteracting. In the example, \( \{1\} \) and \( \{2,3,4,5\} \) form a decomposition. The above concepts of influence and interaction easily lead to a stability theory for stereotype voting groups. See Hegner [3].

When we encounter open subprocesses in the case of voting groups, while the basic simple determinism is lost, some aspects of it generally remain. What remains seems naturally to lead us to the so-called input-output point-of-view of the process. Consider the subgroup \( \{2,3,5\} \). We see that \( \{2,3,5\} = \{2,3,4\} \) so this subgroup generates an open subprocess. We see that voter \#4 is the only external, i.e., exogenous, influence on this subgroup. If we treat \#4 as if his behavior must be externally prescribed, we arrive at precisely an input-output point-of-view. Indeed, given the sequence of votes of voter \#4 plus (as usual) the initial votes of the other voters, determinism is reestablished in the sense that the entire future behavior of all subgroup members is again completely determined. For example, we see

\[
\begin{align*}
\text{INPUT} & \quad \text{Voter \#4} = \{0,0,0,1,1,0,1,1,0,0,0,0,1,1,1,1,1,1,1,1,1,1,...\} \\
\text{OUTPUT} & \quad \text{Voter \#2} = \{1,0,0,0,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,...\} \\
& \quad \text{Voter \#3} = \{0,0,0,0,1,1,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,...\} \\
& \quad \text{Voter \#5} = \{1,1,0,0,0,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,...\}
\end{align*}
\]

Here, we are given the sequence of votes of voter \#4 plus the initial votes of \#2, \#3, and \#5.

In this same context, the concept of control can be explained. Suppose we assume that the behavior of \#4 can be specified in any manner we choose (perhaps a bribe would suffice to persuade him, for instance). Could we prescribe a behavior that would lead to a favorable steady-state behavior on
the part of the \{2,3,5\} subgroup? For example, if we wish voters #2, #3, and #5 to ultimately vote "yes," could it be arranged by specifying a certain stereotype behavior for #4 (other perhaps than that originally prescribed). Indeed, this is possible in our example. Suppose we arrange for #4 to vote "yes" in every situation; then, in the case that #2, #3, and #5 vote "no" initially, we see

\begin{verbatim}
INPUT  Voter #4 = \{1,1,1,\ldots,1,\ldots\}
OUTPUT Voter #2 = \{0,1,1,\ldots,1,\ldots\}
       Voter #3 = \{0,1,1,\ldots,1,\ldots\}
       Voter #5 = \{0,0,1,\ldots,1,\ldots\}
\end{verbatim}

But, the "control" that #4 exerts is even more remarkable than that. For the voting group consisting of #2, #3, and #5 where #4 votes "yes" in every situation, we get the following state transition graph:

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{state_transition_graph.png}
\caption{State transition graph for the voting group consisting of #2, #3, and #5 where #4 votes "yes" in every situation.}
\end{figure}

Clearly, the influence of #4's behavior renders the final state a unanimous "yes"-vote regardless of the initial persuasions of the subgroup.

In future work, we expect to extend and generalize the above development to a general discrete-time system case of recurrence equations. Given the above development and an existing formalism, how to proceed is quite clear. Some questions of style in the formal development are unsettled. A second task to be undertaken concerns the further development of the so-called conditional algorithm as a device to relate the theory of computability with the set-theoretic formalism of general dynamical processes.

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Lattices of Controllable and Observable Spaces and Their Properties

P. Zunde

It is known that the set of all subspaces of a linear vector space form a modular complemented atomic lattice with the binary operations of intersection ($\cap$) and summation ($\oplus$). Denote it by $L(V)$.

The set of all invariant subspaces of the vector space $V$ under an operator $A: V \rightarrow V$ is a sublattice of $L(V)$, which is also modular and atomic (but in general not complemented). In the paper produced by the research [1], various structures of the lattices of invariant subspaces relative to different types of operators $A$ are investigated and described. Necessary and sufficient conditions for the finiteness of these lattices are given, and existence of operators which generate given structures of invariant subspaces is discussed. Furthermore, homomorphisms of vector spaces are related to the homomorphisms of lattices and the properties of images of the lattices of invariant subspaces of the vector space $V$ are described.

Properties of invariant lattices are then related to state controllability, output controllability and observability properties of linear dynamical systems ($S$) of the form:

$$\dot{x}(t) = Ax(t) + Bu(t)$$

($S$)

$$\gamma(t) = Cx(t) + Du(t)$$

In particular, the sets of all input matrices $B$ for which the system ($S$) is completely controllable and the sets of all output matrices $C$ for which the system is observable are characterized in terms of the sublattices at the lattice $L(V)$. Theorems regarding the minimal rank of such matrices $B$ and $C$ are proven. State space decomposition theorems are then related to various classes of input or output equivalent systems.

Finally, applications of this theory to invariance and feedback compensation problems are demonstrated.

Reference

The purpose of this research has been to investigate a queueing system in which, contrary to the assumptions usually made, the servers are not statistically identical. More precisely, we consider a queueing system in equilibrium in which customers arrive according to a Poisson process and request service from a group of parallel exponential servers that are numbered 1, 2, ..., s. An arriving customer is served by the lowest-numbered idle server. The parameter of the exponential distribution that characterizes the $i$th server depends on the index $i$; that is, each server works at its own characteristic rate. A blocked customer (one who finds all s servers busy) may defect from the system or wait in accordance with any scheme such that the states of the system comprise a birth-and-death process. For this model we calculate (i) the probability that an arriving customer will find all s servers busy and $k = 0, 1, \ldots$ other customers waiting in the queue, and (ii) the load carried by (utilization of) each server in the ordered group. These quantities permit straightforward calculation of other important quantities, such as the waiting time distribution function for various queue disciplines.

The problem can be viewed as a natural generalization and combination of two other problems that have received some attention in the literature. The first is that of queues with heterogeneous servers (servers that work at different rates) and the second problem is that of queues with homogeneous (statistically identical) servers in which the servers are ordered (numbered) and each customer is served by the lowest-numbered idle server.

When the servers are homogeneous, the system in equilibrium can be described in the usual manner by the well-known one-dimensional birth-and-death equations that relate the rates at which the system moves from state to state. In this case the "state" of the system is taken simply as the number of customers present, without regard to which servers they occupy. Thus the order of search for an idle server is irrelevant unless one is interested in the behavior or states of a particular server instead of only the behavior of the system as a whole. On the other hand, if the servers work at different rates, then a description of the (birth-and-death) process requires specification of not only the total number of customers present, but also the identities of the particular servers they occupy. Thus, the way in which a customer chooses which server to occupy when more than one is available must be specified when the servers are heterogeneous. Hence, the birth-and-death equations that describe the case of heterogeneous servers are now multidimensional instead of one-dimensional. These multidimensional equations are no more difficult than their one-dimensional counterparts to derive, but they are much more difficult to solve since, unlike the one-dimensional equations, they do not, in general, yield a simple closed-form solution.

Most previous authors who have considered queues with heterogeneous servers have assumed either random or ordered selection of idle servers, and all have approached the problem through solution of the detailed multidimensional
equilibrium birth-and-death equations. For the case where an arrival who finds at least two idle servers chooses his server at random from all those idle, Gumbel [4] has shown that, as sometimes occurs in such problems, the multidimensional birth-and-death equations for this case do admit a simple closed-form solution whose correctness is easily verified by substitution.

On the other hand, if service is provided by heterogeneous servers that are selected in a prescribed order, the problem is more difficult in the sense that the multidimensional birth-and-death equations for this case do not admit a simple closed-form solution. Consequently, this problem (to which this paper is addressed) has previously been studied only for the case $s = 2$ servers, by Krishnamoorthi [6] and Singh [9] (see also pp. 220-223 of [1]) and $s = 3$ servers, by Singh [10], where the number of equations is small enough so that an algebraic solution is easily effected. Additional references are given in [9].

The problem of homogeneous servers that are selected in a prescribed order is of importance in teletraffic theory, particularly in studies of alternate routing of telephone calls and determination of the load carried by each trunk (server) of an ordered group. These efforts, which date from the 1920's, are described in Syski [11] under the headings of alternate routings, gradings, hunting, overflow, and limited availability.

The strategy of the present paper is to attack the problem of ordered heterogeneous servers through application of some ideas that teletraffic theorists have used in studies of ordered homogeneous servers. This approach permits solution of the detailed multidimensional birth-and-death equations.

The model under consideration is the following. Customers request service from a group of servers that are numbered 1, 2, ..., $s$. An arriving customer is served by the lowest-numbered idle server. No server can be idle if a customer is waiting. The probability that exactly one customer will arrive in any interval of length $h$ during which $k$ is the number of customers present is $\lambda_k h + o(h)$ as $h \to 0$, $k = 0, 1, ..., \lambda_k = \lambda$ when $k < s$; and the probability of more than one arrival is $o(h)$ as $h \to 0$, independently of all other considerations. Similarly, the probability that exactly one customer will depart from the system (through service completion or defec-

tion from the queue) in any interval of length $h$ during which $k$ customers are present is $\mu_k h + o(h)$ as $h \to 0$, $k = 0, 1, ..., \mu_k = \mu(1)x_1 + ... + \mu(s)x_s$ when $k \leq s$, and where $x_i$ $(i = 1, 2, ..., s)$ is the realization of a random variable $x_i$ defined by

$$
X_i = \begin{cases} 
0 & \text{when the } i^{th} \text{ ordered server is idle;} \\
1 & \text{when the } i^{th} \text{ ordered server is busy;} 
\end{cases} \quad (1)
$$

also, the probability of more than one departure is $o(h)$ as $h \to 0$. 

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We define $y_1(x)$ by the recurrence

$$y_i(x) = \frac{y_{i-1}[x+\mu(i)]}{1 - y_{i-1}(x) + y_{i-1}[x+\mu(i)]}$$

($i = 1, 2, ... , s-1; \ y_0(x) = \lambda/(\lambda+s)$)

and yet

$$B_i = y_0[\mu(1)]y_1[\mu(2)] ... y_{i-1}[\mu(i)]$$

($i = 1, 2, ... , s$).

Finally we define

$$A_k = \begin{cases} 1 & (k = 0) \\ \frac{\lambda_1 \lambda_{s+1} ... \lambda_{s+k-1}}{\mu_{s+1} \mu_{s+2} ... \mu_{s+k}} & (k = 1, 2, ...) \end{cases}$$

and

$$A = \sum_{k=0}^{\infty} A_k$$

Then we have the following results:

(i) If $P_i$ is the equilibrium probability that there are $i$ customers in the system (in service or waiting for service) at an arbitrary instant, then $P_i = 0$ ($i = 0, 1, ...$) when $A = \infty$; if $A < \infty$, then

$$P_{s+k} = \frac{B_s}{1 + (A-1)B_s} A_k$$

($k = 0, 1, ...$)

If $\pi_i$ is the equilibrium probability that an arriving customer finds $i$ other customers in the system, then

$$\pi_i = \frac{\lambda_i P_i}{\lambda \left[ 1 - \sum_{k=0}^{\infty} P_{s+k} + \sum_{k=0}^{\infty} \lambda^s+k P_{s+k} \right]}$$
(ii) If $P_j$ is the load carried by (or the utilization of) the $j$th ordered server (that is, $P_j = P(X_j = 1)$), then

$$P_j = \frac{\lambda_{(j)}}{\mu_{(j)}} (B_{j-1} - B_j) \left[ 1 - \sum_{k=1}^{\infty} P_{s+k} + \sum_{k=1}^{\infty} P_{s+k} \right]$$

$$j = 1, 2, \ldots, s; B_0 = 1$$

The model discussed raises several obvious questions. One class of questions concerns optimization—that is, the allocation of resources to achieve a desired objective at the lowest possible cost. For example, suppose that slow servers are cheaper than fast servers. How does one identify the set of servers and the order of search that will meet a prespecified criterion, such as providing a mean sojourn time not to exceed a given value, at lowest cost?

Another interesting system is one in which each customer minimizes his own sojourn time by (possibly) refusing to accept service from an idle server if he can reduce his expected remaining sojourn time by waiting for a faster server to become idle. This problem was considered by Godini [3], who set up, but did not solve, the detailed equilibrium probability state equations. Although these problems can perhaps be solved by brute force for systems with only two or three servers, more sophisticated methods are necessary to deal with an arbitrary number of servers.

It is worth observing that the probabilities (6) and (7) differ from the corresponding probabilities for the ordinary one-dimensional birth-and-death queueing models by only a constant. Therefore, all quantities that depend essentially on only the probabilities for states that correspond to all servers busy require no new theory for their calculation. For example, in the ordinary $M/M/s$ queue with order-of-arrival service, if $W$ is the waiting time then it is well known that $P(W > t | W > 0) = \exp[\{-(1-\rho)sut\}]$, where $\mu^{-1}$ is the mean service time and $\rho = \lambda/su$. In the corresponding problem with heterogeneous servers, the same results hold with $su = \mu(1) + \ldots + \mu(s)$.

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Digital Simulation of a Prairiedog Town

T. G. Windeknecht, S. F. Powell

In an earlier study, a quite sophisticated mathematical model of the day-to-day evolution of a colony of prairiedogs was constructed [16]. A novel feature of this model was the representation of individual prairiedogs as "stereotype" individuals; i.e., no aggregation of individuals was employed. The model was simulated on a digital computer and a thorough investigation made of run-time and memory requirements as a function of the number of individuals represented. Some impressive computer capabilities for this kind of disaggregated model were demonstrated. In the present study, considerable attention was paid to verification of the above model. Subsequently, some interesting (although preliminary) simulation results were obtained on (i) deterministic mechanisms for cycles and (ii) genetic factors in prairie-dog populations.

The detailed results for 1972/73 include:

a. A verification study of the original model of a prairiedog town; in the end, the model was altered significantly (with the aid of Dr. L. Chiaraviglio). For example, considerably simplified models for the movement, health, and mating behavior of prairiedog individuals were adopted and a simple model for a genetic factor was introduced.

b. An APL simulation program for the revised model was written.

c. An extensive simulation study of population dynamics was conducted in APL.

d. A FORTRAN translation of the APL program was written to facilitate further, and more elaborate, studies of the new model.

e. A document [12] was prepared providing both prospective and background for this disaggregation approach to modeling societal systems and further surveying the relevant literature, particularly on simulation languages.

In the stereotype approach to model-building [4,5,15,17], one models a group of interacting individuals by the technique of replacing each individual in the system by a simplified, deterministic (nonrandom) stereotype of real behavior. In particular, this stereotype behavior includes a mechanism for the interaction of the individual being modeled with other (stereotype) individuals. Conceptually, one replaces the real system of individuals by an identically structured system of interacting, almost robot-like, stereotype individuals. The most important feature of this approach is the fact that the identity of individuals, although simplified, is preserved.

In adopting the stereotype approach to modeling, one makes a basic conjecture; namely, that a group of interacting stereotypes will exhibit group
characteristics very similar to the actual group of the interacting individuals thus represented. One suspects that the validity of the conjecture is enhanced as the number of individuals becomes larger. But of course these are precisely the circumstances under which the understanding of group behavior becomes difficult and vital in applications.

A sizable literature [1-3,6-9,11,13,14] exists on the behavior and habits of the North American black-tailed prairie dog (Cynomys ludovicianus). The prairie dog is a member of the ground squirrel (spermophile) family. As such, he builds underground homes by burrowing in the ground. Prairie dogs inhabit western North America and southern Canada to northern Mexico. The black-tailed species is found in the open plains and appears to be quite gregarious.

A reasonable description of the eating habits, social order, territoriality, emigration, mating and breeding characteristics, life-span, etc., is to be found in the above-mentioned references. The main points are that the prairie dog is a grass and forb eater observing a strict social order wherein a dominant male controls a territory containing a number of burrows, females, and their young; alimental migration or emigration is the only mass movement of the species; the prairie dog does not store food nor does it hibernate but, rather, it lives off its fat during the winter months; it is not a prolific breeder having only one litter of offspring per year, usually of three to six animals; it is promiscuous; and it enjoys a life-span of up to eight years (rarely) with sexual maturity occurring between one and three years. The family unit, called a coterie, consists typically of one adult male, two or more females, yearlings, and the young of the year [9].

Given these facts from the literature, the construction of a deterministic, stereotype model of prairie dog individuals and their interactions was undertaken. The resulting model appears in [16], together with some impressive statistics on computer capabilities (simulation runs involving around 10,000 state variables have been taken using this model). Briefly, the model consists of a number of coterie locations with a fixed geometry and a number of prairie dog individuals who occupy these locations with a basic social organization. A coterie location is described by an identification number, a measure of the vegetation present, and the vegetation growth rate. A stereotype prairie dog is described by an identification number, sex, age, health index, location, mating status, and genetic type. Basically, the locations and prairie dogs are updated on a daily basis during the spring mating season while the rest of the year (during which time prairie dogs do not change locations) is updated in one step. The spring season is divided into several time periods in which social disintegration, competition for territory, and social renewal (oestrus) occur. It terminates with the birth of the young.

An analysis of early simulation results was carried out with the objective to compare the early model characteristics with known facts about prairie dog dynamics. This resulted in a number of modifications in the model being introduced:
a. Yearling prairiedogs remain at the location of their birth until their second spring.

b. When vegetation at a coterie location is exhausted, the growth rate becomes zero until the next spring, at which time it assumes one-half its nominal value. Once mated prairiedogs reoccupy the location and the growth rate assumes the nominal value once more.

c. The health indicator for a prairiedog is simply the total number of days in its life when it found no food. The percentage of such days in the life of a prairiedog, when exceeding a certain threshold, results in the early death of an animal.

d. A prairiedog changes location only if (i) there is no vegetation at that location; or (ii) it is an adult male, it is the spring mating season, and at least one more dominant adult male is present at the location; or (iii) it is an adult female, it is the spring mating season, and there are at least two more dominant adult females present.

e. When a prairiedog changes its location, it moves to the north, south, east, or west according to a throw of dice (with equal probabilities).

f. A normal coterie consists of nineteen prairiedogs (one adult male, two adult females, eight yearlings—four of each sex, and eight pups—four of each sex).

g. There is a genetic factor of two states ("one" or "two") which appears as a multiplier in calculating the animal's dominance. In the birth of pups, the first and third of a litter are males whereas the second and fourth are females; the first and second take the genetic factor of the mother whereas the third and fourth inherit the father's type.

h. Females die automatically at the start of their fourth spring; males their third.

Verification studies were conducted on a town with nine coterie locations (and a nominal carrying capacity of 171 prairiedogs). While a great deal of detailed data is available, we shall content ourselves here with recounting some of the main results:

a. Basically, in terms of population dynamics, coterie composition, mating and eating behavior, health, life-span, movement, etc., the current model is consistent with the extensive field observations of King [9]. At the same time, the complete model is significantly simpler than that studied earlier in the large-scale situation (300 coterie locations and 1700 prairiedogs).

b. Populationwise, classical growth curves, die-offs, and cycles are easily demonstrated.
c. Several deterministic mechanisms for the creation of population cycles were demonstrated; in particular, very modest changes in male spacing behavior, coterie composition, vegetation growth rates, and vegetation storage capacity, all create extreme population instability with cycles of typically six or seven year periods. In short, social organization is crucial to the efficient utilization of resources and the creation of population stability.

d. Genetic selection can be controlled by environmental factors and, in the simulation, is very sensitive to them. For example, altering the pattern of emigration (e.g., fencing the animals in) creates great forces for increasing the rate of natural selection. This is consistent with recently advanced propositions which suggest a strong influence of genetic factors in population cycles of rodents. (See [10].) In fact, any situation resulting in population decline, widespread starvation, increased death rate, decreased birth rate, etc., is accompanied by a significant increase in the rate of genetic selection.

Further studies of the prairiedog simulation are planned. (See [12].)

References


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Audiographic Learning Technology in Public Education

A. P. Jensen, J. M. Gehl, P. C. Hankamer, P. J. Siegmann

Audiographic learning technology [1-3] provides for the storage and replay of blackboard, narrative/line graphics lectures and instructional materials. An extremely important feature of this novel development in educational technology is its economy—a low cost both in equipment and in the preparation and storage of learning materials. In its more advanced form, as implemented in the Audiographic Learning Facility of the School of Information and Computer Science, the system provides for random access retrieval of audiographic lessons via telephone, under the control of instructors or students. Applications of audiographic technology therefore hold the promise of upgrading the quality of instruction of students through presentations of high-quality learning materials, prepared by and recorded by outstanding teachers, in classrooms manned by less experienced or qualified teachers; of supplementing curricula of inadequately staffed schools; of aiding in teacher-training; of implementing individualized self-instruction of motivated students; and of providing for a more flexible delivery of instruction. The primary goal of the particular experiment described in these pages has been to make an initial assessment of the utility and effectiveness of this new instructional technology in public education. The "laboratories" in which the experiment was conducted were selected Georgia secondary and elementary schools, and the experimenters were ten practicing, professional school teachers who used their classrooms to introduce audiographic learning technology to public education.

Audiographic technology facilitates the electronic storage of learning materials in two forms, visual and audio. The visual consists of motion line-graphics (handwriting, drawing, etc.) synchronized with narrative audio presentations. A Victor Electrowriter transmitter is used to generate frequency modulated signals representing handwritten line graphics. These multiplexed FM signals are recorded on one channel of a stereo magnetic tape in synchronization with a second channel of the same stereo magnetic tape.

The mechanism for delivering audiographic materials has two essentially different, but complementary, levels: one utilizing decentralized storage at individual user locations, the other utilizing storage managed at one central location (usually under control of a small computer). The first level of use is the one which was employed in this experiment in public education. At this level, students receive instruction by means of stereo cassette recordings made and played on portable audiographic units, each of which includes a modified cassette recorder player unit and associated special electronics equipment which generates FM signals to a speaker from one channel and to a Victor Electrowriter receiver on the other channel.

An ordinary microphone is used for entry of the audio portion of the lesson; an Electrowriter transmitter is used for entry of the graphics portion. Using the transmitter's writing stylus (similar in appearance to a ballpoint pen), the teacher may enter formulas, diagrams, drawings, or any other
"chalkboard-type" materials. When it is desirable to have more writing space, the teacher may in effect "erase the board" by signaling for a page change. The used surface will then roll out of the transmitter, and new paper will be fed from a roller in the front.

The wires extending from the microphone and transmitter lead to a specially modified recording unit, which makes it possible to capture the audio portion on one channel of the stereo cassette and the graphics portion on the other. The left track contains frequency modulated signals generated by the position coordinates of the writing stylus of the transmitter. (The main reason for the modification is to provide for the removal of distortions which would otherwise occur in graphics reproduction as the result of normal wow and flutter characteristics of all tape recorders.) The graphics and audio entries are recorded synchronously and completely, including all page change signals. It is thus possible to replay the lesson exactly as it was recorded. The replaying of the lesson is then effected through the use of a Victor Electrowriter receiver system, which consists of a unit for accepting the recorded graphics signals and reproducing graphics materials on an acetate surface, and a projector which is used to enlarge those graphics and project them onto a wall or screen. In addition, a speaker attached to the recorder allows simultaneous reproduction of the recorded narrative (audio) portion of the lesson.

With the above serving as a general introduction to audiographic technology, it is appropriate now to focus specifically on the administration of the past year's experiment.

From the beginning of the project, it was emphasized to the participants that it was not the intention of the experiment to impose a single administrative approach on all participating schools; rather, it was hoped that from the diversity of environments would emerge a welcome diversity of ideas that would provide a valuable resource for guiding the future development of the ALF system. In all cases, teachers were free to select for themselves what kinds of lessons they wanted to adapt for this experiment, and were free to decide which percentage of each classroom hour would be devoted to the use of audiographic technology. Indeed, all decisions having to do with conducting the class were left to the discretion of the individual teacher.

In anticipation of delivery of the equipment, the teachers began the task of developing general plans for the lesson sequences which they would subsequently prepare and record. It was suggested that the teachers develop their plans in such a way as to facilitate the development and formalization of multiple "learning strategies" from which a learner might choose one which best satisfies his own information needs. It became apparent, however, that the teachers did not feel entirely comfortable with this suggestion; the reason for this uncertain response to an attempt at individualization seems to be rooted in the fact that the experience of classroom teachers is developed in the context of a search for a common denominator among the students. Thus, a good teacher usually adopts a middle-ground approach: trying to go neither too fast for the slower student nor too slow for the more gifted one.
The compromise which this instructional tactic represents is an entirely prudent and justifiable one, given the exigencies of classroom teaching and the desirability of being fair to all students. However, the habit of searching for the common denominator is perhaps not the best preparation for developing and formalizing multiple learning strategies. In future experiments, therefore, this task would probably be best assigned to subject specialists, who would develop lesson specifications to guide teachers in the preparation of instructional material to meet specific needs in a well-planned lesson base.

In the course of progress review sessions, it was determined that primary evaluation would emerge, not from a series of small, formal experiments but from the professional assessments of participating educators. In obtaining such assessments, it was fortunate that the project had recruited the diverse talents of a group of educators whose collective experience spans a broad range of subject-area expertise. The diffusion of effort resulting from such a recruitment plan was more than justified by the need to obtain enough experience in each subject area to allow a prudent focusing of subsequent research efforts on the one area which promises the biggest payoff in terms of Georgia's educational priorities. Thus, the schools chosen for the experiment were selected on the basis of three principal criteria: the desire to participate; a history of innovation in education; and an ability to represent any one important segment of Georgia education. Application of these criteria resulted ultimately in the selection of one elementary school, four high schools, and one post-secondary school. Three of the schools are administered by country school systems; two by city school systems; and one of the schools is an area-wide post-secondary vocational and technical facility.

The broad goal of initial technology assessment contained within it four more specific objectives: (1) the development of experience to guide the production of standard techniques and procedures for the preparation, recording and management of learning materials in audiographic form; (2) the introduction of audiographic instruction in selected schools and the preliminary assessment of its potential for improving the quality of instruction and for receiving the acceptance of teachers and students; (3) the evaluation of technological devices under conditions of extended usage; and (4) the assessment of the associated direct and indirect costs and benefits of audiographic instruction and self-instruction.

With respect to the first objective, it is necessary to evaluate the trade-off which exists between the articulation of standard techniques and the insistence on the preeminence of the individual teacher. A teacher fills a dual role: part author, part tutor. As a tutor, the teacher makes use of learning materials designed by others; as an author, he in some sense creates his own material, as he would write his own book. Thus, in his authorship role, the teacher will tend to exercise the prerogatives of authorship, and do things the way he wants to (which may in fact be simply the only way he knows). To the extent that, in a given situation, it is desirable to standardize instruction, to that same extent will it be necessary to have
subject-specialists preempt the authorship function somewhat by supplying the teacher with detailed, content-oriented instructions for the preparation of an audiographic lesson.

The second objective of the evaluation requires interpretation in the context of a specific educational environment, and the answers to the questions it poses may well change from school to school. Like any other technology or like any other teaching tool, audiographic technology will be relatively more or less useful to a teacher depending on his own attitude toward it. Since audiographic technology is in its infancy, the decision to pursue extended developmental research within a particular application area must depend to a large extent on the demonstrated interest of the user and on his ability to utilize the technology effectively. No innovative and experimental system is ever received with equal enthusiasm and resourcefulness by all users. Therefore, the purpose of this study was partially to acquire sufficient knowledge of the participants in the experiment so that an effective reallocation of future efforts could be accomplished in such a way as to consolidate those efforts in the one application area which shows greatest potential for extended development.

The third objective was to test the equipment itself "under conditions of extended usage." The nature of "extended usage" has two dimensions: temporal and spatial. In regard to the first dimension, the objective meant determining how the equipment functioned week after week and month after month; in regard to the second dimension, the objective meant determining how the equipment functioned when installed at a number of widely separated "field locations" not frequently visited by trained technical personnel. Each of the two dimensions of the question yielded a somewhat different answer during the course of the experiment. The equipment has required, over time, only the most minor and routine of adjustments, and in that sense has therefore performed superbly. However, because of the diffusion of effort at six different locations besides Atlanta, minor technical problems sometimes translated into major frustrations for teachers with no technical knowledge of the system. This state of affairs is certainly not out of the ordinary for the implementation of an innovative technology, but it reinforces the desirability of consolidating research efforts at one location while system refinement continues.

The fourth objective was simply to assess the associated direct and indirect costs and benefits of audiographic instruction and self-instruction. Of course, only tentative cost/benefit relationships can be derived from a study which did not attempt extensive implementation within any given environment; however, certain broad conclusions are quite possible even from an inquiry restricted to small-scale experimentation in diverse settings.

In summary, it may be said that the goal of the study was to explore the potential of audiographic technology from the points of view of two kinds of economy--dollar economy and learning economy. From the former viewpoint it was desirable to gain some experience concerning both hardware costs, maintenance costs, software costs and usage costs, all of which now appear to be
quite modest in terms of educational experimentation and in the context of a large-scale implementation at a single location. From the latter viewpoint it was desirable to gain some experience concerning the system's ability to capture the interest of practicing teachers (contrasted with media experts)—for the greatest single resource of an educational system is the experience of its teachers, and no system which (in the name of technological advancement) underutilizes that resource can claim to be economical. Rather, an educational technology must be economical both with financial resources and learning resources. In this experiment it has therefore been important to establish that audiographic technology is emphatically "learning effective" in the sense that professional, experienced teachers are able to accept it as an innovation and agree to offer their own expertise as a valuable "system input."

Since the motivation for the development of the Audiographic Learning Facility has been the desire to use technology to effect an efficient and effective dissemination of instructional materials, the Audiographic Learning Facility is essentially an educational "delivery system" which provides useful new communication links between teachers and learners. A requirement of a technology for such a delivery system is that it must serve as a relatively unobtrusive and relatively neutral part of the learning process. That is, it must not force a teacher to adopt some arbitrary and unnatural mode of expression, to present all material in a single unchanging format, or to abandon the teaching skills learned patiently after a number of years of experience at a chalkboard in front of live classes. For the essential purpose of an educational delivery system is not to force a change on education, but rather to facilitate education—by respecting the special idiosyncratic qualities of individual experienced teachers.

The Audiographic Learning Facility meets these requirements by making it possible for a teacher to record a lesson in virtually the same manner in which the material would be presented in either a classroom or a tutorial setting. The process of recording a lesson for the Audiographic Learning Facility is in most respects the same as the process of delivering a lecture at the chalkboard or of using a scratchpad to work problems with an individual learner.

One of the important pedagogic features of audiographic technology is its capability for capturing the dynamics of a graphic illustration. In a textbook, the usual method of presentation of a graphic is to show only its finished state; thus, a textbook illustration of a bookkeeping journal would fail to convey how the transactions were actually recorded in the journal one step at a time. Even if some attempt were made in the textbook to suggest the dynamics of the journal at various moments in time, the result would still be incomplete unless a separate snapshot were given after each and every step—an impractical suggestion. In addition, the essential lifelessness of such snapshot reproductions cannot help but give them a diminished reality in the mind of the learner. In contrast, audiographic technology allows the teacher to show a learner exactly how an illustration builds up, using the same teaching methods that would be used at a teacher's
chalkboard or on a tutor's scratchpad. Whether it is used for journal entries, sentence transformations, equation solutions, or numerous other kinds of exercises, this dynamic capability can be used to extremely good effect.

However, at the present state of equipment development, the graphics capability of the system is limited somewhat as to the level of detail which can be presented. The writing area on the Electrowriter receiver is simply not large enough to allow an extremely detailed or lengthy illustration. Virtually all the teachers who have worked with the system have expressed the desirability of having a writing area which allows a somewhat greater level of graphic detail, and this consensus has provided a valuable input to the developmental effort. The eventual solution to this problem will probably lie not in the enlargement of the actual writing surface, but in a system modification which incorporates a receiver capable of receiving and clearly projecting more complicated and more finely detailed illustrations than are now possible. On the other hand, the participants in the experiment agreed that enhancement of receiver capabilities was, though desirable, not essential to the effective use of the system. The limited size of the graphics surface is a constraint like any other constraint: even with a chalkboard a teacher can wish for more space. The real answer is careful lesson planning; with a well-planned lesson a teacher is seldom seriously hampered by insufficient writing space. To the contrary, the division of particularly complicated graphics into logical segments can enhance the clarity (as well as improve the pace) of the presentation.

In conclusion, it may be asserted that the principal indicators of whether a technology-based instructional delivery system is likely to make an important contribution to education are: its economy; its administrative flexibility; its potential for facilitating individualization of instruction; its ability to allow re-use and interchange of learning materials; and its technological compatibility with an extended network of remotely connected learning resource centers. As is indicated by the following discussions of the past year's experiment, audiographic technology continues to appear extremely attractive with respect to each of these characteristics.

Economy. In addition to system hardware costs it is necessary to consider equipment maintenance costs, cost of materials, and software costs (including especially the cost of preparing instructional materials for use on the system). Currently, the cost of a complete cassette-version portable system is approximately only $4,300, including graphics transmitter, stereo recording unit modified with a specially designed compensator, graphic receiver unit, and projector. (In a remote application a typical learning station would be equipped simply with a data set, a receiver and a projector, and would thus be even less expensive than a self-contained portable unit; total cost of such a learning station would be under $2,000.) Since none of the components of the present system are yet produced in large quantities, it is projected that future versions of the system will be available at dramatic cost reductions. The projector, for example, now costs approximately $600, which is approximately ten times what it would cost when mass-production techniques are applied in anticipation of full-scale implementation. Cost
of materials consists essentially of minor expenses for ink, paper, acetate, and ordinary stereo cassettes. The cassettes, of course, are reusable--both in the sense that they may be replayed for any number of learning groups, and in the sense that they can be erased and used for new instructional purposes. However, the most powerful example of the economy of audiographic learning technology is to be found in software costs. Thus, contrasted with the exorbitant requirements of, for example, either video production or the production of well-designed programmed instruction materials, audiographic technology is virtually cost-free, for the cost of producing a (reusable) ALF lesson is no higher than the cost of carefully preparing an ordinary classroom lecture. No special computer "author" languages need be learned; no elaborate staging techniques need be mastered. All that is required is an instructor's interest and acquired teaching skill.

Flexibility. When considering the ability of ALF to contribute to administrative flexibility, a distinction needs to be made between conditions of use in an experimental setting and conditions of use in an established operating program. Since the former conditions have existed during the past year, the scope of administrative concern was of course enlarged rather than reduced. However, the experience gained during the past year corroborates the view which sees that audiographic technology carries a strong potential for enhancing administrative flexibility. The fact that on various occasions during the experiment ALF lessons were successfully supervised by substitute teachers indicates that audiographic technology holds the promise of having a high impact on school administration, particularly in regards to class scheduling, to the employment of different levels of teachers for different purposes (lecturing, tutoring, etc.), to the more effective use of substitute teachers, and so on. Further, the system's still largely untapped capability for economical use or re-use at any hour of day or night offers an extraordinary opportunity for remarkably extending the utilization of existing educational resources.

Individual Learning. Audiographic technology allows economical individualization of instruction in several different ways. One important system capability is its "instant replay" feature, which allows a portion of a tape to be replayed, if desired, immediately after its first use. This capability is particularly important for slower students, who may need to see a presentation over again in precisely its original form. The facility for instant replay was used extensively by a number of participants in the experiment. However, perhaps an even more important contribution which audiographic technology makes to individualization of instruction is its ability to allow the teacher to extend his or her own "presence" simultaneously to two or more groups.

In short, it seems clear from the past year's experience that the only limit on the system's ability to provide new dimensions in individualized instruction has been due to the constraining realities of limited resources. No one school has had more than two ALF units, and with only two units at a location extremely limited student access is inevitable. With a larger number of units at the disposal of a single school, individualization of instruction will increase impressively.
Interchange of Materials. Opportunities for interchange of learning materials between schools and school systems could be explored only tentatively during the past year, mainly as the result of the impact of several largely unanticipated adjustments to the project schedule. However, the eventual prospects for such exchange seem bright indeed. In the one instance where some cassettes made at one school were sent to another school in another system, the principal's response was positive in the extreme. Such exchanges will in the future no doubt prove to be extremely beneficial to the cause of public education by promoting variety, cross-fertilization, and superior instruction.

In summary, the experiment described in these pages has confirmed the proposition that audiographic technology presents a wide range of opportunities for improving the quality and increasing the flexibility and scope of public education, while at the same time holding the costs associated with instructional delivery within acceptable bounds. A school system which accepts the promise offered by audiographic technology will not only be able to extend its resources, diversify its curricular offerings, and maximize opportunities for individualization of instruction, but will also be able to achieve these benefits in the context of local requirements.

This last consideration is important. Any instructional technology (e.g., video cassettes, film strips, educational television, and so forth) adds to the instructional resources of a school; the uniqueness of audiographic technology is that it allows an individual classroom teacher to amplify and extend his own presence. Media can be economically prepared by and for local systems to meet specially perceived local needs.

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Application of Semantic Information Measures Utilizing Conversational Methodology to Analyze Human Information Processing

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For the period covered by the report five areas of research have been identified. The first of these areas concerns the effects of semantic information measures and grammatical transformations on human information processing time. Previous results in the literature indicated that negative and passive transformations of kernel sentences require significant processing time. These experiments however failed to control for the amount of semantic information measured on the transformed sentences. Sentences and transformations were constructed to provide an orthogonal test of the effects of transformations and semantic information. Processing time was determined by presenting sentences in written form and requiring the subject to determine the truth or falsity of the presented sentence relative to pictorial information presented in a visual display. Analysis of results for 15 subjects demonstrated highly significant effects for grammatical transformation. No differences were found for semantic information measures, and there were no significant interactions. Additional study suggested that further research was required to analyze the pictorial visual search task into components if definitive results were to be obtained. Since this projected research required instrumentation that was not available, and was judged to be of lower priority than competing research topics, further research on the effects of grammatical transformation and semantics information was held in abeyance.

A second area of research has been the development of a rehearsal model to account for rehearsal strategies observed in conversational learning tasks. A model for rehearsal was developed which contained parameters indicating (a) retention in short-term memory, (b) transfer from short-term to long-term memory, (c) confidence threshold for performance selected by the subject. The model permits the inference of the confidence level chosen by the subject on the basis of information transmitted in the set of trials to initial rehearsal. The remaining parameters were determined from prior experimental data.

Data have been collected from ten subjects to verify the model. It is anticipated that the model will be fit to the data in the near future to complete this phase of the research.

A third research task has been the analysis of the elementary processors and programs required to account for the behavior graphs obtained from conversational rule learning experiments. The results to date indicate that there is considerable commonality in the required processors from subject to subject; however, it is anticipated that substantial individual differences in programs will be found. Analysis of protocols is incomplete at this time, and is scheduled for completion by the end of the summer quarter.

The fourth research project resulted in the development of a mathematical proof which demonstrates that the search strategies displayed in an
individual behavior graph are optional within constraints imposed by the human processing system. This research will be extended to permit a comparison of information equivalent strategies and to assess the possible effects of external memory on performance.

Finally, in the fifth research area, explanatory data have been obtained on the effects of conversational learning on long-term retention, and utilization of a read-only external visual memory on acquisition and retention performance. These preliminary data suggest that long-term retention is significantly better for conversational learning as compared with conventional presentation of learning material.

Preliminary data have also been collected which confirms the assumption that access to an external memory permits more effective learning, but requires the support of the external memory for effective retention. Performances with and without external memory during acquisition have been compared. It is assumed that the utilization of an external memory will permit subjects to display an acquisition strategy which more closely approximates an optimal strategy. The paradigm guiding this research is based on adumbration of optimal search strategies and the assumption that human acquisition strategies will approach prescriptive optimum performance as memory constraints are reduced. Utilization of external memory permits the study of such effects by reducing internal memory constraints.

References


The Elementary School Trainer

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In a previous study, a quite sophisticated mathematical model of the learning dynamics and economic processes of a six-grade elementary school was constructed; the model was then simulated on a digital computer and a thorough study of it was conducted. Results appear in [1,2,4]. The model is unusual in that individual students and teachers are explicitly represented and in that the evolution of the individuals is observable as a function of administrative decision-making. It appears that this simulation model, with some modifications and improvements, could provide a useful tool in university courses for the preparation of elementary school administrators. The current research is aimed at a practical test of this conjecture.

The results obtained during 1972/73 are as follows:

a. Preliminary plans were made for the creation of a laboratory course at Georgia State University in which graduate students will interact with the elementary school simulation in the role of decision-makers performing the long-range planning function.

b. Funds in the amount of $15,000 were secured from the Urban Life Extension Budget at Georgia State for operation of this laboratory.

c. A proposal [5] was written and submitted concurrently to the National Institute of Education to support the modification of the existing simulation program for the graduate laboratory (in particular, to render it highly interactive).

d. The elementary school simulation program was modified and rendered operational on the B-5500 digital computer of the School of Information and Computer Science, Georgia Institute of Technology.

e. Work on the preliminary design of the software to support the graduate laboratory was carried out.

f. A document [3] was prepared providing some prospective and background for the study including an extensive investigation of relevant literature on (i) simulation of educational systems and (ii) university education using computer simulation as a training device.

Originally, a primary reason for implementing a digital simulation of an elementary school was to establish the technical feasibility of a new, disaggregated method for simulating a complex system involving human decision-makers, particularly in terms of memory requirements and run-times and in

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terms of developing an understanding of such a complex system using a reason-
able scheme for outputing data. Basically, the technical problems were
easily dealt with and are not of concern in the present research. (Simula-
tion of the operation of the 180-student school for a ten-year period takes
about three minutes on an IBM 360/44 digital computer using only a fraction
of its 150,000 byte memory.)

A complete description of the model is given in [1]. The school that was
modeled is a six-grade elementary school (grades 1 through 6) having approx-
imately 30 children per grade. There is one main teacher for each grade
with the possibility of aides (nonprofessionals) and assistants (profession-
al). Each child is characterized by three variables: his achievement rel-
ative to grade (-2.5 to 4.0), his grade (1 through 6), and an intelligence
factor (0.8 to 1.2). Each teacher is characterized by six variables: his
experience in years, his motivation at the start of the year (-1,0,1),
satisfaction with his previous success as a teacher (-1,0,1), satisfaction
with his presently assigned load (-1,0,1), his innate motivation (-1,0,1),
and a talent factor (-1,0,1).

The condition of the physical plant for each class is characterized by a
single variable (-1,0,1) that depends on initial cost, present value, the
maximum value it has ever had, and the annual investment. The condition of
books and supplies is combined into a single variable (-1,0,1) that depends
on the accumulative investment made in this area over the past five years.

An effective student load is determined for each class. It is a complex
calculation depending on the student mix, the teacher's experience, talent,
and motivation, the conditions of the physical plant and books and supplies,
and the presence of aides and assistants. The learning dynamics for each
child is such that the annual achievement for a child is determined from his
achievement level at the start of the year, his intelligence factor, and the
effective student load for his class.

The primary decision makers (e.g., the school board), on the basis of either
local, state, or national policies and/or the progress they observe in the
school, determine how the annual budget is to be divided. In particular,
general policies are applied for allocating funds to faculty and staff,
physical plant, and books and supplies. Implicit in this are policies for
hiring faculty and for allocating excesses (plus or minus). In addition,
there are internal decision makers (e.g., the principal) who determine mat-
ters such as the basis for hiring an aide or an assistant for a particular
class, the strategy used in hiring a teacher from several that might be
available, tenure policies, etc. Clearly, the distinction between primary
decision makers (e.g., school board) and the internal decision makers (e.g.,
principal) is arbitrary and, in practice, seldom clear-cut. Fortunately,
who makes the final decision is generally not as important as what the
decision is.
A simulation of the given model was implemented at Michigan Technological University in early 1972 in the FORTRAN computing language on an IBM 360/44 digital computer. In addition to the implementation of the model relations, the simulation requires mechanisms for introducing students and faculty into the school, mechanisms for setting initial conditions, and mechanisms for turning over students and faculty for reasons other than graduation and retirement. These mechanisms, although not a fundamental part of the model of the school, are essential parts of the simulation. The effectiveness of a particular decision strategy generally depends strongly on the inputs and initial conditions, which should in some way correspond to a set of conditions considered likely for the real system; perhaps even more useful in evaluating the decision strategies being considered is the introduction of a set of conditions which are considered to be the worst likely.

For this simulation of a school system, a mechanism was implemented for generating students such that distributions of intelligence factors and achievement, and the correlation between them, can be varied to simulate various kinds of school districts (e.g., ghetto, university town, etc.). A faculty turnover mechanism was implemented so that it is possible to simulate conditions prevalent in growing school districts, decaying school districts, unpopular school districts, etc. Conditions can also be set in a faculty bank so that varying degrees of teacher availability can be assumed, thus reflecting various teacher job markets. Thus, with a single basic simulation, it is possible to test decision strategies for a wide variety of schools under various conditions.

Using the existing school model, what is now intended is to create a laboratory situation in which graduate students studying elementary school administration interact with a digital computer simulation of an elementary school in a decision-making role. Typically, these students will operate the simulated school for an extended period (ten school-years in the simulation) and annually make decisions concerning budget allocation into faculty salaries, plant investment, and books and supplies; hire teaching staff; make tenure policy; establish a policy on record-keeping; initiate a scheme for testing the achievement of students; implement policy concerning students who repeatedly fail; etc. The computer, after receipt of a student's decisions for the year, will give feedback in the form of English language statements concerning the school (e.g., "the condition of the fourth-grade classroom is deplorable," "the first-grade teacher is very unhappy with her load," "the overall average achievement is significantly below the state average," "your policy is not implementable because you have not provided for plant operation at a minimal level," "your policy is not implementable because of an accounting error--your overall budget is overspent by 9%," etc.). In addition, the results of achievement tests (selected by and paid for by the decision maker out of the school's operating budget), the results of interviews conducted with staff (initiated by the decision maker), statistical data concerning the past operation of the school (previously stored by and then requested by the decision maker), etc., will be available from the computer. These various kinds of information will serve
to give indicators for the evaluation of previously made decisions and the present state of the school and thereby affect the making of subsequent decisions. It is envisioned that, in the course of one quarter, each graduate student in a laboratory class of 20-30 will carry out three (ten-year) runs with the school simulation, i.e., a very significant period of computer interaction. In the first two of these runs he will encounter an "average" urban school; thus, he will have the opportunity to affect and observe improvements in the second run as compared to the first. In the third run, he will be presented with a school where the characteristics of the students differ markedly, e.g., the above-mentioned situation of a ghetto school.

References


Audiographic Technology in Continuing Graduate-Level Science Education


Audiographic technology [1,2] permits inexpensive storage, telephone transmission, and synchronous replay of narrative and line graphic presentations, thus capturing the primary content of blackboard lectures. The Audiographic Learning Facility (ALF), a quasi-conversational self-instruction system utilizing this technology developed at the School of Information and Computer Science, strongly indicates the practicability of this economical, widely applicable approach to effective self-instruction by mature learners and groups of learners.

Based on early indications of promise gathered from limited usage of ALF at the high school, college and graduate levels of education, the Georgia Institute of Technology commenced, with support from NSF grant GN-2628, a two-year project seeking to implement and evaluate operationally an ALF system for continuing self-instruction at the graduate level. The project has been a cooperative effort between the School of Information and Computer Science and the Department of Administrative Services of the State Government of Georgia. The Department of Administrative Services is responsible, among other functions, for the planning, design and operation of information processing activities and facilities of the various agencies of the State Government, and it employs numerous professionals who are college graduates in the mathematical and information sciences.

The principal objective of this trial implementation of ALF is the evaluation of its cost effectiveness in programs of continuing graduate education. To meet this objective, the project participants have been engaged during the past year on the following major tasks: the development of a curriculum base; the design and implementation of a physical facility for self-instruction using audiographic technology; and the refinement of an appropriate experimental design for evaluation of the project results.

The Lesson Base. Each recorded audiographic learning unit contains as a minimum a graphic-supported narrative presentation on a single, self-contained topic. In addition to this "lesson," the instructor may include in the learning unit two other distinct elements: an example (or set of examples) and a test (and its solution).

Since ALF is a system for self-directed learning, instructors have been encouraged to make as much use as possible of this capability of the system for allowing the learner to verify his understanding of the material explicated by calling in a separately addressable example or self-test.

On the other hand, the learner may choose to by-pass the example and/or tests associated with a lesson or sequence of lessons. This he might do either because he has full confidence that he has mastered the material, or because he wants to achieve a quick survey of the material (either for
review or for initial overview). Alternatively, the learner may by-pass the lessons themselves, and instead "browse" through a selected sequence of tests. In this way he can in effect sample the material, verify his understanding or lack of understanding of particular topics, and find his own level of competence (and thereby establish a starting point for a new learning goal).

As discussed in the next section of this report, the system has been developed to provide the learner with a substantial degree of control in assessing learning materials formatted in this manner. Thus, when a lesson segment is concluded the system will halt in anticipation of a response from the learner. The learner may repeat the lesson; call for the example or the test, by means of the simple mnemonic commands X or T; or call for the next lesson.

In selecting "the next" lesson, the learner will be guided by a printed directory of learning materials which identifies various suggested sequences of learning modules and characterizes those carefully planned sequences according to their level of difficulty and according to the different learning goals to which they lead.

Each of these identified sequences may be considered a tutor-recommended learning strategy; however, there is nothing to preclude a learner from choosing from the directory of learning materials a sequence of lessons not officially sanctioned by an instructor as a recommended learning strategy (or packaged "course"). One of the interests of the experiment will be to determine to what extent students will choose to use the learning system to develop unique and personal learning strategies, as well as to gauge the effectiveness of those strategies as compared to standard courses. This evaluation will be made possible by a special log program which has been written for the PDP computer; the program will monitor and record both individual and group activity and tabulate it by user-code for subsequent statistical analysis.

The process of identifying recommended learning strategies to meet typical student learning goals will be finalized when the total lesson base is fully developed. The planning and development of the lesson base is an on-going effort, and actual recording of lessons has been in progress since March 1973. When completed, the lesson base produced for this experiment will include a collection of learning materials on (1) systems theory; (2) computer systems and computer systems management; and (3) information and data base systems design and management.

Hardware Design Features. The hardware for the ALF system is designed to connect a user to a pre-taped lesson efficiently while allowing as much user freedom as is practical.
In order to achieve this, the user is expected to have at his station a standard telephone Touch-Tone pad, in addition to the audio receiving device, the Electrowriter graphic receiver, and two phone lines. The Touch-Tone pad should be connected to the telephone line used for audio or voice transmission.

The user connects to the system by dialing (in any order) the graphics phone number and the audio phone number, on his respective phones. He then is expected to key in digits in a pre-arranged sequence that may inform the computer who he is, what lesson he desires, or any other pre-arranged information that may be coded in a combination of 12 digits.

Shifting attention now to the ALF site, the two telephones have been automatically answered through a relay circuit that triggers on the bell current. The audio phone line goes through a network which changes the telephone two-way transmission pair of lines into two pairs, one pair leading into the site hardware, one serving as output from the hardware to the user.

The input pair of lines goes through a tuned RC (resistor-capacitor) decoder (commercially manufactured) that detects which key the user depressed, and transmits this information to a load-in interface which generates an interrupt request to the PDP-8/I processor, and which, when serviced, informs the processor that a button has been depressed and identifies which one it was.

The software takes over at this point, until a recognizable sequence of digits has been transmitted. Suppose the sequence transmitted tells the machine the user wants to hear lesson X. Once the machine ascertains which tape deck contains the tape with lesson X, and where lesson X is relative to the present tape position, the machine activates a load-out interface that signals the tape deck via a relay register, beginning a function. Suppose lesson X is 14 marks forward on tape unit 3. Then the load-out interface activates the "forward" solenoid on deck 3, while another interface selects the proper track. At the same time, a photo-transistor mounted on the tape deck is detecting the white markers placed on the tape. Each time a mark passes the photo-transistor another interface informs the processor that a mark has passed. When 14 have passed, the processor activates the "stop" operation, then actuates "play" (again through the relay register). If marks are encountered as the tape is played, the processor is so informed; thus the position on the tape is always known. Now lesson X is playing. Another load-out interface operates a switching array which directs the output of tape unit 3 to the proper phone lines.

Associated with the output are two devices. The compensator unit alters the graphics output to compensate for tape deck wow and flutter, by comparing a reference frequency which was recorded on the tape with a standard oscillator. In addition, line devices are needed on each line, to serve as a control over the signal strength which is output over the telephone lines and to buffer the output signal to meet telephone company restrictions.
At this point the user is receiving the audio and graphics transmission that he requested. If at any time he desires to stop the tape, or perform any given operation, he merely keys in the appropriate sequence of numbers, and the same process described above is followed to carry out his wishes. It should be noted that the operations mentioned occur at microsecond-magnitude speeds, with the exception of tape operation on the decks themselves, which are obviously constrained to normal tape-deck-operation speeds.

At termination of connection, the user signals the machine, and the two phone lines are disconnected upon the reception of a user-on-hook signal.

System Software. The software for the Audiographic Learning Facility is designed to provide system users with the flexibility needed to utilize the system effectively, while still permitting the system to retain complete control over all hardware components and their respective functions. This design objective may be viewed as a problem in process control, with real-time system functions occurring at random times. The Control Program was written to provide software to satisfy this requirement. The Control Program has three basic tasks: the first is to initialize the system with information from the operator on the location and contents of the lesson segments; the second is to control, based on established algorithms, the various operations of the system (i.e., tape recorder control and spot detection, phone line switching, Touch-Tone input and conversion, timing, etc.); the third is to log the important system occurrences for future reference.

Controlled response time to various system occurrences is made according to an established priority; because each of the hardware components has a unique set of operating speeds and characteristics, response must be dependent upon a priority basis to insure that firm control is maintained. This priority is established through software, utilizing the interrupt structure of the PDP-8/I computer.

An ancillary function of the software system is to provide a data-gathering capability for recording all important system occurrences, so that this data may then be used to formulate system statistics. The "log" function within the Control Program provides a basic data-gathering capacity by storing the raw log information in a disk file. A separate Log Program then operates on this file to generate desired statistics.

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Research and development in the field of science information during the past
decade has resulted in the establishment of large banks of descriptive in-
formation and bibliographic data. Stored on digital and analog media, these
collections, along with the organization and dissemination of their data and
information, comprise science and technical information centers, or science
information systems.

So far, the almost exclusive clientele of science information systems has
been the community concerned with research, development and production of
either ideas or goods. It is logical that the scientific and technical re-
search community be considered as the principal beneficiary of science in-
formation systems: the impetus for the establishment of these systems was
given by concern with the efficiency of scientific research and development
in a society in which both the quantity of science information and the number
and variety of its users have registered a substantial growth trend. At the
same time, however, the scientific research community as a market is not
characterized by either the volume or the frequency of information use which
would exhaust the capacity and potential of present-day science information
systems. It is thus very appropriate to inquire whether the contents and
services of these systems can be made available to science endeavors other
than research and development. The appropriateness of this inquiry is un-
questionable; science information is a social and national resource whose
value potential is closely related to the level of its prudent use.

In searching for other markets for science information, the obvious direc-
tion is to look toward human activities which are heavily dependent on in-
formation inputs from external "science memories." Obviously, human science
learning is an example of such an activity which fundamentally depends on
information transfer from external information sources into the human mind.
Science education, the organized social system for such learning, is intui-
tively an attractive market for science information.

The notion of a symbiosis between science information and learning is not
new, although until very recently it has received little overt attention.
Watson Davis [1] is reported having observed "a curious lack of follow-up
among documentalists" to the Utopian idea of a "world brain" suggested by
H. G. Wells--a centralized store of knowledge used for education. More
recently, the Interuniversity Communications Council proposed to bring the
contents of various existing and potential information stores to bear on the
educational process; after an initial period of enthusiasm [3], the concept
still remains to be seriously explored, as do the premises which led to the
"networks for knowledge" federal legislation of the mid-1960's. Apart from
a few serious advocates of such a symbiosis [4], the respective orientations
of science information and education have remained diverse, even on occa-
sions when the two met to communicate on a shared platform of educational
technology.
However, several recent events are indicative of a high-level concern with the relationship of science information and education. Prominent among these is a study of the Organization for Economic Cooperation and Development entitled *Information for a Changing Society* (OECD, 1971). In response to a major conclusion of this study (that "information systems of the future must be dynamic, capable of educating, and adaptable to the changing educational systems of the world"), OECD recommends that "evaluation of educational requirements of modern societies should take account of the need for information transfer systems that are better adapted to the continuing re-education of adults."

In a parallel vein, specific attention has now been drawn to the necessity of adapting science information systems to the science educational process and system of the future: "The information systems stimulated by the National Science Foundation have heretofore focused primarily on the needs of specialists; greater attention should be paid to the life-long educational process of the [scientific] non-specialist" [2].

In the context of the work represented here, science information is defined as recorded knowledge, usually in the form of primary publications stored on analog or digital media, emanating from the intellectual work of the scientific and technical community. The management of the inventory of science information, and the enhancement of its utility to mankind, are the primary purposes of science information systems. In the attempt to meet these purposes, science information systems collect, evaluate, organize and store science information, and they provide tools for its purposeful use. In modern science information systems, the tools comprise primarily devices and mechanisms for accessing science information—devices and mechanisms such as descriptive notations, indices, abstracts, searching methods, etc. The function of science information systems may be said to be that of a couple between science information and its users, insofar as present-day systems are generally limited only to the storage of science information surrogates.

In their role of searchable bibliographic directories the use of science information systems is not limited to the research community; their use by others depends, however, on their need for science information and on its utility. For reasons which remain to be carefully assessed the use of science information systems in science education has been sporadic, and largely confined to individuals engaged in research rather than in scientific or technical instruction or learning. It is quite apparent that the flow of science information into science education is characterized by discontinuity, lack of intensity, and time delay; hence its utilization in science education is suboptimal.

Unless the use of science information systems in science education is to be for purposes other than an occasional bibliographic search on a topic of momentary interest, the possibility of an effective flow of science information into education appears to be predicated on the existence, availability and use of external, manipulable stores of learning materials. A direct flow of science information from its repositories into the highly volatile
and transitive environment of live classroom instruction is difficult to imagine; the updating of the knowledge of human instructors is an idiosyncratic process of habitual characteristics which are not easily modified. On the other hand, stored learning materials (textbooks, instructional films, etc.) are a solid client of science information services, and a strong element in the educational process.

The realistic possibility of an intensified influx of science information into instruction and learning in the sciences is therefore given by the recent emergence and development of "learning systems," broadly defined as technology-aided instruction/learning facilities which allow learners to interact with organized learning materials stored in an animate, manipulable device or memory. The more powerful of these systems are "conversational"—that is, interactive systems which provide, in addition to a modular store of learning materials, models of the live interaction between a student and a human tutor. Despite the relative simplicity of the present-day models, the conversational learning systems hold promise of being able to sustain realistically the process of self-instruction. Furthermore, given certain types of memories of learning materials to support the self-instruction process, it is possible to consider science information as constituting an important input into these systems.

The objective of the present project is to study, design and experimentally evaluate man-machine mechanisms for enhancing the transfer of science information from its present repositories into science learning systems.

The postulated mechanism for the transfer of science information into learning systems, which can only be sketched at this time, is illustrated in Figure 1. The main characteristic of this transfer mechanism is the use of certain outputs of science information systems, enhanced and modified as appropriate, as inputs to the learning systems. The transformation of the outputs, and the ease and economy with which the transfer can be accomplished, are the crucial aspects of the mechanism. It is unlikely that the process can be performed fully automatically; rather, the educator-author is the key human interface responsible for the transformation of information.

Within its general objective of investigating the mechanisms of science information transfer into science education, the ongoing research has the following specific goals: (1) to describe operationally the human process of transformation of science information system outputs for the purpose of integrating them into the content of ALF-type learning systems; (2) to investigate comparatively the design and operating characteristics of science information systems and ALF-type science learning systems, particularly from the viewpoint of requirements for transferring information between them via a man-machine interface; and (3) to implement an experimental design of limited transfer mechanism from appropriate existing science information systems into an ALF-type science learning system, and to evaluate selected aspects of that mechanism.
Fig. 1. Utilization of Science Information in Learning Systems
The findings of the proposed research should result in conclusions concerning the minimum design requirements for the compatibility of science information systems and science learning systems, and in an evaluation of an operational method for a rapid integration of up-to-date science information into the content of modular facilities for self-instruction in science.

In the first phase of the project, research efforts were focused on the following tasks: (1) analysis of relevant parameters of existing science information systems; (2) human interface characteristics for science information transfer; and (3) investigation of design alternatives of the STITE system. (STITE is an acronym for "Scientific and Technical Information and Transfer for Education.")

The above tasks and the state of research are described in greater detail in [5].

References
Evaluation of Remote Bibliographic and Physical Access to a University Library

P. J. Siegmann, H. R. Citron, P. V. Martin

In this project, the School of Information and Computer Science jointly with the Georgia Tech Library has been evaluating the operation of an extended bibliographic and physical access system for the use of the faculty of the Institution [1]. The overall evaluation is concerned with the effects of the system on (1) faculty use and information-gathering habits; (2) library operation and service policy; and (3) costs of operating the system. The part of the study reported here concerns only the first aspect.

The system being evaluated provides bibliographic access by (a) placing in each academic and research department a microfiche copy of the card catalog updated with a cumulative bimonthly supplement; (b) offering computer search services to the published technical journal literature through the Georgia Information Dissemination Center (GIDC);* and (c) providing remote physical access by means of a scheduled document delivery service of requested items. (The delivery system also provides a method for returning all library materials.)

A microfiche format was chosen for the library catalog for several reasons: (1) microfiche readers are economical, appear to be reliable, and are easy to use; (2) technical library users are generally accustomed to using microfiche documents; (3) the microfiche format developed at Georgia Tech for reproducing the card catalog is compatible with the Computer Output Microfilm (COM) catalog generated from the magnetic tape record; and (4) multiple copies of the catalog and its updating supplements are inexpensive to reproduce. The system, in operation since March 1972, is an integrated program of several components, with the microfiche catalog providing a complete and up-to-date index to the Library's monographic and serial holdings. The system is extended by supplementing the Georgia Tech catalog with the computer search capabilities of the Georgia Information Dissemination Center (GIDC) at the University of Georgia, thus introducing into the system a current index approach to scientific journal articles and the very extensive literature found in technical reports.

Physical delivery of the document accompanies the remote bibliographic capability. This access is provided through a telephone request system combined

*The Georgia Information Dissemination Center was established at the University of Georgia in 1968 as a means of providing faculty with computer searches of published literature. Its services have been extended to all institutions in the University System of Georgia. At Georgia Tech these searches are provided at no cost to the faculty since the library handles the transaction and its direct overhead. Both retrospective (within the limitations of the data base) and current awareness searches are provided. Georgia Tech Library staff members are responsible for construction of the user profiles.
with delivery of the requested document (book or copy of journal article) to the requester's department. Incoming requests from the dispersed stations are received, the availability of the requested document is checked immediately against the circulation file, and the document, if available, is pulled and placed in the delivery procedure. If the material is not immediately available, the requester is given the options of delayed delivery, cancellation of the order, or interlibrary loan request. Requests for photocopies of journal articles or sections of books are handled through the copying section of the Library's Information Exchange Center which already handles copying requests for interlibrary loan and for business and industry. Actual physical delivery is accomplished through the use of a panel delivery truck manned by library personnel who run a regular route twice daily. Requested documents are delivered to the office of each department. Books, government documents, microfiche, and other library material to be returned to the Library are picked up at the same location. In effect, the total reader's service operation of the Library is extended outside the building into every department and office on campus.

The entire concept hinges on the satisfied user receiving the physical document upon request promptly and without "red tape." The use of a dual bibliographic accessing system--(a) microfiche catalog for books; (b) computer data bases for periodical literature--in combination with a document delivery system, provides the possibility of overcoming many of the obstacles, inconveniences and frustrations facing users of most academic library operations.

Prior to the planned study of individual users it appeared necessary to determine the bibliographic resources available at the departmental level and to assess awareness of the LENDS service. Thirty-four interviews were conducted with department heads and LENDS representatives. Information about the LENDS system had previously been communicated by (a) individual mailings of brochures describing LENDS service, (b) demonstration of the microfiche catalog conducted at the main Library, and (c) presentations at general faculty meetings. The purposes served by the interview study were: (1) to determine the degree to which departmental collections duplicate main library collections; (2) to establish the possible functions served by these departmental collections; (3) to solicit recommendations for extending LENDS service, and (4) to improve the effectiveness of communication about LENDS. It appears that many technically superior services have not been utilized fully due to a lack of effective communication. These interviews were partially confirmed by relevant information elicited by questionnaires distributed during the 1972/73 Georgia Tech Self-Study.

It was found that, with the exception of four departments (Industrial Development Division of the Engineering Experiment Station, the School of Aerospace Engineering, the School of Architecture, and the School of Chemistry), 17 of the remaining 30 departments possess limited collections which will require evaluation. The four departments noted maintain rather extensive collections and are considered separately. It was found that these 17 departmental collections were informally acquired, were not professionally maintained, and served limited functions.
Such departmental collections usually contain (a) standard references—e.g., technical dictionaries, handbooks, etc., (b) internally generated reports on on-going or completed research projects including theses and dissertations, (c) back files of journals and books, (d) current core journals, (e) abstracting and indexing services, (f) equipment catalogs, (g) operating and service manuals. With the exception of service and operating manuals, all the documents in the departmental collections are duplicated by the main Library collection and are available through LENDS. These local collections appear to serve the following functions:

1. **Limited Reference.** This is reflected by standard reference works, such as bibliographies, dictionaries, encyclopedias, handbooks, tables, directories, catalogs, and manuals. In most cases the reference works available in the departments have been superseded by more current and extensive information available in the main Library collection. Many relevant references are located only in the main Library due to cost, size, and availability of professional acquisition policies. Only equipment and operating manuals are not available in the main Library.

2. **Orientation to Departmental Research.** This function is served by research reports and theses which are also available in the main Library collection. Some departments do not maintain a complete collection of their own publications.

3. **Limited Current Awareness.** This function is served primarily by selected abstracting and indexing services and current core journals. All relevant journals and services are available in the main Library. In addition to comprehensive computer-based service, GIDC is available on an individual basis.

4. **Limited Browsing.** This function is served by the informal collection of books, reports and back files of journals.

The effectiveness with which these functions are served by departmental libraries will be determined in a later study. The most common functions served were reference and orientation to departmental research. Only 40 per cent of the departmental collections were adequate to serve any current awareness function. In no case were the collections adequate to support retrospective searches.

The four departments which maintain extensive collections can be considered in two categories—those duplicated in the main Library collections and those which do not overlap with the main Library. The Industrial Development Division (IDD) and the School of Architecture possess materials which are not substantially duplicated by the main Library. The IDD collection contains information pertaining to the development of local communities in Georgia, maintains a substantial newspaper clipping file, and is managed professionally. The School of Architecture Library is a branch of the main Library and contains most of the current literature to support the Architectural program. The Chemistry and Aerospace Engineering collections are
duplicated by the main Library. The function the Chemistry collection serves may reflect the extensive use of Chemical Abstract services by chemists generally, and may be unique to this discipline. Insufficient information is available on the function served by the Aerospace Engineering collection at this time. Further study of both collections is required. Statistics of LENDS service to both departments indicates high use of the main Library collection.

The department heads and LENDS representatives interviewed had a general awareness of the LENDS services available due to prior orientation by library personnel. The interviews elicited only a limited number of suggestions for improvement of LENDS. Generally the interviewees were favorably disposed toward LENDS and recommended that the services be made available to graduate students. Unfortunately, awareness of LENDS services by LENDS representatives does not insure adequate dissemination of this information to the entire faculty, and this is subject to future study.

The following is a list of specific facts which, it was learned through the interviews, were not commonly known by LENDS representatives: (1) inter-library loan books are delivered through LENDS; (2) computer-based current awareness searches from GIDC are delivered through LENDS; (3) all circulating library materials including maps, government documents, and technical reports, both in hard copy and microfiche, may be borrowed through LENDS; (4) holds, locates, and newly-received books ordered by a faculty member are delivered through LENDS; (5) copies of journal articles, papers, and parts of books or reports within the "fair use" limits are delivered and charged through LENDS; (6) end-of-the-quarter renewals can be made through LENDS; (7) all library materials, no matter how they were obtained, can be returned to the Library through LENDS; (8) requests for additional LENDS materials may be sent to the Library through LENDS; (9) each Department now has a microfiche reader and all microfiche held by the Library can be read on it; (10) instruction in library use can aid in effective use of the microfiche catalog and other library services (this instruction is offered by the Library).

Finally, the interviews focused on the effectiveness of the publicity on LENDS services. It should be noted that the LENDS representatives had been contacted prior to the inauguration of the service. During the interview, suggestions were solicited for improving awareness of available services among the faculty. In general, these suggestions emphasized the importance of personal contact and the opportunity for question-answer exchanges about LENDS. This is not to suggest that prior publicity such as brochures has been ineffective but only that the population reachable by such mechanisms has stabilized and that different modes of publicity are required to reach additional faculty.

Dissemination of information on available LENDS services to the faculty seems to be spotty and varies from department to department. Since even department heads and LENDS representatives who had received prior personal orientation were unaware of many specific LENDS services, it is not anticipated that the average faculty member will be well-informed about LENDS.
Finally, to reiterate a previous point, personal contact with library employees appeared to be an important factor in effective use of LENDS. For example, LENDS representatives indicated in the interviews that they frequently addressed questions to a particular person in the Library as their access point, even though this employee's job position is not directly relevant to the information requested. Informal discussion with library personnel confirms this observation and librarians frequently handle requests for information outside their area of concern or expertise.

To summarize this phase of the study, the following conclusions were reached: (1) Sixty per cent of the departments maintain collections which serve limited reference and current awareness functions for the faculty. Within the concept of a centralized library, these are considered legitimate functions. Improved coordination between the main Library and departmental collections is recommended. (2) Substantial collections were maintained by four departments. Two of these collections require further study to determine their appropriate functions. (3) Department heads and LENDS representatives show enthusiasm for the service and have few recommendations for improvement. Despite prior orientation, however, they were unaware of some fairly specific options available through LENDS.

LENDs provides a coordinating link between the functions and resources of the departmental collections and the Library. This study has pointed out the need for reassessing the functions of local collections and broadening the concept of the centralized Library.

Reference

During the past year the Information and Computer Science Laboratory acquired two additional computing systems, and the major thrust of Laboratory activities has been the integration of all systems and equipment into one unified computational facility for research and academic activities.

The operation of a Burroughs-5500 computer was assumed by the School of Information and Computer Science at the beginning of the year. The equipment is utilized for a number of purposes within the School: (a) for high-level language translation and program execution for students in various ICS graduate and undergraduate courses where programming assignments are required; (b) for support of other ICS courses (e.g., by providing simulation packages that students may be required to utilize); (c) for offering powerful timesharing capabilities for sponsored and unsponsored faculty and student research; and (d) for support of other student projects and institutional needs.

Management of the system has been accomplished within the School's existing resources, and most operation and programming tasks have been performed by students. Operational costs have been kept to an absolute minimum. The system has been operational essentially 24 hours a day, 7 days a week on a timesharing basis; in addition, batch support has been provided during working hours of the day. The performance of the system has improved steadily as the result of an intensive campaign to isolate hardware and software difficulties and to upgrade performance in all possible respects. Notable have been enhancements to the Burroughs standard software (itself an advanced and fine set of programs) in order (a) to provide a more usable system for processing large amounts of student activity; (b) to designate certain classes of timesharing users to predetermined time periods, effecting an overall greater accessibility; (c) to enhance the logging and accounting capability of the system; and (d) to increase the efficiency of often-used routines. Hardware problems have been referred to Burroughs engineers for correction.

Much effort has been devoted to the task of increasing production throughput and turnaround to all users on both a remote and batch basis. The batch workload has averaged just under 200 runs per eight-hour day and, considering the size of the jobs and the concurrent timesharing taking place, this represents a fairly heavy workload, close at times to the capacity of the machine; even so, turnaround has been kept to under 30 minutes during most periods.

Many unique applications have been developed on the system since its acquisition by ICS; a few of note will be mentioned. (1) A sophisticated image processing technique implemented in Fortran was developed in conjunction with a Ph.D. dissertation [1]. This software was utilized to an extent with a course in computer graphics and in research efforts by other faculty members. (2) Another Ph.D. research effort [7] utilized the B-5500 to
develop a resource allocation system for a multiprogrammed computer system; the system is able to simulate a given multiprogrammed computer system, and utilizing various measures of performance, compare philosophies of resource allocation which may be necessary or reasonable to be studied. (3) Considerable work involving simulation techniques was accomplished. A group of faculty and students has been developing general-purpose "life-like" simulations in specific areas: for example, one package simulated a time span in the life of a prairiedog town [8]; another showed the effects of real-time decision making by public school administrators [5]. A number of different computer systems have been simulated for use by students (PDP-8, S/360, MIX), in a course with topics covering computing hardware [6]. (4) Student projects have involved implementing prototype sections of operating systems within the overall B-5500 structure.

Finally, concerning the B-5500, emphasis has been placed on codification of operating guidelines, user policies and information, software documentation availability, etc. There is still unfinished work in these areas, but a substantial improvement in the amount and quality of documentation has been accomplished.

A Digital Equipment Corporation PDP-11/45 has recently been installed and become operational. Usage is just beginning, with primary emphasis on high-speed data acquisition and evaluation techniques. In conjunction with this, image processing and enhancement, digital voice compression, and other specific areas in this category are being introduced to the equipment. Plans have been made to interface the PDP-11 with both of the other computers in the laboratory to permit a wide range of equipment and computing power within a small network. Possibilities exist for integrating other equipment or computers into this network through hard-wiring methods or communications interfaces.

Two other specific activities have been initiated. One consists of the design of a generalized multi-user APL system on the PDP-11, which will be a superset of other APL implementations, notably IBM and Burroughs. The system will be capable of being implemented on a mini-computer, and yet will be able to provide users the type of APL capabilities they have had access to on large machines. Another project will be to study the practical possibilities of implementing audiographic learning systems with the PDP-11. Certain hardware features of the machine provide useful and straightforward methods of implementing process control systems, and a knowledge of such features will be useful in the future design and implementation of learning systems.

The Digital Equipment Corporation PDP-8 continues to provide the base for a considerable range of computer-controlled research activities. While much of the time is being dedicated to development of the Audiographic Learning Facility, other interesting activity has also taken place.

A number of computer graphics efforts have been worked on by students. Some of the more interesting involve representing physical dynamical systems
graphically using a programmatically refreshed graphics scope. One in particular displays the results of social interactions on deterministic individuals. In this work, one or more humans are displayed in an environment grid, where they are subjected to various forcing functions generated by objects (placed by the user) or other humans within the grid. The humans will move so as to decrease their respective levels of uneasiness, and thus pseudo-intelligence of these human representations may be studied graphically. Another project was to interface a high-speed data line to a graphics terminal for rapid transmission of time graphics over a communications network.

A generalized plotting package permitting users to utilize the on-line plotting system through higher-level language processors has been developed. A number of common display functions have been included to facilitate its use. An implementation of the IBM tutor instructional system was accomplished using a Basic version available on the PDP-8. Other departments on campus have used a mark-sense document grader system developed by ICS. Additional software power has been added through contacts at other institutions and through the Digital Equipment Corporation's user's society. They include a Fortran IV package with a real-time operating monitor; an improved disk operating system, with additional system programs; and an enriched Basic system.

A widely recognized contribution to PDP-8 software has been the development of DECSYSTEM-8 [2,3,4]. DECSYSTEM-8 adds 13 new commands to the FS/8-OS/8 command set, while retaining compatibility with existing programs. Provision is made for user extension by adding commands to a short program rather than changing the monitor itself. Machine usage records may be kept, and batch processing is provided for users as small as 8K.

Many improvements have been made to the Audiographic Learning Facility, representing additional hardware add-ons and corresponding software revisions. A touch-tone converted interface complete with automatic phone answer hang-up capability has been designed, built, installed and tested. Additionally, a method of automatic location indication on the lesson storage equipment has been implemented. The program changes will utilize these and other hardware features to accomplish more intimate control over the system functions. A software logging function has been enlarged to encompass the accumulation of various types of statistics of interest to the ALF managers.

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