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Award ID: 0217860
Organization: GA Tech Res Corp - GIT

Title:
Collaborative Research: A Framework for Effective Optimization via Simulation

Project Participants

Senior Personnel

Name: Andradottir, Sigrun
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Name: Prudius, Andrei
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Gupta, Vivek
Worked for more than 160 Hours: Yes
Contribution to Project:

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Northwestern University

Other Collaborators or Contacts

Barry L. Nelson and L. Jeff Hong at Northwestern University

Activities and Findings

Research and Education Activities:

Most algorithms designed for solving discrete optimization-via-simulation problems are either not provably convergent or require the feasible region to be finite. Yet many discrete optimization problems are naturally formulated as having countably infinite feasible regions.

Consequently, we have developed a framework for designing optimization-via-simulation algorithms that are provably convergent with probability one to the set of global optimal solutions of the underlying optimization problem when the feasible region is countably infinite. Our framework is general enough to allow for a lot of flexibility in developing provably convergent algorithms that also perform well in practice. This generality is accomplished in part by letting the estimate of the optimal solution be the point with the best estimated objective function value among points that have been visited 'often enough' by the optimization algorithm. When this approach for estimating the optimal solution is used, it is not necessary to make restrictive assumptions about how much computational effort is expended in each iteration of the algorithm, such as requiring the algorithm to allocate the same amount of computer effort to estimate the objective function values at all points visited by the algorithm regardless of their performance.

In joint work with Andrei A. Prudius, a Ph.D. student at the Georgia Institute of Technology, we have identified desirable features that algorithms for solving discrete optimization-via-simulation problems should possess. Our BEESE approach involves maintaining appropriate balance between exploration, exploitation, and estimation throughout the search for a global optimal solution, where exploration involves searching for promising sub-areas within the feasible region, exploitation involves searching for improved solutions within such sub-areas, and estimation involves increasing the precision of the estimated objective function values at selected feasible points (by expending additional simulation effort on the corresponding system designs). We have also developed two algorithms that fall within our framework, are provably convergent to the set of global optimal solutions with probability one, and show attractive empirical performance.

Moreover, most random search methods for solving discrete optimization-via-simulation problems are 'Markovian' in that only the most recently obtained simulation results are used to decide where the algorithm will next conduct simulation experiments in the search for an optimal solution. While this feature is desirable from the perspective of proving convergence, it means that not all the available information about the performance of each potential system design is used to guide the search for improved designs, which may not yield the most rapid convergence to an optimal design in practice. Together with Andrei A. Prudius, we have developed a framework for using the average of all available simulation results for each design to guide the search for improved designs. We have also used this framework to analyze two versions of the simulated annealing algorithm (with a decreasing cooling schedule) adapted to solve discrete optimization-via-simulation problems. These two algorithms differ primarily in that one uses averaging and adaptively allocates simulation effort, while the other one employs neither averaging nor adaptive allocation of simulation effort. We prove that both algorithms are globally convergent with probability one under mild conditions, and use numerical results to show that the use of averaging and adaptive allocation of simulation effort can be very effective.

This grant has also supported on-going work with Andrei A. Prudius on solving simulation optimization problems with little known structure and continuous (uncountable) feasible regions. In particular, we have developed two frameworks for addressing the noise in the estimated objective function values in this (uncountable) setting, and have proved the convergence of the resulting algorithms. Preliminary numerical studies suggest that our methods preform well in comparison with existing approaches.

Together with former Ph.D. student L. Jeff Hong, now an assistant professor at the Hong Kong University of Science and Technology, we have developed ranking-and-selection procedures for use within local-improvement steps of adaptive random search algorithms. One set of procedures minimizes the overall computational cost of reaching a correct selection (choosing the best candidate solution) by specifically accounting for the cost of taking additional simulated samples from a solution and the overhead cost of switching to the simulation of a different solution. Another set of procedures guarantees that whenever the search is terminated, or at any intermediate iteration along the way, the current sample-best solution is the best of all visited solutions with a prespecified probability.

We have also developed a framework we call 'Convergent Optimization via Most-Promising-Area Stochastic Search' (COMPASS) for discrete-decision-variable optimization via simulation. COMPASS is a form of adaptive random search, but it differs in many significant respects from anything that has appeared previously in the literature. First, it guarantees convergence to a local optimal solution, rather than being globally convergent (or not convergent at all). Convergence of COMPASS to a local optimal solution can be proved without the requirement to visit every feasible solution, and therefore something like actual convergence can actually occur in practice. A locally convergent algorithm can be more aggressive than one that is globally convergent, yielding better finite-time performance. COMPASS' aggressiveness comes from adaptively building its neighborhood structure in reaction to information gained during the search, rather than using a static neighborhood. COMPASS can be made globally convergent, if desired, by adding enough pure random search or intelligent restarting. A second key contribution of COMPASS is that it can be applied to discrete-decision-variable problems with unbounded feasible regions, not just to the finite solution spaces that are typical in the literature.

Working with Northwestern University second-year Ph.D. student Jie Xu, and Jeff Hong, we have been incorporating our work on ranking and selection and COMPASS into an optimization algorithm and software we call Industrial Strength COMPASS (ISC). ISC is a particular implementation of a general framework that includes a Global Phase (specific implementation being a niching genetic algorithm), a Local Phase (specific implementation being COMPASS) and a Clean-Up Phase (specific implementation being a ranking-and-selection procedure). Using a suite of realistic test problems we have shown that ISC is competitive with commercial solvers such as OptQuest in terms of the features it offers (e.g., large-scale problems with constraints, rapid progress toward good solutions) while maintaining the convergence guarantees and statistical inference that commercial solvers do not provide.

Finally, with former Ph.D. student Jamie Wieland, we have developed ranking-and-selection procedures for 'Bernoulli selection problems,' which are optimization-via-simulation problems in which the simulation outputs are zero-one (success or failure). Such problems typically arise in reliability simulations.

During the period funded by this grant we have also conducted research aimed at increasing the efficiency of computer simulations; we have developed policies for assigning cross-trained workers to tasks with the goal of improving the system throughput; we have derived factor-screening methods as a pre-processing step before beginning optimization via simulation; and we have developed

algorithms for fitting cycle time-throughput moment and percentile
curves to the simulated output of semiconductor manufacturing systems.

Findings:
Information about our major findings is provided in the description of our major research and education activities above.

Training and Development:
This grant as provided training in simulation, stochastic processes, optimization, and probability to the student participants.

Outreach Activities:

Journal Publications

Sigrun Andradottir, Hayriye Ayhan, and Douglas G. Down, "Dynamic Server Allocation for Queueing Networks with Flexible Servers", Operations Research, p. 952, vol. 51, (2003). Published

Sigrun Andradottir and Mehdi Hosseini-Nasab, "Parallel Simulation of Transfer Lines by Time Segmentation", European Journal of Operational Research, p. 449, vol. 159, (2004). Published

Nilay Tanik Argon and Sigrun Andradottir, "Replicated Batch Means for Steady-State Simulations", Naval Research Logistics, p. 508, vol. 53, (2006). Published

Sigrun Andradottir and Hayriye Ayhan, "Throughput Maximization for Tandem Lines with Two Stations and Flexible Servers", Operations Research, p. 516, vol. 53, (2005). Published

Sigrun Andradottir and Peter W. Glynn, "Computing Bayesian Means Using Simulation", Submitted for Publication, p. , vol. , ( ). Submitted

L. Jeff Hong and Barry L. Nelson, "The Tradeoff Between Sampling and Switching: New Sequential Procedures for Indifference-zone Selection", IIE Transactions, p. 623, vol. 37, (2005). Published

Mahmoud H. Alrefaei and Sigrun Andradottir, "Discrete Stochastic Optimization Using Variants of the Stochastic Ruler Method", Naval Research Logistics, p. 344, vol. 52, (2005). Published

Nilay Tanik Argon and Sigrun Andradottir, "Partial Pooling in Tandem Lines with Cooperation and Blocking", Queueing Systems, p. 5, vol. 52, (2006). Published

L. Jeff Hong and Barry L. Nelson, "Selecting the Best System when Systems are Revealed Sequentially", IIE Transactions, p. , vol. , ( ). Submitted

L. Jeff Hong and Barry L. Nelson, "Discrete Optimization via Simulation using COMPASS", Operations Research, p. 115, vol. 54, (2006). Published

Hong Wan, Bruce E. Ankenman, and Barry L. Nelson, "Controlled Sequential Bifurcation: A New Factor-Screening Method for Discrete-Event Simulation", Operations Research, p. 743, vol. 54, (2006). Published

L. Jeff Hong and Barry L. Nelson, "A Framework of Locally Convergent Random-Search Algorithms for Discrete Optimization via Simulation", ACM Transactions for Modeling and Computer Simulation, p. , vol. , ( ). Submitted

Jie Xu, L. Jeff Hong, and Barry L. Nelson, "Industrial Strength COMPASS: A Comprehensive Algorithm and Software for Optimization via Simulation", Working Paper, p. , vol. , ( ). Working Paper

V. Lesnevski, Barry L. Nelson, and Jeremy Staum, "Simulation of Coherent Risk Measures Based on Generalized Scenarios", Management Science, p. , vol. , ( ). Submitted

Barry L. Nelson and Jeremy Staum, "Control Variates for Screening, Selection, and Estimation of the Best", ACM Transactions of Modeling and Computer Simulation, p. 52, vol. 16, (2006). Published

Seong-Hee Kim and Barry L. Nelson, "On the Asymptotic Validity of Fully Sequential Selection Procedures for Steady-state Simulation", Operations Research, p. 475, vol. 54, (2006). Published

Seong-Hee Kim, Barry L. Nelson, and James R. Wilson, "Some Almost-sure Convergence Properties Useful in Sequential Analysis", Sequential Analysis, p. 411, vol. 24, (2005). Published

Hong Wan, Bruce E. Ankenman, and Barry L. Nelson, "Simulation Factor Screening with Controlled Sequential Bifurcation in the Presence of Interactions", INFORMS Journal on Computing, p. , vol. , ( ). Submitted

F. Yang, Bruce E. Ankenman, and Barry L. Nelson, "Cycle Time Percentile Curves for Manufacturing Systems", IIE Transactions, p. , vol. , ( ). Submitted

F. Yang, Bruce E. Ankenman, and Barry L. Nelson, "Efficient Generation of Cycle Time-Throughput Curves through Simulation and Metamodeling", Naval Research Logistics, p. , vol. , ( ). Accepted

Sigrun Andradottir, "Simulation Optimization with Countably Infinite Feasible Regions: Efficiency and Convergence", ACM Transactions on Modeling and Computer Simulation, p. , vol. 16, (2006). Accepted

Christos Alexopoulos, Sigrun Andradottir, Nilay Tanik Argon, and David Goldsman, "Replicated Batch Means Variance Estimators in the Presence of an Initial Transient", ACM Transactions on Modeling and Computer Simulation, p. , vol. 16, (2006). Accepted

Sigrun Andradottir, Hayriye Ayhan, and Douglas G. Down, "Compensating for Failures with Flexible Servers", Operations Research, p. , vol. , ( ). Accepted

Sigrun Andradottir, Hayriye Ayhan, and Douglas G. Down, "Dynamic Assignment of Dedicated and Flexible Servers in Tandem Lines", Submitted for Publication, p. , vol. , ( ). Submitted

Andrei A. Prudius and Sigrun Andradottir, "Balanced Explorative and Exploitative Search with Estimation for Simulation Optimization", Submitted for Publication, p. , vol. , ( ). Submitted

Sigrun Andradottir, Hayriye Ayhan, and Douglas G. Down, "Maximizing the Throughput of Tandem Lines with Flexible Failure-Prone Servers and Finite Buffers", Working Paper, p. , vol. , ( ). Working Paper

Andrei A. Prudius and Sigrun Andradottir, "An Averaging Framework for Simulation Optimization with Applications to Simulated Annealing", Working Paper, p. , vol. , ( ). Working Paper

Andrei A. Prudius and Sigrun Andradottir, "Adaptive Random Search for Continuous Simulation Optimization", Working Paper, p. , vol. , ( ). Working Paper

Books or Other One-time Publications

Sigrun Andradottir, Hayriye Ayhan, and Douglas G. Down, "Dynamic Allocation of Servers to Tasks for Queueing Systems with Infinite Buffers", (2003). Conference Proceedings Article., Published
Bibliography: Proceedings of the 2003 NSF Design, Service, and Manufacturing Grantees and Research Conference

Sigrun Andradottir and Barry L. Nelson, "A Framework for Effective Optimization via Simulation", (2003). Conference Proceedings Article., Published
Bibliography: Proceedings of the 2003 NSF Design, Service, and Manufacturing Grantees and Research Conference

L. Jeff Hong and Barry L. Nelson, "An Indifference-zone Selection Procedure with Minimum Switching and Sequential Sampling", (2003). Conference Proceedings Article., Published
Bibliography: Proceedings of the 2003 Winter Simulation Conference

Seong-hee Kim and Barry L. Nelson, "Selecting the Best System: Theory and Methods", (2003). Conference Proceedings Article., Published
Bibliography: Proceedings of the 2003 Winter Simulation Conference

Hong Wan, Bruce Ankenman and Barry L. Nelson, "Controlled Sequential Birfurcation: A New Factor-Screening Method for Discrete-Event Simulation", (2003). Conference Proceedings Article., Published
Bibliography: Proceedings of the 2003 Winter Simulation Conference

Sigrun Andradottir and Barry L. Nelson, "Selection Error Control and Statistical Inference for Simulation Optimization", (2004). Conference Proceedings Article., Published
Bibliography: Proceedings of the 2004 NSF Design, Service, and Manufacturing
Grantees and Research Conference

Sigrun Andradottir and Hayriye Ayhan, "Server Assignment Policies for Queueing Systems with Two Stations in Tandem", (2004). Conference Proceedings Article., Published
Bibliography: Proceedings of the 2004 NSF Design, Service, and Manufacturing Grantees and Research Conference

Seong-Hee Kim and Barry L. Nelson, "Selecting the Best System", (2006). Book Chapter., Published
Bibliography: Elsevier Handbooks in Operations Research and Management
Science: Simulation, edited by Shane G. Henderson and Barry L. Nelson

Sigrun Andradottir, "An Overview of Simulation Optimization via Random Search", (2006). Book Chapter, Published
Bibliography: Elsevier Handbooks in Operations Research and Management Science: Simulation, edited by Shane G. Henderson and Barry L. Nelson

Jamie R. Wieland and Barry L. Nelson, "An Odds-Ratio Indifference-Zone Selection Procedure for Bernoulli Populations", (2004). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2004 Winter Simulation Conference

David Goldsman, Seong-Hee Kim, and Barry L. Nelson, "Statistical Selection of the Best System", (2005). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2005 Winter Simulation Conference

V. Lesnevski, Barry L. Nelson, and Jeremy Staum, "Simulation of Coherent Risk Measures", (2004). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2004 Winter Simulation Conference

Andrei A. Prudius and Sigrun Andradottir, "Simulation Optimization Using Balanced Explorative and Exploitative Search", (2004). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2004 Winter Simulation Conference

Sigrun Andradottir and Barry L. Nelson, "Algorithms for Effective Optimization via Simulation", (2005). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2005 NSF Design, Service, and Manufacturing Grantees Conference

Sigrun Andradottir and Nilay Tanik Argon, "Partial Pooling for Improving the Performance of Tandem Queues", (2005). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2005 NSF Design, Service, and Manufacturing Grantees and Research Conference

Seong-Hee Kim, Sigrun Andradottir, Bob Diamond, and David Goldsman, "GOALI: Efficient Simulation Techniques for Comparing Constrained Systems", (2005). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2005 NSF Design, Service, and Manufacturing Grantees and Research Conference

Sigrun Andradottir, David Goldsman, and Seong-Hee Kim, "Finding the Best in the Presence of a Stochastic Constraint", (2005). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2005 Winter Simulation Conference

Andrei A. Prudius and Sigrun Andradottir, "Two Simulated Annealing Algorithms for Noisy Objective Functions", (2005). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2005 Winter Simulation Conference

Sigrun Andradottir and Barry L. Nelson, "Effective Optimization via Simulation: Algorithms, Convergence, and Statistical Guarantees", (2006). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2006 NSF Design, Service, and Manufacturing Grantees and Research Conference

Seong-Hee Kim, Sigrun Andradottir, Bob Diamond, and David Goldsman, "Statistical Selection Procedures for Finding the Best in the Presence of a Stochastic Constraint", (2006). Conference Proceedings Article, Published
Bibliography: Proceedings of the 2006 NSF Design, Service, and Manufacturing Grantees and Research Conference

Web/Internet Site

URL(s):
www.iems.northwestern.edu/~nelsonb/OptVSim
Description:

Other Specific Products

Contributions

Contributions within Discipline:
These results are fundamental steps toward providing algorithms and supporting theory for general-purpose optimization via simulation with respect to discrete decision variables. In contrast to the heuristic optimization tools currently available in commercial simulation packages, our results have allowed us to construct efficient and theoretically sound algorithms that provide specific guarantees of, and inference on, their performance.

Contributions to Other Disciplines:
Computer simulation is used to understand and improve system behavior in a wide variety of disciplines. Consequently, our work on effective optimization via simulation has enhanced the suite of tools for system design available to practitioners in industral engineering and other disciplines.

Contributions to Human Resource Development:
This grant has provided support for Andrei A. Prudius, a Ph.D. student in the School of Industrial and Systems Engineering at the Georgia Institute of Technology. Vivek K. Gupta, another Ph.D. student in the School of Industrial and Systems Engineering at the Georgia Institute of Technology, has also worked on this project. Finally, we have worked with L. Jeff Hong, who has graduated with a Ph.D. from the Department of Industrial Engineering and Management Sciences at Northwestern University.

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Activities and Findings: Any Outreach Activities

Any Product
Contributions: To Any Resources for Research and Education
Contributions: To Any Beyond Science and Engineering