

DISCRETE EVENT DYNAMIC SYSTEMS MODELING AND
OPTIMIZATION
WITH APPLICATIONS TO C³I PROBLEMS

FINAL REPORT

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13. ABSTRACT (Maximum 200 words) The PI's have accomplished the following research tasks: (1) Established solid foundations of the Ordinal Optimization approach and applied it to a number of applications heretofore considered to be beyond reach or impractical [see www.hrl.harvard.edu/~ho for references, explanations and demos]. (2) Further analyzed and proposed new schemes for stochastic fidelity preservation issues in hierarchical simulation modeling. (3) Further developed the rational approximation approach for small probability estimation.				
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A. STATEMENT OF THE PROBLEM STUDIED

In this research project we further developed a general optimization approach, the Ordinal Optimization approach, for DEDS performance optimization. We also further developed a rational approximation approach to performance analysis for many computer and communications systems. We further developed methods for preserving the stochastic fidelity in hierarchical battle simulation models.

B. SUMMARY OF THE MOST IMPORTANT RESULTS

The work accomplished under the support of DAAH04-95-0148 and its predecessor DAAL03-91-G-0194 are closely related. Below we report our findings and accomplishments under the support of the grants.

B.1. Works of the DEDS group under Y.C. Ho at Harvard

The major thrust of my research for the past ten years can be summarized in one sentence: **TO MAKE SIMULATION A PRACTICAL OPTIMIZATION TOOL FOR DIFFICULT SYSTEMS DESIGN PROBLEMS.** The underlying rationale is that other than heuristics, simulation is the only general purpose performance evaluation tool. The only problem is that its computational burden makes simulation infeasible for design optimization for many real world systems problems. Our research efforts have been aimed at reducing this burden by achieving orders of magnitude reduction in computational requirements for performance evaluation via simulation. We have been quite successful in the pursuit of the above goal. The two principal achievements have been the invention and establishment of two techniques, **PERTURBATION ANALYSIS** and **ORDINAL OPTIMIZATION**. Over one hundred papers and three books have been published on the subjects by authors all over the world, a journal was established, and several international awards were given to members of our research group.

Objective Evidence of Accomplishment

- Gave 133 invited talks worldwide on various topics in Discrete Event Dynamic Systems, Simulation, and Optimization (6/1987-6/1997) including 14 keynote or plenary addresses at various World Congresses and International Conferences:
 - following are awards given to current or former member of the DEDS group at Harvard
- 1985 IEEE-AC Best paper award to X.R. Cao (former student)
1987 Election to the National Academy of Engineering (Y.C. Ho)
1989 IEEE Field Award on Control Engineering and Science (Y.C. Ho)
1990 Editor-in-chief, Journal on Discrete Event Dynamic Systems
Editor, Book Series on DEDS, Kluwer Publishing (Ho)
1989 Associate Editor, Journal on Mathematical Systems and Control (Ho)
1991 TIMS College on Simulation Best Publication Award to Cao-Suri-Zazanis (former students)
1992 TIMS College on Simulation Best Publication Award to P. Glasserman (former student)
1993 Associate Editor, Journal on Control, Estimation, and Discrete Event Systems (Ho)
1993 MasPar Massively Parallel Computing challenge

- runner up award to Chen-Patsis-Larson (current students)
- 1993 Chiang Technology Achievement Prize (the HongKong Prize) to Ho
- 1994 IEEE Control Systems Technology Award to Suri-Diehl (former students)
- 1997 Ho elected to become Life Fellow of IEEE
- 1999 Ho was given the Bellman Control Heritage Award of the American Automatic Control Council

- Over 120 papers on all aspects of Discrete Event Dynamic Systems (DEDS), Perturbation Analysis (PA), and Ordinal Optimization in refereed publications,
- Two books on PA were published one of which won the best simulation publication award in 1992).
- One tutorial video tape (2 hours) introducing DEDS
- 17 Ph.D. Theses completed

B.2. Works of the Complex Systems Modeling and Control Laboratory (CSMCL) under Weibo Gong at the University of Massachusetts.

The Complex Systems Modeling and Control Laboratory (CSMCL) in the Department of Electrical and Computer Engineering at the University of Massachusetts, Amherst, has been working on the following projects under the partial support of the ARO grants:

- Hierarchical Simulation Modeling
- Rational Interpolation for QoS in High Speed Networks
- Knowledge Modeling and Information Fusion Theory
- Large Scale Optimization
- Monte Carlo Method for VLSI Design Optimization
- High Dimensional Data Clustering and Applications
- Fluid Simulation of High Speed Networks
- Analysis of Network Control Algorithms
- Computationally Complex Performance Analysis Problems
- Numerical Methods in Polymer Modeling

Publications resulted from the research are listed in Section C. Weibo Gong has been associate editor for the IEEE Transactions on Automatic Control, IEEE Transactions on Robotics and Automation, Journal of Optimization Theory and Applications. He is a recipient of the IEEE Control Systems Society 1997 George Axelby Outstanding Paper Award and elected IEEE Fellow in 1998.

C. LIST OF PUBLICATIONS AND TECHNICAL REPORTS

The older papers have been reported and copies provided. Below we only provide listing of new papers since the last report.

- (1) M.Deng and Y.C. Ho, "Sampling Selection Methods for Ordinal Optimization", *Automatica*, Vol 35, No.2, 1999
- (2) Y.C. Ho, "An Explanation of Ordinal Optimization - Soft Optimization for Hard Problems", *Information Sciences*, Janaury 1999.
- (3) L.H. Lee, E.T.K. Lau and Y.C. Ho, "Explanation of Goal Softening in Ordinal Optimization", *IEEE Trans. on Automatic Control*, Vol.44, No. 1., pp94-99, 1999.

- (4) V. Misra, W.B. Gong and D. Towsley, "Stochastic Differential Equation Modeling and Analysis of TCP-Window Size Behavior", To appear, *Proceedings of Performance'99*, July 1999.
- (5) W.B. Gong, "Some Tools in Modeling Complex Stochastic Systems", *Proceedings of the 32nd CDC*, 1996, San Diego.
- (6) W.B. Gong and H. Yang, "On the Convergence of Global Rational Approximants for Stochastic Discrete Event Systems", *Discrete Event Dynamic Systems: Theory and Applications*, 7, 93-116 (1997)
- (7) A. Yan and W.B. Gong, "Time-Driven Fluid Simulation for High-Speed Networks with Flow-Based Routing", *Proceedings of Telecommunication Conference*, 1997, Boston.
- (8) W.B. Gong, Y.C. Ho and W. Zhai, "Stochastic Comparison Algorithm For Discrete Optimization with Estimation", to appear on *SIAM J. on Optimization*.
- (9) W. Zhai, P. Kelly and W. Zhai, "Genetic Algorithm with Noisy Fitness", *Mathl. Comput. Modelling*, Vol. 23, No. 11/12, pp131-142, 1996
- (10) A. Yan and W.B. Gong, "Time-Driven Fluid Simulation for High-Speed Networks", To appear, *IEEE Transactions on Information Theory*, June 1999.
- (11) W.B. Gong, Y.C. Ho and W. Zhai, "Stochastic Comparison Algorithm for Discrete Optimization with Estimation", To appear, *SIAM Journal on Optimization*, June 1999.
- (12) C. Liu, H. Yang, W.B. Gong and D. Towsley, "Rational Interpolation for Loss Probability Calculation in Finite-buffer Queues", Submitted to *Performance Analysis*, 1998
- (13) C. Liu, W.B. Gong, C.M. Krishna and Y. Q. Yin, "Rational Interpolation Method in Performance Analysis", Submitted to *IEEE Trans. on Computers*, 1998
- (14) C. Liu, C.M. Krishna and W.B. Gong, "Real-Time System Evaluation: A Rational Interpolation Approach", *Proceedings of the 37th IEEE Conference on Decision & Control*, Florida, pp1680-1685, Dec 1998.
- (15) C. Liu, I. Acar and W.B. Gong, "On Computation of Bit Error Probability in Communication Systems", *Proceedings of the 35th Conference On Decision and Control*, Japan, pp1360-1361 Dec 1996.

**D. LIST OF ALL PARTICIPATING SCIENTIFIC PERSONNEL
SHOWING ANY ADVANCED DEGREES EARNED BY THEM WHILE
EMPLOYED ON THE PROJECT**

- (1) Yu-Chi Ho, PI, Division of Applied Sciences, Harvard University.

Students graduated and where are they now:

Jian-Qiang Hu (1992)	Asso. Prof	Boston University
Bin Zhang (1992)	MTS	Pacific Gas & Electric

Leyuan Shi (1993)	Asst. Prof	U. of Wisconsin, Madison
Li-Yi Dai (1993)	Asst. Prof	Washington University
Chun-Hung Chen (1994)	Asst. Prof.	U. of Pennsylvania
Mei Deng (1995)	MTS	Lucent Technology
Michael Larson (1995)	MTS	??
Edward T.W. Lau (1997)	Post doc	Harvard
Loo Hay Lee (1997)	Asst. Prof.	Singapore National University
Mike S. Yang (1998)	MTS	Lucent Technology
Nikos Patsis (1998)	Quants	Ross Capital Mgmt
David Weigang Li (1998)	MTS	Nortel

(2) Wei-Bo Gong, Co-PI, Department of Electrical and Computer Engineering, University of Massachusetts at Amhest.

Students Graduated and where they are now:

Anlu Yan (1992,1997)	MTS	Lucent Technology
Soracha Nananukul (1998)	MTS	Nokia
Hong Yang (1994,1997)	MTS	Cisco
Xianghong Yin (1999)	MTS	Ascent

5. REPORT OF INVENTIONS NONE

6. BIBLIOGRAPHY NONE

7. APPENDIXES. NONE