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From the Guest Editor Special Cluster on Operations Research in Electrical and Computer Engineering

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My research in optimization at the Department of Systems and Computer Engineering at Carleton University has brought me into contact with researchers in the Department of Electronics, our sister department in the general field of Electrical and Computer Engineering (ECE), which has a major research thrust in computer-aided design (CAD) of very large scale integrated (VLSI) circuits. I have come to realize that the design of VLSI systems consists in large part of solving incredibly massive mixed-integer nonlinear optimization problems, together with enormous circuit simulations. This is impossible without the use of CAD techniques. Over time, ECE-CAD researchers have both borrowed useful standard techniques from operations research (OR) and have invented their own, often to deal with the sheer scale and complexity of the design problems they face. Interaction between the OR and ECE-CAD communities would seem to be a natural development.

Coincidentally, the *INFORMS Journal on Computing* had an area entitled "High Performance Computation" that covered (i) the solution of OR problems using new computing technologies, (ii) the application of OR techniques in the design and use of high-performance computing and communication systems, and (iii) solution methods for ultra-large-scale OR applications. The viability of this area was debated during 2003 as some of its aspects migrated to other areas (e.g., the new "Telecommunications and Electronic Commerce" area), and the number of submissions declined. The area was eventually closed, although I argued that the overlap between OR and ECE-CAD, essentially covering items (ii) and (iii), was a very active research area. This Special Cluster of papers was conceived as a way to test that argument.

I was recruited at the same time to prepare a tutorial on ECE-CAD for the 2004 INFORMS Annual Meeting (see John W. Chinneck, Michel Nakhla, and Q. J. Zhang 2004. Computer-aided design for electrical and computer engineering. H. J. Greenberg, ed. *Tutorials on Emerging Methodologies and Applications in Operations Research*. Springer, New York, 6-1 to 6-44). The preparation of the article reinforced my observation about the research overlap between OR and ECE-CAD. A search of the electrical engineering literature for 2000 through early 2004 turned up 46,725 papers mentioning "simulate" or "simulation" as keywords in the abstract, 14,216 papers mentioning "optimization" or "optimize," and relatively smaller numbers for specific techniques such as "neural network" (6,251), "genetic algorithm" (2,603), "linear programming" (576), "simulated annealing" (448), and "branch and bound" (199). One surprise was the relatively small number of papers using the generic keywords "mathematical programming" (68) or "operations research" (37).

The general conclusion of the tutorial article is that the OR and the ECE-CAD communities have much to offer each other. This is certainly the case for the papers gathered in this Special Cluster. We see known OR techniques adapted for use in ECE-CAD. In "Integer Linear Programming Models for Global Routing," Behjat et al. apply integer linear programming in a heuristic to solve enormous NP-hard connection routing problems for VLSI circuits. In "Task Scheduling in a Finite-Resource, Reconfigurable Hardware/Software Codesign Environment," Loo and Wells use simulated annealing, genetic algorithms, and random search techniques to solve scheduling problems in hardware-software co-design.

We also see new techniques specifically developed by the ECE-CAD community to deal with problems of extreme scale. In "A Projection-Based Reduction Approach to Computing Sensitivity of Steady-State Response of Nonlinear Circuits," Pai et al. develop methods for sensitivity analysis in extremely large nonlinear programs, especially those in which the objective function is very costly to evaluate. The methods have special relevance for simulation-based

optimization. In "A Discrete Adjoint Variable Method for Printed-Circuit Board Computer-Aided Design," Ali et al. develop an approximate nonlinear numerical sensitivity analysis technique that is suitable for large scale applications and apply it in printed circuit board and structured antenna design. In both cases knowledge about how to deal with models of extreme scale is transferable to the OR community.

In the final paper, "Using Eigenvectors to Partition Circuits," Kucar and Vannelli describe an eigenvector-based technique for improved graph partitioning applied to a problem in VLSI circuit design. This paper draws almost evenly from the OR/mathematics community and the ECE-CAD community.

Assembling and refereeing the papers for this Special Cluster presented several challenges. The first challenge was attracting the right sort of submissions on topics that overlap both OR and ECE-CAD. As shown above, there is an extensive and active literature in the ECE community, but the difficulty is enticing ECE authors to publish in a journal outside of their usual ECE venues. Many thanks to my Guest Associate Editors, Michel Nakhla and Q. J. Zhang, both prominent in the ECE-CAD community, for helping to attract high-quality submissions. To make sure that each paper was fairly reviewed, it was assigned one referee with an ECE background and one with an OR background. The second challenge lay in finding ECE referees willing to look at OR-related papers and vice versa.

I arrived at several conclusions as a result of this experiment. First, there is a huge opportunity for operations researchers to make significant contributions in ECE-CAD. There are simulation and optimization problems of immense size to be solved, making for enticing research opportunities. Second, the techniques developed by the ECE-CAD community show significant promise for transfer to the OR community, especially for dealing with models of extremely large scale. Third, the two communities continue to operate largely independently despite the potential gains from the sharing of expertise. This is shown by the few mentions of "operations research" as a keyword in the ECE-CAD literature, by the relative difficulty in attracting papers from the ECE-CAD community for publication in an OR journal, and by the challenge in finding suitable referees knowledgeable about both fields. However, the opportunity for breakthroughs in both directions remains; some effort in learning about the ECE-CAD field will yield rewards for operations researchers. Perhaps this Special Cluster and the tutorial article mentioned above will help in bridging the gap, for the betterment of both communities.

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