Leftovers

Janet K. Allen
Farrokh Mistree
and David Rosen

"The Orphans", featuring...
Matt Chamberlain
Nathan Rolander
Andrew Schnell
Chris Williams
Challenges and Research Areas

- Applications of Decision-Based Design
- Layer-based manufacturing
- Concurrent Engineering
- Multi-Scale Modeling
- Simulation-Based Design
- MEMS
- Redesign
- Product family design

- Chris Williams
- Andrew Schnell
- Nathan Rolander
- Matt Chamberlain
Decision Templates in Microsystem Design

Andrew Schnell

Primary Requirement:
Microsystem Design is difficult because it has a “broad and steep learning curve” for designers, “mutable” knowledge about fabrication, expensive design iterations, and satisficing multiple stakeholders.

Primary Research Question:
How can microsystem design be structured to permit the sharing of knowledge among multiple stakeholders, to reduce the number of design iterations in a process, account for advances in technology, and to permit the storing and reuse of this knowledge?

Primary Hypothesis:
The use of decision templates to embody the decisions that are commonly made in microsystem design will allow designers to make decisions using the knowledge of multiple stakeholders that can be stored and reused, making design iterations faster and more meaningful.
Decision Templates in Microsystem Design

Example Problem:
Developing a separation column for a microscale gas chromatography system.

Create Decision Templates to do the following:
- Satisfice the geometry of the column such that the performance of the column is maximized.
- Satisfice the geometry to maximize the number of prototypes fabricated on a single substrate
- Satisfice the geometry to minimize process variables to save cost
Decision Templates in Microsystem Design

Combine Decision Templates to quickly gauge the effects of changing design criteria and improved analysis models on the overall design.
Closure
Connection to SRL, Progress, Legacy

Decision Templates in Microsystem Design

Increasing Modularity of Decision Templates
- Jitesh Panchal
- Marco Fernandez
- Greg Mocko

Knowledge Representation of Microsystem Design
- Greg Mocko
- Chris Paredis & Co.
- Sungshik Yim
- Nsikan Udoyen
- Jitesh and Marco

Selection and Utility/Cost functions for Microfabrication
- Jamal Wilson
- Microelectronics Research Center
- RPMI Dr. Rosen's Students
- Dr. Hesketh's Students

Feasibility of Additional Manufacturing Processes Microsystems
- Ameya Limaye
- RPMI Dr. Rosen's Students
- Dr. Hesketh's Students
- MIRC
### Proficiencies and Deficiencies

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<thead>
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<th>Technical Proficiencies</th>
<th>SRL Experience &amp; Domain Proficiencies</th>
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<td>MATLAB</td>
<td>cDSP &amp; sDSP</td>
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<tr>
<td>iSight</td>
<td>DSPT</td>
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<tr>
<td>ModelCenter</td>
<td>Microsystem fabrication</td>
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<tr>
<td>OpenMind</td>
<td>Ideation Tools</td>
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<tr>
<td>Visual Basic</td>
<td>6101 Teaching Associate</td>
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<tr>
<td>Protégé</td>
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<table>
<thead>
<tr>
<th>SRL/Domain Interests</th>
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<tr>
<td>Knowledge Management</td>
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<td>Information Modeling</td>
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<td>DL</td>
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<td>Additive manufacturing</td>
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Challenges and Research Areas

Applications of Decision-Based Design
Layer-based manufacturing
Concurrent Engineering
Multi-Scale Modeling
Simulation-Based Design
MEMS
Redesign
Product family design
Decision-making under multiple advisors

Chris Williams
Andrew Schnell
Nathan Rolander
Matt Chamberlain
An Approach to Decision Support for Strategic reDesign

Matthew Chamberlain

Primary Requirement:
Support the decision-making process that designers must go through in the process of redesigning an existing system to meet new market demands. The high-level decisions that may need to be made include what combination of subsystems to redesign, which should be left alone, and what kind of change should be made.

Primary Research Question:
How can an existing system be efficiently redesigned as the basis for a product family while taking into account the demands of the present and future?

Primary Hypothesis:
The Product Platform Concept Exploration Method (PPCTM) can be augmented as part of a two-step systematic decision-based redesign method that will support designers in the synthesis of a family of products meant to address current and future market demands.
The Problem with Serial Redesign

How do we achieve variety?

Design Barriers

Response #1 / Function

Legal Barriers

Response #2 / Performance

Initial System Design

Response #4 / Performance

Response #5 / Performance

(Derivative) System Design #3

(Derivative) System Design #2

(Derivative) System Design #4

(Derivative) System Design #5
Issues and Opportunities in Serial Redesign

● **Issues:**
  - There are myriad options available
  - Time and/or money is limited
  - Leveraging is desirable
  - Barriers to new development may exist:
    ● Technological or
    ● Module/Subsystem design
    ● Legal, external etc
    ● Architectural / Configuration
  - Change in demand may have multiple fronts/facets
  - Change in demand may be ongoing

● **Opportunities:**
  - The goals are the same as in product family design: provide variety quickly and at low cost
  - The difference is that we usually assume in product family design* that we have a blank slate
Research Areas, Building Blocks, and Tasks

**Potential Research Questions:**
- How can a large number of design options be considered when resources are limited?
- How can one model and measure redesign?
- How can an architecture of redesign be synthesized to offer variety?
- How can we redesign to consider products with different functions?
- How can we design with different schedules of product release in mind

**Building Blocks:**
- PPCTM (and extensions)
  - Provides a systematic method for synthesis of a product family
- Robust Design Techniques
  - RCEM-DCI for Type II robustness to find a range of specs for a range of targets
- Commonality indices

**Tasks:**
- Adapt PPCTM
- Adapt RCEM-DCI
- Develop metrics/indices
  - Significance of changes in high-level design specs?
Proposed Method (Pictorially)

Existing System

Existing Variety

Common (platform)

Potential Demand Variety

Potential (but uncertain) Future Demands

How can we identify and separate these parts?

Which changes should we make to which parts of the system in order to satisfy the various future demands?
Closure
Connection to SRL, Progress, Legacy

- **Connectivity**
  - Builds upon:
    - PPCTM (Gabriel Hernandez, Chris, Rakesh)
    - Robustness, RCEM, and VBPDM (Angran Xiao, Wei Chen, Tim Simpson, and their students)
    - PFRS (Zahed Siddique, Brian Corbett)?
  - Most closely related to work in the lab by:
    - Chris’s MS work (he’s still here so he counts)

- **Progress**
  - PhD Proposal – 2\textsuperscript{nd} week in July

- **Legacy**
  - A systematic high-level decision-support method for redesign
    - Method for answering this question: Out of a whole system, what ends up in a platform? What is used to offer variety?
    - Method for hierarchically organizing modes of offering change in the existing system
    - Metrics or rules for evaluating redesign options
    - Incorporation of different functions
    - Different schedules for product release
My Toolbox

- **SRL Methods**
  - Various DSP’s
    - Utility-based
    - Mathematical underpinnings in goal programming
  - MDO and multi-level optimization schemes like BLISS
  - Various robustness-related methods including:
    - RCEM, RCEM-DCI
  - Product family design methods:
    - PPCEM (and extensions like VBPDM), PVTEM, PPCTM (and extensions)

- **Software Specialties**
  - CATIA (That’s PLM, folks)
  - Photoshop/CorelDraw
  - That old version of WebCT
  - Languages: C++, Matlab
Challenges and Research Areas

Applications of Decision-Based Design
  - Bilateral symmetry
  - Layer-based manufacturing
  - Concurrent Engineering
  - Multi-Scale Modeling
  - Simulation-Based Design
  - MEMS
  - Product family design
  - Redesign
  - Decision-making under multiple advisors

Chris Williams
Andrew Schnell
Nathan Rolander
Matt Chamberlain
Design and Development of a Layer-Based Additive Manufacturing Process for the Realization of Metal Parts of Designed Mesostructure

Christopher Williams
Low-Density Cellular Materials

“… referring to a metallic body in which any kind of gaseous voids are dispersed. The metallic phase divides space into closed cells which contain the gaseous phase.”

- Banhart, J. “Manufacturing Routes for Metallic Foams”

Benefits:
- High strength
- Low mass
- High stiffness
- Acoustic & vibration dampening
- Strain isolation
- Energy absorption
- Excellent heat transfer ability

Applications:
- Lightweight structures
- Sandwich cores
- Heat / sound shields
- Skins for defensive applications
- High temp. filters
- Structural heat exchangers
### Manufacturing Limitations

<table>
<thead>
<tr>
<th>Structures</th>
<th>Processes</th>
<th>Repeatable</th>
<th>Material Freedom</th>
<th>Mesostructure Freedom</th>
<th>Macrostructure Freedom</th>
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<tbody>
<tr>
<td><strong>Stochastic</strong></td>
<td>Hydro / Alcam / Combal</td>
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<td>(via crimping &amp; stamping)</td>
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<td>(via extrusion &amp; reduction)</td>
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<td>(via Layer-based Additive</td>
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<td>Manufacturing)</td>
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Elevator Pitch

The Proposal

It is proposed to design, develop, and analyze a manufacturing process that is capable of producing metallic cellular materials.

The Gap

Current cellular material manufacturing techniques do not offer designer freedom in the determination of material, mesostructure, and macrostructure.

The Research Question

How to manufacture three-dimensional, low-density, cellular metal structures while maintaining designer freedom in the selection of the material and the design of the part mesostructure and macrostructure?

The Research Hypothesis

Low-density cellular metal structures can be manufactured via layer-based additive manufacturing of metal-oxide ceramic slurry followed by post-processing in a reducing atmosphere.

The Research Plan

Conceptual Design & Preliminary Embodiment ➔ Analysis ➔ Embodiment Design
It is proposed to design, develop, and analyze a manufacturing process that is capable of producing metallic cellular materials and providing a designer the freedom to specify material type, material composition, void morphology, and mesostructure topology for any conceivable part geometry.

**Phase One**
- **Conceptual Design & Rough Embodiment**
  - Task 1.1: Identify Design Requirements
  - Task 1.2: Develop Feasible Working Principles
  - Task 1.3: Select a Principal Solution
  - Task 1.4: Configure the Design

**Phase Two**
- **Analysis**
  - Task 2.1: Analyze Fundamental Characteristics of Design
  - Task 2.2: Validation of Design and Analysis

**Phase Three**
- **Embodiment Design**
  - Task 3.1: Embodiment Design
  - Task 3.2: Develop Build-Time and Cost Models
Proposed Manufacturing Process

Step One
Paste Preparation

Oxide Powders  H₂O  Additives

Compounding

Flexible Die Design

Step Two
Additive Manufacturing

Step Three
Direct Reduction

H₂

Drying

Finished Metal Part

Adapted from Cochran, McDowell, et al.
My Toolbox

SRL Methods
- PPCTM, PPCTM+
- u-cDSP
- (preliminary) selection DSP

Programs / Languages
- JAVA / C++
- iSight
- UG NX 3.0
- TrussCreator

Other stuff
- Manufacturing modeling
- Production design processes
- Ceramic & Metal Additive Manufacturing technologies
Challenges and Research Areas

Applications of Decision-Based Design
- Bilateral symmetry
- Layer-based manufacturing
- Concurrent Engineering
- Multi-Scale Modeling
- Simulation-Based Design
- MEMS
- Security (Benay)
- Product family design
- Redesign
- Decision-making under multiple advisors

Chris Williams
Andrew Schnell
Nathan Rolander
Matt Chamberlain
Robust Design of Air Cooled Server Cabinets for Thermal Efficiency
Nathan Rolander

**Primary Requirement:** Data centers receive new high output servers every 2-3 years while infrastructure is upgraded every 25 years, yielding thermal management challenges where redundancy and reliability are paramount.

**Primary Research Question:** How can data centers server cabinets be configured for efficient cooling while allowing for variability of both internal and external operating conditions?

**Primary Hypothesis:** The construction of Proper Orthogonal Decomposition based reduced order models enable the application of the compromise DSP using robust design principles to determine the system parameters required to meet the desired performance constraints and objectives under variable operating conditions.
Background: What is a Data Center?

- 10,000-500,000 square ft. facilities filled with rows of cabinets which house data processing equipment, servers, switching equipment etc.
- Tens to hundreds of MW power consumption for computing equipment and cooling hardware >> trend is towards very high power density servers which require stringent thermal management >> air temperature & humidity regulation with ~100% reliability
- 2-10% of all electric power generated in the U.S. used for computer, office equipment and network usage
Unique Challenges: Multi-scale modeling & design

- Multi-scale:

- Complex Turbulent Flow:
Approach

- Robust design application to a heat transfer problem:
- Integration of three disciplines
  - POD modeling construct
  - Robust Design Principles (Type I & II)
  - Compromise DSP

- Three case studies of increasing detail & complexity
  - 1) Aisle cross section, simple flow
  - 2) Cabinet cross section, complex flow
  - 3) Full 3D cabinet, highly complex flow

- Experimental validation of trends & models using measurements of mock cabinet temperature profile
Modeling Overview

- **Proper Orthogonal Decomposition:**
  - Maximize the projection of the basis functions onto the observations:

  \[
  \begin{align*}
  &\max \{ <u, \varphi> \mid \|\varphi\|^2 = 1 \} \\
  &\int_{\Omega} \bar{C}(x, x')\bar{\varphi}(x')dx' = \lambda \bar{\varphi}(x') \\
  &\bar{C}(x, x') \equiv <\bar{u}(x) \otimes \bar{u}^*(x') > \in \mathbb{R}^{n \times n}
  \end{align*}
  \]

  - Vector-valued eigenvectors form empirical basis of \( m \)-dimensional subspace, called **POD modes**
  - Creates the optimal linear subspace spanning the observation domain

- Use reconstructed flow field with turbulent numerical heat transfer solver to compute temperature profile

- 1e5 oom reduction in problem degrees of freedom
Results

- Robust & efficient solutions enable 2x the power dissipation of the same cabinet geometry
- Generation of families of solutions on a Pareto curve enable selection of solution for varying levels of robustness

- Applicable to all cabinet designs
Connectivity & Future

- **Multi-scale modeling (SRL & METTL)**
  - Collaboration with Jitesh on multi-scale FEM
  - Extension to micro & nano scale chip level design

- **Response Surface Modeling (ISYE)**
  - Integration of experimental results with high and low fidelity models into single, accurate response surface
  - Carolyn initiated this work with Wu in ISYE

- **Design of Observations for POD (SRL & Math)**
  - Initiated work into integration of DOE with POD observation generation
  - Needs further with with greater knowledge of DOE

- **Integration of Facility, Cabinet, & Sever manufacturers in collaborative effort through CEETHERM initiative**
Skillz

- **SRL Constructs**
  - Compromise DSP formulation & solution
  - Selection approaches & application
  - Robust design I & II formulation & solution
  - RCEM & Response surface modeling

- **Heat Transfer**

- **Software**
  - MATLAB, Simulink, MathCAD, EES, C++, VBA, LISP
  - LabVIEW, DAQ systems, etc.
  - FLUENT, FEMLAB, Analytix
  - AutoCAD, Inventor, Solidworks, 3D Studio, Adobe products
  - HALO 2