

# Randal E. Bryant

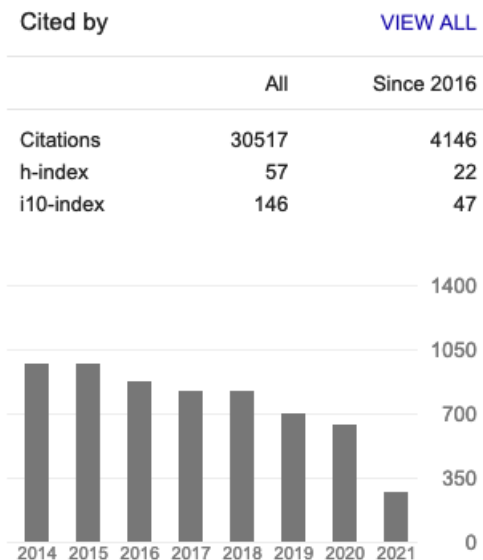
## Education

- 1974–1981 Massachusetts Institute of Technology, Department of Electrical Engineering and Computer Science, S.M. (1977), E.E. (1978), PhD (1981). Thesis Supervisor: Prof. Jack B. Dennis. MS Thesis Title: “Simulation of Packet Communication Architecture Computer Systems.” PhD Thesis Title: “A Switch-Level Simulation Model of Integrated Logic Circuits.”
- 1970–1973 University of Michigan, College of Engineering (Applied Math), B.S. (1973).

## Employment

- 2020–present Founders University Professor of Computer Science Emeritus, Carnegie Mellon University. Research areas: Boolean satisfiability, formal hardware and software verification.
- 2004–2020 University Professor of Computer Science, Carnegie Mellon University. Research areas: formal hardware and software verification, system testing, and computer science education. Teaching subjects: computer systems, distributed systems, parallel computing.
- 2014–2015 Assistant Director for Information Technology Research and Development, White House Office of Science and Technology Policy. Activities in: robotics, machine learning, high-performance computing, semiconductor technology, and cloud computing.
- 2004–2014 Dean, School of Computer Science, Carnegie Mellon University.
- 1999–2004 Head, Computer Science Department, Carnegie Mellon University.
- 1997–2004 Robert M. M. Professor of Computer Science, Carnegie Mellon University. Research areas: formal hardware and software verification, computer security. Teaching subjects: computer systems, computer networking, algorithms.
- 1992–1997 Professor of Computer Science, Carnegie Mellon University. Research areas: VLSI circuit verification, symbolic manipulation, and parallel computation. Teaching subjects: computer architecture
- 1987–1992 Associate Professor of Computer Science, Carnegie Mellon University. (Tenure granted Sept., 1990.) Research areas: VLSI simulation, VLSI circuit verification, symbolic manipulation, and parallel computation. Teaching subjects: introductory computer science, computer architecture, advanced VLSI design.
- 1990–1991 Visiting Research Fellow, Fujitsu Laboratories, Ltd., Kawasaki, Japan.
- 1984–1987 Assistant Professor of Computer Science, Carnegie Mellon University.
- 1984–present Courtesy appointment in Electrical and Computer Engineering, Carnegie Mellon University.
- 1981–1984 Assistant Professor of Computer Science, California Institute of Technology. Research areas: VLSI circuit models, logic simulation, and circuit testing. Teaching subjects: computer architecture, digital systems theory, and computer algorithms.

## Publication and Research Highlights



Google Scholar Citation Count. Downloaded 25-Jun-2021.

### Most Cited Publications

1. R. E. Bryant, “Graph-Based Algorithms for Boolean Function Manipulation,” *IEEE Transactions on Computers*, Vol. C-35, No. 8 (August, 1986), pp. 677–691.

Foundational paper describing binary decision diagrams (BDDs) as data structure and algorithms for representing and manipulating Boolean functions in symbolic form. BDDs were described by Donald Knuth in a 2008 lecture as “one of the only really fundamental data structures that came out in the last twenty-five years.”

2. R. E. Bryant, “Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams,” *ACM Computing Surveys*, Vol. 24, No. 3 (September, 1992), pp. 293–318.

A tutorial and update on BDDs.

3. K. S. Brace, R. L. Rudell, and R. E. Bryant, “Efficient Implementation of a BDD Package,” *27th Design Automation Conference*, June, 1990, pp. 40–45.

Describes a collection of refinements for implementing BDDs. Most BDD packages follow the implementation ideas described in this paper. At the 50th anniversary of the Design Automation Conference, this paper was listed as the one with the sixth highest citation count.

4. M. Christodorescu, S. Jha, S. A. Seshia, D. Song, and R. E. Bryant, “Semantics Aware Malware Detection,” *IEEE Symposium on Security and Privacy*, May, 2005, pp. 32–46.

Shows how to automatically remove the obfuscations generated by polymorphic malware programs to reveal the underlying code.

5. R. E. Bryant, "On the Complexity of VLSI Implementations and Graph Representations of Boolean Functions with Application to Integer Multiplication," *IEEE Transactions on Computers*, Vol. 40, No. 2 (February, 1991), pp. 205–213.

Describes a method for proving that a particular class of Boolean functions will have exponentially-sized BDD representations. Showed that this case holds for the functions representing integer multiplication. This paper has been the subject of many refinements and extensions.

6. R. E. Bryant, and D. R. O'Hallaron, *Computer Systems: A Programmer's Perspective*, Prentice-Hall. First edition 2003, second edition 2011, third edition 2015.

A textbook based on a course created at CMU that covers the combination of hardware, networking, and software that comprises a computer system. This book has been translated into Chinese, Russian, Korean, and Macedonian, and is in use at over 325 institutions worldwide.

7. R. E. Bryant, and Y.-A. Chen, "Verification of Arithmetic Circuits with Binary Moment Diagrams," *32nd Design Automation Conference*, June, 1995, pp. 535–541.

Describes a variant on BDDs that can represent the word-level functionality of arithmetic circuits. Winner of best paper award in category "Verification, Simulation, and Test."

8. R. E. Bryant, "A Switch-Level Model and Simulator for MOS Digital Systems," *IEEE Transactions on Computers*, (February, 1984), pp. 160–177.

Describes the algorithmic basis for MOSSIM II, a logic simulator that models transistors as simple switches. This simulator and its successors were widely used in industry and academia in the 1980s. Intel used it to simulate several generations of microprocessor circuits.

9. R. E. Bryant, *Simulation of Packet Communication Architecture Computer Systems*, Technical Report TR-188, MIT Laboratory for Computer Science, November, 1977.

My masters thesis. Considered the first published work describing fully distributed, discrete-event simulation.

10. C.-J. H. Seger, and R. E. Bryant, "Formal Verification by Symbolic Evaluation of Partially-Ordered Trajectories," *Formal Methods in System Design*, Vol. 6, No. 2 (March, 1995), pp. 147–190.

Describes symbolic trajectory evaluation, a method for formally verifying digital circuits via symbolic simulation. This approach was heavily used within Intel for many years.

## Professional Activities

### Affiliations

2018–present	Chair, Data-Model Convergence Initiative Advisory Committee, Pacific Northwest National Laboratories.
2017–present	Physical and Computational Sciences Directorate Advisory Committee, Pacific Northwest National Laboratories.
2016–2020	XSEDE Advisory Board (NSF-funded program for access to high performance computing resources.)
2015–present	Alumni Advisory Board, University of Michigan Computer Science and Engineering Division.
2011–2014	Infosys Prize jury member, Infosys Science Foundation.
2010	Review Committee for federal Networking and Information Technology Research and Development (NITRD) program on behalf of President’s Council of Advisors on Science and Technology (PCAST).
2010–2017	Council member, Computing Community Consortium
2010–present	American Academy of Arts and Sciences
2010–2014	Technical Advisory Board, Reveal Design Automation
2007–2014	Governing Board, Singapore Centre for Quantum Technology
2006–2012	Technical Advisory Board, NextOp Software (acquired by Atrenta, Inc.)
2006–2014	Academic Research Council, Singapore Ministry of Education.
2006–2009	Computer and Information Science and Engineering (CISE) Advisory Board, National Science Foundation.
2005–2011	Information Technology Advisory Board, Federal Bureau of Investigation.
2003–present	National Academy of Engineering. Section 5 (computer science and engineering) Peer Committee 2008–2009, Nominating Committee, 2010. Search committee executive 2010–2012. Vice Chair 2013–2014, Chair 2014–2015.
2003–2009	Technical Advisory Board, Nusym (acquired by Synopsys in 2010)
2000–2006	Board of Directors, Computing Research Association.
1999–2003	Technical Advisory Board, Innologic Systems (acquired by Synopsys in 2003).
1998–2000	Technical Advisory Board, Simplex Solutions (acquired by Cadence in 2002).
1993–2005	Technical Advisory Board, Fujitsu Labs of America, San Jose, CA.
1981–1985	Consultant: Hewlett Packard, Litton Data Systems, Digital Equipment Corporation, IBM, and other companies.
1978–present	ACM. Elected Fellow, 1999.
1977–present	IEEE. Elected Fellow, 1990.

### Awards

2013	Design Automation Conference. Recognized as coauthor of one of the 10 most cited papers, as one of the ten most cited authors, and for having published over 25 papers during the 50 year history of the conference.
2010	Elected to American Academy of Arts and Sciences.

- 2010 ACM/IEEE A. Richard Newton Technical Impact Award in Electronic Design Automation. Recognizing the impact of the 1986 paper “Graph-based algorithms for Boolean function manipulation.”
- 2009 Phil Kaufman Award, Electronic Design Automation Consortium (EDAC) and IEEE Council for Electronic Design Automation. Citation: “for his seminal breakthroughs in the area of formal verification.”
- 2008 University of Michigan Distinguished Engineering Alumni Award.
- 2007 IEEE Emanuel R. Piore Award. Citation: “For seminal contributions to the field of computer-aided circuit design and verification, including the development and promulgation of ordered binary decision diagrams.”
- 2003 IEEE CAD Transactions Best Paper Award. For paper coauthored with Ph.D. student Yirng-An Chen.
- 2003 Elected to National Academy of Engineering. Citation: “For contributions to symbolic simulation and logic verification.”
- 2003 Paper selected for inclusion in *The Best of ICCAD, 20 Years of Excellence in Computer-Aided Design*, a collection of 42 out of over 2,200 papers that have been presented at the International Conference on Computer-Aided Design between 1983 and 2002.
- 2000 Golden Jubilee Medal. Awarded to 118 members of the IEEE Circuits and Systems Society for professional contributions.
- 1999 Elected Fellow, ACM.
- 1998 Allen Newell Research Excellence Medal, Computer Science Department, Carnegie Mellon University.
- 1998 ACM Kanellakis Theory and Practice Award. Shared with Ken McMillan, Edmund M. Clarke, and Allen Emerson for the development of symbolic model checking
- 1996 Technical Excellence Award, Semiconductor Research Corporation. Shared with Ken McMillan and Edmund M. Clarke for the development of symbolic model checking.
- 1995 Litton Fellow, Carnegie Mellon Computer Science Department.
- 1995 Best Paper Award, Simulation, Verification, and Test Category, 32nd Design Automation Conference, for paper coauthored with Ph.D. student Yirng-An Chen.
- 1990 Elected Fellow, IEEE. Citation: “for contributions to switch-level simulation of very large scale integrated circuits.”
- 1990 Inventor Recognition Award, Semiconductor Research Corporation, for the BDD symbolic Boolean manipulation software library.
- 1989 Inventor Recognition Award, Semiconductor Research Corporation. for the COSMOS switch-level simulator.
- 1989 IEEE W. R. G. Baker Award for “The most outstanding paper reporting original work in any of the IEEE *Transactions*, *Proceedings of the IEEE*, journals, or magazines issued during the previous year.”
- 1988 Best Paper Award, Design, Simulation and Test Category, 25th Design Automation Conference. For paper coauthored with Ph.D. student Derek Beatty.
- 1988 Two papers selected for inclusion in *Twenty Five Years of Electronic Design Automation*, a collection of 77 of the over 1600 papers presented at the Design Automation Conferences for the years 1964–1987.
- 1987 IEEE CAD Transactions Best Paper Award.

- 1983, 1984 IBM Faculty Development Award (One of 100 recipients of special grant for junior faculty.)
- 1974–1978 National Science Foundation Graduate Fellow.

### **Academic Review Committees**

- 2017 Stanford University, Computer Science Department.
- 2015 Iowa State University, Electrical and Computer Engineering Department.
- 2012 University of Michigan, Computer Science and Engineering Division.
- 2011 University of California, San Francisco, Bioinformatics Advisory Panel.
- 2010 Washington University St. Louis, School of Engineering and Applied Science.
- 2009 University of Tokyo, Graduate School of Information Science and Technology.
- 2009 University of Utah, School of Computing.
- 2009 Princeton University, Computer Science Department.
- 2009 University of Virginia, Computer Science Department.
- 2009–2013 Massachusetts Institute of Technology, Department of EECS.
- 2009 University of Washington, Computer Science Department.
- 2007 Georgia Institute of Technology, College of Computing.
- 2007 Stanford University, Computer Science Department.
- 2005 University of Virginia, Computer Science Department.
- 2004 Kuwait University, Graduate program in computer science.
- 2004 Information Technology University of Copenhagen, Denmark.
- 2003 University of Pittsburgh, Computer Science Department.
- 2003 University of Utah, School of Computing.
- 2002 University of Texas, Computer Science Department.
- 2001 Stanford University, Electrical Engineering Department.
- 2000 Technion, Haifa, Israel, Faculty of Computer Science.

### **Conference Committees**

- 2018 Organizing Committee, NITRD Big Data and High End Computing Interagency Working Groups Joint Workshop.
- 2015 Co-organizer, White House Workshop on the National Strategic Computing Initiative
- 2011, 2012 Program Committee, International Conference on Theory and Applications of Satisfiability Testing.
- 2008 Co-organizer, Hadoop Summit and Symposium on Data-Intensive Computing, Sunnyvale, CA.
- 2002–2004 Program Committee, Design and Test in Europe.
- 1996, 1998, 2000, 2002, 2004 Program Committee, International Conference on Formal Methods in Computer-Aided Design.
- 1990, 1994, 2000–2001, 2004, 2006 Program Committee, International Conference on Computer-Aided Verification.
- 1994–2000 Executive Committee, Design Automation Conference (tutorial chair 1994–1995, program co-chair 1998–1999).

- 1990, 1992 Program Committee, TAU International Workshop on Timing Issues in the Specification and Synthesis of Digital Systems.
- 1991, 1993 Program Committee, International Workshop on Logic Synthesis.
- 1989 Program Committee, IFIP Workshop on Applied Formal Methods for Correct VLSI Design.
- 1986–1992 Program Committee, Design Automation Conference.
- 1989–1990 Program Committee, Microelectronic System Education Conference.
- 1989 Program Committee, International Conference on Computer-Aided Design.
- 1988 Program Committee, IFIP Conference on Design Methodologies for VLSI and Computer Architecture.
- 1987 Program Committee, IEEE VLSI Workshop, Clearwater Beach, Florida.
- 1985–1991, 1997 Program Committee, Conference on Advanced Research in VLSI (held at MIT, Caltech, UNC, Brown, and Michigan).
- 1983 Chairman, Third Caltech Conference on Very Large Scale Integration.
- 1979 Organizer, MIT Workshop on Self-Timed Systems.

### **Proposal Review Committees**

- 2001 Texas Advanced Research/Advanced Technology Programs Reviewer.
- 2001 National Science Foundation CAREER Program Proposal Panel.
- 2001 National Science Foundation ITR Program Preproposal Panel.
- 1990 National Science Foundation Graduate Fellowship evaluation panel.

### **Editorships and Reviewing**

- 1995–1997 Editor-in-Chief, *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*.
- 1991–2000 Editorial Board, *Formal Methods in System Design*
- 1989–1995 Associate Editor, *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*.
- 1976–present Reviewer for papers submitted to *IEEE Transactions on Computers*, *IEEE Computer*, *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, *IEEE Transactions on Software Engineering*, *IEEE Transactions on Circuits and Systems*, *ACM Transactions on Computing Systems*, *Journal of the ACM*, *International Journal of Parallel Programming*, *Communications of the ACM*, *Theoretical Computer Science*, *Information Processing Letters*, and numerous conferences.
- 1983–1988 Reviewer for ACM Distinguished Dissertation Award

### **University Service**

- 2020–2021 Academic Freedom Commission, reviewing CMU’s policies on academic freedom and freedom of expression
- 2020–2021 Faculty Senate Chair Emeritus.
- 2019–2020 Faculty Senate Chair.

- 2019–2020 Member of review committee for Dean of Dietrich College of Humanities and Social Science.
- 2017–2019 Faculty Senate Vice Chair.
  - 2017 Chair of search committee for Dean of Carnegie Mellon University, Qatar.
- 2015–2016 Member of review committee for Dean of Carnegie Mellon University, Qatar.
  - 2007 Member of Search Committee for Dean of Mellon College of Science
  - 2004 Member of Search Committee for Director of Robotics Institute.
  - 2000 Member of Provost Search Committee
- 1998–1999 Co-Chair of School of Computer Science Dean Search Committee
- 1993–1999 In charge of faculty reappointments and promotions, Computer Science Department.
- 1991–1993 School of Computer Science Graduate Council. Chairman-Elect 1991–1992, Chairman 1992–1993.
- 1991–1993 Member, CMU Faculty Development Awards Committee
  - 1992 Member of School of Computer Science Dean Search Committee
- 1988–1989 Presidential appointee to CMU Faculty Senate.
- 1988–1990 Graduate Admissions Committee, CMU Computer Science (Chairman, 1989).
- 1985–1987 Qualifier Review Committee, CMU Computer Science Dept. (Chairman, 1986–1987).
- 1986–1987 University Research Council, CMU.
- 1986–1988 Facilities Advisory Committee, CMU Computer Science Dept.
- 1981–1984 Organized Computer Science Seminar series, Caltech.
- 1982–1984 In charge of Computer Science Library, Caltech.
  - 1982 Computer Science Graduate Admissions Committee, Caltech.

## Publications

### Books and Book Chapters

- R. E. Bryant, “Binary Decision Diagrams,” *Handbook of Model Checking*, E. M. Clarke, T. A. Henzinger, H. Veith, and R. Bloem, eds., Springer, 2018, pp. 191–218, Available as  
<http://www.cs.cmu.edu/~bryant/pubdir/hmc-bdd18.pdf>.
- R. E. Bryant, and D. R. O’Hallaron, *Computer Systems: A Programmer’s Perspective, Third Edition*, Prentice-Hall, 2015. More information available at <http://csapp.cs.cmu.edu/>.
- R. E. Bryant, and D. R. O’Hallaron, *Computer Systems: A Programmer’s Perspective, Second Edition*, Prentice-Hall, 2011. More information available at <http://csapp.cs.cmu.edu/>.
- R. E. Bryant, and J. H. Kukula, “Formal Methods for Functional Verification,” in *The Best of ICCAD: 20 Years of Excellence in Computer-Aided Design*, A. Kuehlmann, ed. Kluwer Academic Publishers, 2003, pp. 3–16. Available as  
<http://www.cs.cmu.edu/~bryant/pubdir/iccad-best02.pdf>.
- R. E. Bryant, and D. R. O’Hallaron, *Computer Systems: A Programmer’s Perspective*, Prentice-Hall, 2003.
- R. E. Bryant, and C. Meinel, “Ordered Binary Decision Diagrams,” in *Logic Synthesis and Verification*, S. Hassoun and T. Sasao, eds., Kluwer Academic Publishers, 2001.
- R. E. Bryant, ed., *Proceedings of the Third Caltech Conference on Very Large Scale Integration*, Computer



Science Press, March, 1983.

R. E. Bryant and J. B. Dennis, “Concurrent Programming,” in *Research Directions in Software Technology*, P. Wegner, ed., MIT Press, June, 1979, pp. 584–610. Revised version in *Operating Systems Engineering, Lecture Notes in Computer Science 143*, M. Maekawa and L. A. Belady, eds., Springer-Verlag, 1982, pp. 426–451. Electronic version available as

<http://www.cs.cmu.edu/~bryant/pubdir/MIT-CSG-148-2.pdf>.

## Refereed Journal and Book Articles

R. E. Bryant, “Chain Reduction for Binary and Zero-Suppressed Decision Diagrams,” *Journal of Automated Reasoning*, Vol. 64, No. 7 (2020), pp. 81–98. Available as

<http://www.cs.cmu.edu/~bryant/pubdir/jar20.pdf>.

R. E. Bryant, “Data-Intensive Scalable Computing for Scientific Applications,” *IEEE Computing in Science and Engineering*, Vol. 13, No. 6 (2011), pp. 25–33.

R. E. Bryant, D. Kroening, J. Ouaknine, S. A. Seshia, O. Strichman, and B. Brady, “An Abstraction-Based Decision Procedure for Bit-Vector Arithmetic,” *International Journal of Software Tools for Technology*, Springer-Verlag Vol. 11, No. 2 (April, 2009), pp. 95–104.

R. M. Jensen, M. M. Veloso, and R. E. Bryant, “State-Set Branching: Leveraging BDDs for Heuristic Search,” *Artificial Intelligence*, Vol. 172, Issues 2–3 (February, 2008), pp. 103–139. Available as

<http://www.cs.cmu.edu/~bryant/pubdir/aij07.pdf>.

S. K. Lahiri, and R. E. Bryant, “Predicate Abstraction with Indexed Predicates,” *ACM Transactions on Computational Logic*, Vol. 9, No. 1 (Dec., 2007). Available as

<http://www.cs.cmu.edu/~bryant/pubdir/tocl06.pdf>.

S. A. Seshia, K. Subramani, and R. E. Bryant, “On Solving Boolean Combinations of UTVPI Constraints,” *Journal of Satisfiability, Boolean Modeling and Computation*, Vol. 3 (2007), pp. 67–90. Available as

<http://www.cs.cmu.edu/~bryant/pubdir/jsat07.pdf>.

M. N. Velev, and R. E. Bryant, “TLSim and EVC: A Term-Level Symbolic Simulator and an Efficient Decision Procedure for the Logic of Equality with Uninterpreted Functions and Memories,” *International Journal of Embedded Systems*, Vol. 1, No. 1/2 (2005), pp. 134–149. Available as

<http://www.cs.cmu.edu/~bryant/pubdir/ijes05.pdf>.

S. A. Seshia, and R. E. Bryant, “Deciding Quantifier-Free Presburger Formulas Using Parameterized Solution Bounds,” *Logical Methods in Computer Science*, Vol. 1, Issue 2, Paper 7 (December, 2005). Available as

<http://www.cs.cmu.edu/~bryant/pubdir/lmcs05.pdf>.

M. N. Velev, and R. E. Bryant, “Effective Use of Boolean Satisfiability Procedures in the Formal Verification of Superscalar and VLIW Microprocessors,” *Journal of Symbolic Computation*. Vol. 35, No. 2 (February, 2003), pp. 73–106. Submitted version available as

<http://www.cs.cmu.edu/~bryant/pubdir/jsc03.pdf>.

R. E. Bryant and M. N. Velev, “Boolean Satisfiability with Transitivity Constraints,” *ACM Transactions on Computational Logic*, Vol. 3, No. 4 (October, 2002). Available as

<http://www.cs.cmu.edu/~bryant/pubdir/tocl-trans01.pdf>.

Y.-A. Chen, and R. E. Bryant, “An Efficient Graph Representation for Arithmetic Circuit Verification,” *IEEE*

*Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. 20, No. 12 (December, 2001), pp. 1442–1454. Winner of 2003 IEEE CAD Transactions Best Paper Award. Preprint version available as

<http://www.cs.cmu.edu/~bryant/pubdir/tcad01-chen.pdf>.

R. E. Bryant, and Y.-A. Chen, “Verification of Arithmetic Circuits Using Binary Moment Diagrams,” *Software Tools for Technology Transfer*, Springer-Verlag, Vol. 3, No. 2 (May, 2001), pp. 137–155. Submitted version available as

<http://www.cs.cmu.edu/~bryant/pubdir/sttt-submit.pdf>.

C. B. McDonald and R. E. Bryant, “CMOS Circuit Verification with Symbolic Switch-Level Timing Simulation,” *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. 20, No. 3 (March, 2001), pp. 458–474. Preprint version available as

<http://www.cs.cmu.edu/~bryant/pubdir/tcad01.pdf>.

R. E. Bryant, S. German, M. N. Velev, “Processor Verification Using Efficient Reductions of the Logic of Uninterpreted Functions to Propositional Logic,” *ACM Transactions on Computational Logic*, Vol. 2, No. 1 (January, 2001). Available as

<http://www.cs.cmu.edu/~bryant/pubdir/tocl01.pdf>.

M. Pandey, and R. E. Bryant, “Exploiting symmetry when verifying transistor-level circuits by symbolic trajectory evaluation,” *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. 18, No. 7 (July, 1999), pp. 918–935. Winner of 2001 IEEE Circuits and Systems Society Outstanding Young Author Award. Preprint version available as

<http://www.cs.cmu.edu/~bryant/pubdir/tcad99.pdf>.

C.-J. H. Seger, and R. E. Bryant, “Formal Verification by Symbolic Evaluation of Partially-Ordered Trajectories,” *Formal Methods in System Design*, Vol. 6, No. 2 (March, 1995), pp. 147–190. Preprint version available as

<http://www.cs.cmu.edu/~bryant/pubdir/fmsd95.pdf>.

R. E. Bryant, J. D. Tygar, and L. P. Huang, “Geometric Characterization of Series-Parallel Variable Resistor Networks,” *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, Vol. 41, No. 11 (November, 1994), pp. 686–698. Manuscript version available as

<http://www.cs.cmu.edu/~bryant/pubdir/tcas94.pdf>.

L. P. Huang, and R. E. Bryant, “Intractability in Linear Switch-Level Simulation,” *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. 12, No. 6 (June, 1993), pp. 829–836.

R. E. Bryant, “Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams,” *ACM Computing Surveys*, Vol. 24, No. 3 (September, 1992), pp. 293–318. Preprint version published as CMU Technical Report CMU-CS-92-160,

<http://www.cs.cmu.edu/~bryant/pubdir/CMU-CS-92-160.pdf>. Also available as

<http://www.cs.cmu.edu/~bryant/pubdir/acmcs92.pdf>

S. A. Kravitz, R. E. Bryant, and R. A. Rutenbar, “Massively Parallel Switch-Level Simulation: A Feasibility Study,” *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. 10, No. 7 (July, 1991) pp. 871–894.

R. E. Bryant, “A Methodology for Hardware Verification Based on Logic Simulation,” *J.ACM*, Vol. 38, No. 2 (April, 1991), pp. 299–328. Preprint available as

<http://www.cs.cmu.edu/~bryant/pubdir/jacm91.pdf>.

R. E. Bryant, “On the Complexity of VLSI Implementations and Graph Representations of Boolean Functions with Application to Integer Multiplication,” *IEEE Transactions on Computers*, Vol. 40, No. 2 (February, 1991), pp. 205–213. Preprint available as

<http://www.cs.cmu.edu/~bryant/pubdir/ieeetc91.pdf>.

R. E. Bryant, “Formal Verification of Memory Circuits by Switch-Level Simulation,” *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. 10, No. 1 (January, 1991), pp. 94–102. Preprint available as

<http://www.cs.cmu.edu/~bryant/pubdir/tcad91.pdf>.

D. L. Beatty, and R. E. Bryant, “Incremental Switch-Level Analysis,” *IEEE Design and Test of Computers*, Vol. 5, No. 6 (December, 1988), pp. 33–42.

R. E. Bryant, “A Survey of Switch-Level Algorithms,” *IEEE Design and Test of Computers*, Vol. 4, No. 4 (August, 1987), pp. 26–40.

R. E. Bryant, “Algorithmic Aspects of Symbolic Switch Network Analysis,” *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. CAD-6, No. 4 (July, 1987), pp. 618–633. Winner of 1987 IEEE CAD Transactions Best Paper Award, and the 1989 IEEE W. R. G. Baker Award. Available as

<http://www.cs.cmu.edu/~bryant/pubdir/tcad87a.pdf>.

R. E. Bryant, “Boolean Analysis of MOS Circuits,” *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. CAD-6, No. 4 (July, 1987), pp. 634–649. Winner of the IEEE W. R. G. Baker Award. Available as

<http://www.cs.cmu.edu/~bryant/pubdir/tcad87b.pdf>.

R. E. Bryant, “Graph-Based Algorithms for Boolean Function Manipulation,” *IEEE Transactions on Computers*, Vol. C-35, No. 8 (August, 1986), pp. 677–691. Reprinted in M. Yoeli, *Formal Verification of Hardware Design*, IEEE Computer Society Press, 1990, pp. 253–267. Electronic version with annotations available as

<http://www.cs.cmu.edu/~bryant/pubdir/ieeetc86.pdf>.

W. J. Dally and R. E. Bryant, “A Hardware Architecture for Switch-Level Simulation,” *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. CAD-4, No. 3 (July, 1985), pp. 239–249.

R. E. Bryant, “A Switch-Level Model and Simulator for MOS Digital Systems,” *IEEE Transactions on Computers*, Vol. C-33, No. 2 (February, 1984), pp. 160–177.

## Refereed Conference Articles

R. E. Bryant and M. J. H. Heule, “Dual Proof Generation for Quantified Boolean Formulas with a BDD-Based Solver,” *Computer-Aided Deduction CADE 2021*, LNAI 12699, July, 2021, pp. 433–449. Available as

<http://www.cs.cmu.edu/~bryant/pubdir/cade21.pdf>.

R. E. Bryant and M. J. H. Heule, “Generating Extended Resolution Proofs with a BDD-Based SAT Solver,” *Tools and Algorithms for the Construction and Analysis of Systems TACAS 2021*, LNCS 12651, April, 2021, pp. 76–93. Available as

<http://www.cs.cmu.edu/~bryant/pubdir/tacas21.pdf>.

- R. E. Bryant, “Chain Reduction for Binary and Zero-Suppressed Decision Diagrams,” *Tools and Algorithms for the Construction and Analysis of Systems TACAS 2018*, LNCS 10805, April, 2018, pp. 81–98. Available as  
<http://www.cs.cmu.edu/~bryant/pubdir/tacas18.pdf>.
- B. P. Railing, and R. E. Bryant, “Implementing Malloc: Students and Systems Programming,” *49th ACM Technical Symposium on Computer Science Education SIGCSE 2018*, February, 2018. Available as  
<http://www.cs.cmu.edu/~bryant/pubdir/sigcse18.pdf>.
- R. M. Fujimoto, R. Bagrodia, R. E. Bryant, K. M. Chandy, D. Jefferson, J. Misra, D. Nicol, and B. Unger, “Parallel Discrete Event Simulation: The Making of a Field,” *Winter Simulation Conference 2017*, December, 2017. Available as  
<http://www.cs.cmu.edu/~bryant/pubdir/wsc17.pdf>
- H. Cui, J. Šimša, Y.-H. Ling, H. Li, B. Blum, X. Xu, J. Yang, G. A. Gibson, and R. E. Bryant, “PARROT: A Practical Runtime for Deterministic, Stable, and Reliable Threads,” *24th ACM Symposium on Operating Systems Principles*, 2013.
- J. Šimša, R. Bryant, G. A. Gibson, and J. Hickey, “Scalable Dynamic Partial Order Reduction,” *3rd International Conference on Runtime Verification*, 2012.
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- R. E. Bryant, “Simulation on a Distributed System,” *First International Conference on Distributed Systems*, IEEE, October, 1979, pp. 544–552. Electronic version available as  
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## Unrefereed Articles

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- R. E. Bryant, “A View from the Engine Room: Computational Support for Symbolic Model Checking,” *25 Years of Model Checking*, H. Veith and O. Grunberg, eds. LNCS-4925, Springer-Verlag, 2007, available as  
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- R. E. Bryant, “Formal Verification of Infinite State Systems Using Boolean Methods,” *Logic in Computer Science LICS 2006*, IEEE, July, 2006, pp. 3–4, available as  
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- R. E. Bryant, S. A. Seshia, “Decision Procedures Customized for Formal Verification,” *Automated Deduction CADE 2005*, LNCS 3632, Springer-Verlag, July, 2005, pp. 255–259. Available as  
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- R. E. Bryant, and S. K. Rajamani, “Verifying Properties of Hardware and Software by Predicate Abstraction and Model Checking,” *International Conference on Computer-Aided Design ICCAD '04*, November, 2004, pp. 236–243. Available as  
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- R. E. Bryant, “System Modeling and Verification with UCLID,” *Formal Methods and Models for Co-Design MEMOCODE '04*, June, 2004, IEEE, June, 2004, pp. 3–4. Available as  
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- R. E. Bryant, “Reasoning about Infinite-State Systems Using Boolean Methods,” *Foundations of Software Technology and Theoretical Computer Science FSTTCS '03*, December, 2003. Available as  
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- R. E. Bryant, S. German, and M. N. Velev, “Microprocessor Verification Using Efficient Decision Procedures for a Logic of Equality with Uninterpreted Functions,” *Tableaux '99*, N. Murray, ed., LNAI 1617, Springer-Verlag, June, 1999. Available as  
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- R. E. Bryant, “Formal Verification of Pipelined Processors,” *Tools and Algorithms for the Construction and Analysis of Systems TACAS '98*, B. Steffen, ed., LNCS 1384, Springer-Verlag, March 1998, pp. 1–4.
- R. E. Bryant, “Multipliers and Dividers: Insights on Arithmetic Circuit Verification,” Invited paper, *Computer-*

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R. E. Bryant, “Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams,” *Second Makuhari International Conference on High Technology*, Chiba, Japan, 1990.

R. E. Bryant, “Formal Hardware Verification by Symbolic Simulation,” *VLSI Logic Synthesis and Design*, R. W. Dutton, ed., IOS Press, Amsterdam, 1991.

R. E. Bryant, “Verification of Synchronous Circuits by Symbolic Logic Simulation,” in *Hardware Specification, Verification, and Synthesis: Mathematical Aspects*, M. Leeser and G. Brown, eds., Springer-Verlag, 1990, pp. 14–24. Available as  
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S. A. Kravitz, and R. E. Bryant “Massively Parallel Logic Simulation,” *TECHCON-88*, Semiconductor Research Corp., October, 1988.

R. E. Bryant, “Compiled Simulation of MOS Circuits,” *Canadian Conference on VLSI*, October, 1986, pp. 217–219.

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R. E. Bryant, “Switch-Level Modeling of MOS Digital Circuits,” *International Conference on Circuits and Systems*, Rome, Italy, May, 1982, pp. 68–71.

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R. E. Bryant, “Introductory Computer Science Education at Carnegie Mellon University: A Deans’ Perspective,” Technical report CMU-CS-10-140. Available as  
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R. E. Bryant, “Data-Intensive Supercomputing: The Case for DISC,” Technical report CMU-CS-07-128. Available as  
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- R. E. Bryant, “Term-Level Verification of a CISC Microprocessor,” Technical report CMU-CS-05-195. Available as  
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- M. Starkey, and R. E. Bryant, “Using Ordered Binary-Decision Diagrams for Compressing Images and Image Sequences,” Technical Report CMU-CS-95-105, January, 1995. Available as  
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- M. Schuster, and R. E. Bryant, *FMOSSIM: A Switch-Level Logic and Fault Simulator*, unpublished user’s manual, 1985.
- R. E. Bryant, M. Schuster, and D. Whiting, *MOSSIM II: A Switch-Level Simulator for MOS LSI, User’s Manual*, Technical Report 5033, Caltech Computer Science, 1982. Available as  
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- R. E. Bryant, *A Switch-Level Simulation Model for Integrated Logic Circuits*, (PhD thesis), Technical Report TR-259, MIT Laboratory for Computer Science, March, 1981. Available as  
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- R. E. Bryant, *Simulation of Packet Communication Architecture Computer Systems*, (Master’s thesis), Technical Report TR-188, MIT Laboratory for Computer Science, November, 1977. Available as  
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## Technical Presentations

### Professional Meetings and Conferences

Invited talks indicated with asterisk.

- 7/14/20 “Dual Proof Generation for Quantified Boolean Formulas with a BDD-Based Solver,” Computer-Aided Deduction, Held online.
- 4/29/20 “Generating Extended Resolution Proofs with a BDD-Based SAT Solver,” Tools and Algorithms for the Construction and Analysis of Systems, Held online.

- 4/17/18 “Chain Reduction for Binary and Zero-Suppressed Decision Diagrams,” Tools and Algorithms for the Construction and Analysis of Systems, Thessaloniki, Greece.
- \*5/23/16 “Creating Foundations for Parallel and Distributed Computing,” Keynote presentation, NSF/TCPP Workshop on Parallel and Distributed Computing Education, Chicago, IL
- \*4/29/16 “Moore’s Law: Another 50 Years?,” Symposium on Programming: Logics, Models, Algorithms and Concurrency, Austin, TX
- \*3/5/16 “Introducing Computer Systems from a Programmer’s Perspective,” Keynote presentation, Workshop on Connecting Concepts Across the Curriculum, Baton Rouge, LA
- \*11/18/15 “The National Strategic Computing Initiative,” International Conference for High Performance Computing, Networking, Storage and Analysis, Austin, TX
- \*11/18/15 “Supercomputing and Big Data: A Convergence?,” as part of a panel session on “Supercomputing and Big Data: From Collision to Convergence” at International Conference for High Performance Computing, Networking, Storage and Analysis, Austin, TX
- \*9/10/15 “The National Strategic Computing Initiative,” as part of a panel session at HPC User Forum, Broomfield, CO
- \*11/10/12 “Creating a Foundational Curriculum in Computer Science,” University Course Forum in Computer Science, Guangzhou, China
- \*9/19/11 “Computer Science Research Opportunities in Sustainability,” US-China Collaborations in Computer Science and Sustainability, DIMACS, Rutgers.
- \*6/8/11 “Data-Intensive Scalable Computing,” Workshop on Building Blocks for Scalable Cloud Computing, Design Automation Conference, San Diego, CA.
- \*4/14/11 “Data-Intensive Scalable Computing,” Teragrid/Blue Waters Symposium, Pittsburgh, PA.
- \*06/24/10 “Data-Intensive Scalable Computing: Finding the Right Programming Models,” Keynote presentation, High-Performance and Distributed Computing Conference, Chicago, IL.
- 01/29/10 “Data-Intensive Scalable Computing: Prospects and Challenges.” OpenCirrus Consortium, Sunnyvale, CA.
- 10/16/09 “Data-Intensive Scalable Computing for eScience,” Microsoft eScience Workshop, Pittsburgh, PA.
- \*10/13/09 “Data-Intensive Scalable Computing,” Los Alamos Computer Science Symposium, Santa Fe, NM.
- 07/30/09 “Data-Intensive Computing: The Prospects and the Challenges,” Workshop on Enabling Data-Intensive Computing: from Systems to Applications, University of Pittsburgh, Pittsburgh, PA.
- 6/25/08 “Data-Intensive Cloud Computing,” as part of panel session on Cloud Computing at the High-Performance Distributed Computing Conference, Boston, MA.
- \*4/23/08 “Reasoning about Data: Bits, Bit Vectors, or Words,” Keynote Speech, International Symposium on VLSI Design Automation, and Test, Hsinchu, Taiwan.
- \*3/26/08 “Data-Intensive Super Computing,” Symposium on Data-Intensive Computing, Sunnyvale, CA.
- \*3/17/08 “Data-Intensive Super Computing,” Technology@Sun 2008 (an internal meeting of the engineering leadership of Sun Microsystems), Santa Cruz, CA.
- \*11/11/07 “Modeling Data in Formal Verification: Bits, Bit Vectors, or Words,” Tutorial at Formal Methods in Computer-Aided Design, Austin, TX.

- \*6/13/07 “Data-Intensive Super Computing: Taking Google-Style Computing Beyond Web Search,” Special session at Federated Computing Research Conference, San Diego, CA.
- \*8/16/06 “A View from the Engine Room: Computational Support for Symbolic Model Checking,” Workshop on 25 Years of Model Checking, Seattle, WA.
- \*8/12/06 “Formal Verification of Infinite State Systems using Boolean Methods,” Plenary talk, Federated Logic Conference, Seattle, WA.
- \*7/26/05 “Decision Procedures Customized for Formal Verification,” Conference on Automated Deduction (CADE), Tallinn, Estonia
- 11/9/04 “Symbolic, Word-Level Hardware Verification,” Embedded tutorial, ICCAD ’04, San Jose, CA.
- \*6/23/04 “System Modeling and Verification with UCLID,” Keynote talk, Formal Methods and Models for Co-Design, San Diego, CA.
- \*12/15/03 “Reasoning about Infinite-State Systems Using Boolean Methods,” Keynote talk, Foundations of Software Technology and Theoretical Computer Science, Mumbai, India.
- 12/14/03 “SAT-Based Decision Procedures for Subsets of First-Order Logic,” Workshop on Model Checking, Mumbai, India.
- \*11/2/02 “Symbolic Simulation and its Connection to Formal Verification,” Formal Methods in Computer-Aided Design, Portland, Oregon
- \*6/3/02 “Introducing Computer Systems from a Programmer’s Perspective,” David C. Evans Conference on Computer Engineering, Utah
- \*5/00 “Binary Decision Diagrams and Symbolic Model Checking,” Symposium on Algorithms in the Real World, Pittsburgh, PA
- 7/10/99 “Exploiting Positive Equality in a Logic of Equality With Uninterpreted Functions,” Computer-Aided Verification, CAV ’99, Trento Italy.
- 7/9/99 “Optimizing Symbolic Model Checking for Constraint-Rich Models,” Computer-Aided Verification, CAV ’99, Trento Italy.
- \*6/8/99 “Microprocessor Verification Using Uninterpreted Functions,” Tableaux ’99, Saratoga Springs, NY.
- \*4/2/98 “Formal Verification of Pipelined Processors,” European Joint Conferences on Theoretical and Practical Aspects of Software, Lisbon, Portugal.
- \*12/11/97 “Formal Verification of Pipelined Processors,” Third Asian Computing Science Conference, Kathmandu, Nepal.
- 6/24/97 “Exploiting Symmetry When Verifying Transistor Circuits by Symbolic Trajectory Evaluation,” Computer-Aided Verification, CAV ’97, Haifa Israel.
- 6/6/96 “Bit-Level Analysis of an SRT Divider Circuit,” 32nd Design Automation Conference, Las Vegas CA.
- 3/25/96 “BDDs and Beyond: Enabling Technologies for Formal Verification,” DIMACS Workshop on Formal Verification.
- 3/11/96 “BDDs Applied to SAT and Related Problems,” DIMACS Workshop on Satisfiability, Rutgers University.
- 11/6/95 “BDDs and Beyond: Enabling Technologies for Formal Verification,” Embedded tutorial, ICCAD ’95, San Jose, CA.
- \*7/3/95 “Multipliers and Dividers: Insights on Arithmetic Circuit Verification,” Computer-Aided Verification, CAV ’95, Liege, Belgium.



- 2/17/95 “Formal Verification of Arithmetic Circuits with Binary Moment Diagrams,” Computer Systems Seminar, Dagstuhl Seminar on Computer-Aided Design, Dagstuhl, Germany.
- \*5/25/94 “Digital Circuit Verification using Partially-Ordered State Models,” 24th International Symposium on Multiple-Valued Logic, Boston, MA.
- \*11/29/93 “Symbolic Analysis Methods for Masks, Circuits, and Systems,” GMD 25th Anniversary Symposium, Bonn, Germany.
- 11/4/93 “Beyond Digital CAD: New Applications for Binary Decision Diagrams,” ARPA Microsystem Contractors Meeting, Seattle, WA.
- \*10/4/93 “Symbolic Analysis Methods for Masks, Circuits, and Systems,” CAD Plenary Session, International Conference on Computer Design, Cambridge, MA.
- 5/93 “Geometric Characterization of Series-Parallel Variable Resistor Networks,” International Symposium on Circuits and Systems, Chicago, IL.
- \*3/26/92 “Privileged but Illiterate, Report on a Year in Japan,” MIT/Brown Conference on Advanced Research in VLSI and Parallel Systems, Providence, RI.
- 11/14/91 “Privileged but Illiterate, Report on a Year in Japan,” DARPA VLSI Contractors Meeting, Pasadena, CA.
- 11/12/91 “Extraction of Gate Level Models from Transistor Circuits by 4-Valued Symbolic Analysis.” International Conference on Computer-Aided Design, Santa Clara, CA.
- \*6/19/91 “Formal Verification, a Slow, but Certain Evolution,” Panel on Formal Methods, 28th Design Automation Conference.
- 2/4/91 “Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams,” Second Makuhari Conference on High Technology, Chiba, Japan.
- \*10/24/90 “Formal Hardware Verification by Symbolic Simulation,” 1990 Synthesis and Simulation Meeting and International Interchange, Kyoto, Japan.
- \*8/31/90 “Symbolic Simulation—Techniques and Applications,” Japanese Design Automation Workshop, Gamagouri, Japan.
- 6/27/90 “Symbolic Simulation—Techniques and Applications,” 27th Design Automation Conference.
- \*11/15/89 “Symbolic Analysis and Verification of MOS Circuits,” IFIP Workshop on Applied Formal Methods for Correct VLSI Design, Hengelhof, Belgium.
- \*7/5/89 “Verification of Synchronous Circuits by Symbolic Logic Simulation,” Workshop on Hardware Specification, Verification, and Synthesis, Cornell University.
- 6/27/89 “Test Pattern Generation for Sequential MOS Circuits by Symbolic Fault Simulation,” 26th Design Automation Conference.
- \*5/8/89 “Physical/Functional Tool Integration,” panel discussion at 1989 Synthesis and Simulation Meeting and International Interchange, Osaka, Japan.
- 4/3/89 “Test Pattern Generation for Combinational and Sequential MOS Circuits by Symbolic Fault Simulation,” DARPA VLSI Contractor’s Meeting, Snowbird, UT.
- 11/9/88 “Data Parallel Switch-Level Simulation,” International Conference on Computer-Aided Design.
- 6/15/88 “CAD Tool Needs for System Designers,” Panel Session Chairman, 25th Design Automation Conference.
- 3/30/88 “Verifying a Static RAM Design by Logic Simulation,” Fifth MIT Conference on Advanced Research in VLSI.

- 2/1/88 "Verifying a Static RAM Design by Logic Simulation," IEEE VLSI Workshop, Clearwater Beach, FL.
- 11/16/87 "COSMOS Makes its Debut," DARPA VLSI Contractors Meeting, Berkeley, CA.
- \*9/15/87 "Transistor-Level Logic Simulation," Semiconductor Research Conference Topical Research Conference on Design Verification, Pittsburgh, PA.
- 6/29/87 "COSMOS: A Compiled Simulator for MOS Circuits," 24th Design Automation Conference, Miami Beach, FL.
- \*5/26/87 "Symbolic Analysis of MOS Circuits," U.S./Israel Joint Workshop on VLSI Architecture and Design, Tiberias, Israel.
- 2/24/87 "COSMOS: A Compiled Simulator for MOS Circuits," IEEE VLSI Workshop, Clearwater Beach, FL.
- \*10/28/86 "Compiled Simulation of MOS Circuits," Canadian Conference on VLSI, Montreal.
- 10/1/85 "Formal Verification of Digital Circuits by Logic Simulation," DARPA VLSI Contractors Meeting, Seattle, WA.
- \*7/2/85 "Can a Simulator Verify a Circuit?," Workshop on Formal Aspects of VLSI, Edinburgh University, Scotland.
- 6/27/85 "Performance Evaluation of FMOSSIM: a Concurrent, Switch-Level Fault Simulator," 22nd Design Automation Conference, Las Vegas, Nevada.
- 6/27/85 "Symbolic Manipulation of Boolean Functions Using a Graphical Representation," 22nd Design Automation Conference, Las Vegas, Nevada.
- 5/17/85 "Symbolic Verification of MOS Circuits," 1985 Chapel Hill Conference on VLSI, Chapel Hill, North Carolina.
- 4/24/85 "Test Generation for MOS Circuits by Symbolic Fault Simulation," IEEE Workshop on Design for Testability, Beaver Creek, Colorado.
- 3/18/85 "Symbolic Verification of MOS Circuits," DARPA VLSI Contractors Meeting, Salt Lake City, UT.
- \*10/84 "Simulators (Will Always) Provide Superior Models," Panel on Testability Measures, 1984 International Test Conference, Philadelphia, Pennsylvania.
- \*4/84 "Experiments with a Switch-Level Fault Simulator," IEEE Workshop on Design for Testability, Vail, Colorado.
- \*11/28/83 "Switch-Level Models for MOS Digital Systems," Mathematical Methods of VLSI, Mathematisches Forschungsinstitut, Oberwolfach, Germany.
- 8/16/83 "Race Detection in MOS Circuits by Ternary Simulation," VLSI 83, Trondheim, Norway.
- \*6/28/83 "The Role of Simulation in VLSI Design," VLSI for the 80's, Victoria B. C., Canada.
- \*4/25/83 "Switch-Level Fault Simulation," IEEE West Coast Test Workshop, Napa, Calif.
- \*5/10/82 "Switch-Level Modeling of MOS Digital Circuits," IEEE International Symposium on Circuits and Systems, Rome, Italy.
- 8/21/81 "A Switch-Level Model of MOS Logic Circuits," VLSI 81, Edinburgh, Scotland.
- 7/1/81 "MOSSIM: A Logic Simulator for MOS LSI," 18th Design Automation Conference, Nashville, Tennessee.
- 10/5/79 "Simulation on a Distributed System," First International Conference on Distributed Systems, Huntsville, Ala.
- 7/78 "Analytical Models of Interconnection Networks," Workshop on Data Flow Computer

and Program Organization, Dedham, MA.

## Seminars and Colloquia

- 11/9/12 “Creating a Foundational Curriculum in Computer Science,” University of Science and Technology Beijing.
- 10/24/12 “Data Intensive Scalable Computing,” Karlsruhe Institute of Technology, Karlsruhe, Germany
- 6/7/12 “Introducing Computer Systems from a Programmer’s Perspective,” Tsinghua University, Beijing, China.
- 6/5/12 “Data Intensive Scalable Computing,” Peking University, Beijing, China.
- 6/4/12 “Introducing Computer Systems from a Programmer’s Perspective,” Peking University, Beijing, China.
- 2/3/12 “Introducing Computer Systems from a Programmer’s Perspective,” Strathmore University, Nairobi, Kenya.
- 2/1/12 “Data-Intensive Scalable Computing: Finding the Right Programming Model” Computer Science Seminar, Carnegie Mellon Qatar Campus.
- 1/31/12 “Data-Intensive Scalable Computing,” Nico Habermann Memorial Lecture, Carnegie Mellon Qatar Campus.
- 3/16/11 “Data-Intensive Scalable Computing: Finding the Right Programming Model,” Distinguished Lecture, Northwestern University Computer Science Department.
- 3/9/11 “Data-Intensive Scalable Computing: Finding the Right Programming Model,” Los Alamos National Laboratory.
- 11/4/09 “BDDs and SAT Solvers: Applying Boolean Reasoning to Formal Hardware Verification,” Cadence Design Systems, Sunnyvale, CA.
- 1/6/09 “Data-Intensive Scalable Computing: Taking Google-Style Computing Beyond Web Search,” National University of Singapore, Singapore.
- 1/5/09 “Data-Intensive Scalable Computing: Taking Google-Style Computing Beyond Web Search,” Nanyang Technical University, Singapore.
- 11/14/08 “Data-Intensive Scalable Computing: Taking Google-Style Computing Beyond Web Search,” University of Kentucky, Computer Science Department Distinguished Lecture.
- 10/20/08 “Data-Intensive Scalable Computing: Taking Google-Style Computing Beyond Web Search,” RAND Corporation, Washington DC.
- 10/20/08 “Data-Intensive Scalable Computing: Taking Google-Style Computing Beyond Web Search,” National Science Foundation, CISE Distinguished Lecture.
- 10/14/08 “Data-Intensive Scalable Computing: Taking Google-Style Computing Beyond Web Search,” Oxford University Strachey Distinguished Lecture, Oxford, England.
- 10/03/08 “Data-Intensive Scalable Computing: Taking Google-Style Computing Beyond Web Search,” University of Michigan, Computer Science and Engineering Seminar.
- 05/05/08 “Data-Intensive Scalable Computing: Taking Google-Style Computing Beyond Web Search,” Carnegie Mellon University Qatar Campus.
- 3/21/08 “Data-Intensive Super Computing: Taking Google-Style Computing Beyond Web Search,” Barr Systems Lecture Series, University of Florida.
- 3/10/08 “Data-Intensive Super Computing: Taking Google-Style Computing Beyond Web Search,”

- IT Eminent Lecture Series, Louisiana State University.
- 11/14/07 “Data-Intensive Super Computing: Taking Google-Style Computing Beyond Web Search,” Kent State University, Kent, OH.
- 1/12/07 “Bit-Vector Decision Procedures: A Basis for Reasoning about Hardware and Software,” Microsoft Research, Redmond, WA.
- 1/3/07 “Automated Formal Verification of Software: Status and Prospects,” Department of Computer Science, National University of Singapore.
- 5/26/06 “Computer Systems: A Programmer’s Perspective,” Southeast University, Nanjing, China.
- 2/8/06 “Verifying Infinite-State Systems Using Boolean Methods,” MIT CSAIL Michael Der-touzos Distinguished Lecture, MIT.
- 7/12–14/05 Seminars at Intel in Haifa, Israel:
- “SAT-Based Decision Procedures for Linear Arithmetic and Uninterpreted Functions”
  - “System Modeling and Verification with UCLID”
  - “Symbolic Approaches to Invariant Checking and Automatic Predicate Abstraction”
- 6/7/05 “Binary Decision Diagrams and Their Applications,” Information and Communications University, Daejeon, Korea.
- 9/5/04 “Binary Decision Diagrams and Their Applications,” Kuwait University Department of Math and Computer Science.
- 9/3/04 “SAT-Based Decision Procedures for Subsets of First-Order Logic,” Kuwait University Department of Math and Computer Science.
- 8/19/04 “Reasoning about Infinite-State Systems Using Boolean Methods,” Distinguished Lecture, Cadence Corporation, San Jose, CA.
- 4/26/04 “Verifying Infinite-State Systems Using Boolean Methods,” Harvard University.
- 4/14/04 “Verifying Infinite-State Systems Using Boolean Methods,” Distinguished Lecture, Southern Methodist University.
- 10/23/03 “Verifying Infinite-State Systems Using Boolean Methods,” Distinguished Lecture, University of Pennsylvania Computer Science Department.
- 7/14/03 “Verifying Infinite-State Models Using Boolean Methods,” Synopsys, Inc., Hillsboro, OR.
- 4/21/03 “Formal Verification Using Infinite-State Models,” Fujitsu Laboratories, Kawasaki, Japan.
- 3/6/03 “Formal Verification Using Infinite-State Models,” Distinguished Lecture, UCLA Computer Science Department.
- 11/14/02 “Introducing Computer Systems from a Programmer’s Perspective,” Distinguished Lecture, School of Computing, Georgia Institute of Technology, Atlanta, Georgia.
- 7/13/99 “Optimizing Symbolic Model Checking for Constraint-Rich Models,” IBM Haifa Research Laboratory, Haifa, Israel.
- 7/12/99 “Processor Verification Using Efficient Reductions of the Logic of Uninterpreted Functions to Propositional Logic,” Intel Logic Verification Symposium, Haifa, Israel.
- 6/26/98 “Bit-Level Verification of Pipelined Processors,” Intel Corp., Hillsboro, OR.
- 3/26/97 “Hierarchical Verification Based on Symbolic Trajectory Evaluation” Lucent Technologies Bell Laboratories, Murray Hill, NJ

- 12/6/96 “Hierarchical Verification based on Symbolic Trajectory Evaluation” Intel Corp., Hillsboro, OR.
- 10/24/96 “Multipliers and Dividers, Insights on Arithmetic Circuit Verification,” Distinguished Lecture, Department of Computer Science, University of Washington.
- 4/12/96 “Formal Verification of Sequential Processors”, Intel Frontiers in CAD Symposium, Hillsboro, OR.
- 2/22/96 “Multipliers and Dividers, Insights on Arithmetic Circuit Verification,” Distinguished Lecture, Department of Computer Science, University of Utah.
- 12/4/95 “Division Pentium Style: An Analysis of Intel’s Mistake(s),” Distinguished Speaker Series, Cadence Design Systems, Chelmsford, MA.
- 11/8/95 “Multipliers and Dividers, Insights on Arithmetic Circuit Verification,” SRI International, Menlo Park, CA.
- 10/11/95 “Multipliers and Dividers, Insights on Arithmetic Circuit Verification,” EECS CAD Seminar, U. C. Berkeley.
- 7/17/95 “Multipliers and Dividers, Insights on Arithmetic Circuit Verification,” EECS Dept., University of Michigan.
- 4/21/95 “Formal Verification of Arithmetic Circuits with Binary Moment Diagrams,” Distinguished Lecture, University of Southern California.
- 2/22/95 “Division Pentium Style: An Analysis of Intel’s Mistake(s),” Computer Systems Seminar, Carnegie Mellon University Computer Science Department.
- 10/21/94 “Formal Verification of Arithmetic Circuits with Binary Moment Diagrams,” Computer Systems Seminar, Carnegie Mellon University Computer Science Department.
- 10/5/94 “Formal Verification of Arithmetic Circuits with Binary Moment Diagrams,” Distinguished Lecture, University of Texas Computer Science Department.
- 10/3/94 “Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams,” Distinguished Lecture, University of Texas Computer Science Department.
- 12/1/93 “Symbolic Analysis Methods for Masks, Circuits, and Systems,” University of Trier, Trier, Germany.
- 5/93 “A Methodology for Formal Hardware Verification, with Application to a Real Microprocessor,” University of Grenoble, Grenoble, France.
- 5/93 “A Methodology for Formal Hardware Verification, with Application to a Real Microprocessor,” Digital Equipment Corp., Paris Research Laboratory, Paris, France.
- 10/30/92 “Formal Hardware Verification by Symbolic Trajectory Evaluation,” Motorola Corp., Austin, TX.
- 10/29/92 “Formal Hardware Verification by Symbolic Trajectory Evaluation,” IBM Corp., Austin, TX.
- 7/14/92 “Formal Hardware Verification by Symbolic Trajectory Evaluation,” Intel Corp., Hillsboro, OR.
- 3/3/92 “Formal Hardware Verification and Logic Abstraction,” Digital Equipment Corporation, Hudson, MA.
- 3/2/92 “Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams,” Harvard University.
- 5/23/91 “Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams,” Fujitsu International Institute for Advanced Study of Social Information Science, Numazu, Japan.

- 5/22/91 "Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams," Tokyo Institute of Technology, Tokyo, Japan.
- 5/20/91 "Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams," Kyushu Institute of Technology, Iizuka, Japan.
- 5/13/91 "Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams," Fujitsu Laboratories, Kawasaki, Japan.
- 5/9/91 "Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams," Dept. of Information Science, Kyoto University, Kyoto, Japan.
- 3/15/91 "Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams," Nippon Electric Corporation, Kawasaki, Japan.
- 3/15/91 "The COSMOS Project: Switch-Level Modeling and Simulation," Nippon Electric Corporation, Kawasaki, Japan.
- 3/1/91 "Symbolic Boolean Manipulation with Ordered Binary Decision Diagrams," Electrotechnical Laboratory, Tsukuba, Japan.
- 6/8/90 "Formal Verification of MOS Circuits by Symbolic Simulation," Siemens AG, Munich, Germany.
- 6/5/90 "Formal Verification of MOS Circuits by Symbolic Simulation," Bull Research Center, Paris, France.
- 10/23/89 "The COSMOS Project: Switch-Level Modeling and Simulation," Gateway Design Automation Corp., Lowell, MA.
- 6/7/89 "Test Pattern Generation for Sequential MOS Circuits by Symbolic Fault Simulation," Hewlett Packard, Palo Alto, CA.
- 6/2/89 "Test Pattern Generation for Sequential MOS Circuits by Symbolic Fault Simulation," General Electric, Schenectady, NY.
- 5/11/89 "COSMOS: A COMpiled Simulator for MOS Circuits," Fujitsu Laboratories, Kawasaki, Japan.
- 5/10/89 "Switch-Level Simulation," Matsushita Electric Industrial Co., Osaka Japan.
- 1/20/89 "Graph-Based Algorithms for Boolean Function Manipulation," University of Colorado.
- 11/7/88 "Test Pattern Generation for Sequential MOS Circuits by Symbolic Fault Simulation," CAD Seminar, University of California, Berkeley.
- 11/3/88 "Test Pattern Generation for Sequential MOS Circuits by Symbolic Fault Simulation," CMU Center or Dependable Systems Seminar.
- 10/20/88 "COSMOS: A COMpiled Simulator for MOS Circuits," Syracuse University.
- 7/18/88 "Graph-Based Algorithms for Boolean Function Manipulation," IBM Watson Research Center, Yorktown Hts., NY.
- 6/9/88 "COSMOS: A COMpiled Simulator for MOS Circuits," Digital Equip. Corp., Hudson, MA.
- 4/22/88 "COSMOS: A COMpiled Simulator for MOS Circuits," University of Illinois, Coordinated Sciences Laboratory.
- 4/13/88 "COSMOS: A COMpiled Simulator for MOS Circuits," University of Waterloo, Ontario.
- 3/8/88 "COSMOS: A COMpiled Simulator for MOS Circuits," MIT VLSI Seminar.
- 11/18/87 "COSMOS: A COMpiled Simulator for MOS Circuits," Xerox Palo Alto Research Center.

- 11/17/87 "COSMOS: A COMpiled Simulator for MOS Circuits," CAD Seminar, University of California, Berkeley.
- 5/13/87 "COSMOS: A COMpiled Simulator for MOS Circuits," Dept. Elec. Eng., Texas A&M Univ.
- 4/10/87 "COSMOS: A COMpiled Simulator for MOS Circuits," VLSI Seminar, IBM Watson Research Center, Yorktown Hts., NY.
- 1/30/87 "COSMOS: A COMpiled Simulator for MOS Circuits," Computer Systems Seminar, Carnegie Mellon University.
- 12/18/86 "COSMOS: A COMpiled Simulator for MOS Circuits," Dept. Comp. Sci., Univ. of Washington.
- 12/18/86 "Fault Simulation of MOS Circuits," Dept. Comp. Sci., Univ. of Washington.
- 12/1/86 "COSMOS: A COMpiled Simulator for MOS Circuits," AT&T Bell Laboratories, Murray Hill, NJ.
- 10/29/86 "Formal Verification of Digital Circuits by Logic Simulation," Dept. Elec. Engineering, McGill University, Montreal, Canada.
- 10/21/86 "COSMOS: A COMpiled Simulator for MOS Circuits," Design Automation Seminar, CMU Dept. Electrical and Computer Engineering.
- 3/4/86 "Symbolic Verification of MOS Circuits," Computer Science Seminar, Caltech.
- 1/28/86 "Formal Verification of Digital Circuits by Logic Simulation," Computer Science Seminar, Univ. of Utah.
- 11/6/85 "Formal Verification of Digital Circuits by Logic Simulation," Computer Science Seminar, Univ. of Waterloo, Ontario.
- 10/22/85 "Symbolic Verification of MOS Circuits," VLSI Seminar, MIT Dept. of EECS.
- 10/4/85 "Symbolic Verification of MOS Circuits," Stanford Dept. of Elec. Eng.
- 10/3/85 "Symbolic Verification of MOS Circuits," Schlumberger Research, Palo Alto, CA.
- 6/12/85 "Symbolic Methods for MOS Circuits," Texas Instruments, Dallas, TX.
- 4/23/85 "Symbolic Verification of MOS Circuits," ECE Dept. Univ. of Colorado.
- 11/30/84 "Graph-Based Algorithms for Boolean Function Manipulation," AT&T Bell Laboratories, Murray Hill, N.J.
- 11/29/84 "A Switch-Level Model of MOS Circuits," AT&T Bell Laboratories, Murray Hill, N.J.
- 6/84 "The MOSSIM Simulation Engine," Dept. Comp. Sci., Univ. of Washington.
- 6/84 "Experiments with a Switch-Level Fault Simulator," Boeing Corp., Seattle, WA.
- 6/84 "The MOSSIM Simulation Engine," Tektronix, Inc., Portland, OR.
- 6/84 "The MOSSIM Simulation Engine," Intel Corp., Santa Clara, CA.
- 12/6/83 "Concurrent Fault Simulation of MOS Digital Circuits," Universität des Saalandes, Saarbrücken, Germany.
- 11/3/83 "Switch-Level Simulation," Texas Instruments, Dallas, TX.
- 6/26/83 "Switch-Level Simulation," Intel Corp., Santa Clara, CA.
- 5/7/83 "Introduction to VLSI," California Polytechnical Institute, Pomona, CA.
- 10/20/82 "Architectures for VLSI," Fairchild Research Laboratories, Palo Alto, CA.
- 10/19/82 "Switch-Level Simulation and the Verification of MOS Digital Circuits," UCLA Computer Science Seminar, Los Angeles, CA.
- 9/21/82 "Switch-Level Simulation and the Verification of MOS Digital Circuits," VLSI Seminar, MIT Dept. of EECS.

- 9/20/82 “Switch-Level Simulation and the Verification of MOS Digital Circuits,” Digital Equip. Corp., Hudson, MA.
- 4/26/82 “A Switch-Level Model of MOS Circuits,” IBM Watson Research Center, Yorktown Hts., NY.
- 2/16/82 “A Switch-Level Model of MOS Circuits,” Oregon Graduate Center, Hillsboro, OR.
- 4/14/80 “MOSSIM: A Logic Simulator for MOS LSI,” IBM Watson Research Center, Yorktown Hts., NY.

## Outreach

- 1/30/12 “Boolean Methods,” Student workshop, Carnegie Mellon Qatar Campus.
- 07/29/10 “Boolean Methods,” Andrew’s Leap Program, Pittsburgh, PA.
- 11/06/09 “Computers and Robots,” KIPP LA Prep middle school, Los Angeles, CA.
- 11/05/09 “Computers and Robots,” Locke High School, Los Angeles, CA.
- 07/08/09 “Data-Intensive Scalable Computing,” Andrew’s Leap Program, Pittsburgh, PA.
- 07/11/08 “Data-Intensive Scalable Computing,” Andrew’s Leap Program, Pittsburgh, PA.

## Students

### Ph.D. Advisees

- 2013 Jiří Šimša, CMU CS (jointly advised by Garth Gibson). Now at Google.
- 2005 Sanjit Seshia, CMU CS. Now on the faculty at U. C., Berkeley.
- 2004 Miroslav Velez, CMU ECE. Now at Aries Design Automation
- 2004 Shuvendu Lahiri, CMU ECE. Now at Microsoft Research.
- 2004 Amit Goel, CMU ECE. Now at Apple.
- 2003 Rune Jensen, CMU CS (jointly advised by Manuela Veloso). Now on the faculty at IT University of Copenhagen.
- 2001 Clayton McDonald. Now at Synopsys, Inc.
- 1999 Kyle Nelson, CMU ECE.
- 1997 Alok Jain, CMU ECE. Now at Cadence Design Systems.
- 1998 Yirng-An Chen, CMU CS.
- 1997 Manish Pandey, CMU CS. Now at Synopsys.
- 1993 Derek Beatty, CMU CS. Now at Synopsys.
- 1992 Karl Brace, CMU ECE. Now at Intel Corporation.
- 1992 Tom Sheffler, CMU ECE. Now at Roche Sequencing Solutions.
- 1991 Larry Huang, CMU ECE.
- 1989 Saul Kravitz, CMU ECE (jointly advised by Rob Rutenbar). Now at Howard Hughes Medical Institute.
- 1988 Kyeongsoon Cho, CMU ECE. Now on the faculty at Hankuk University of Foreign Studies, Korea.



## MS Advisees

- 2014 Adam Blank, CMU CS. Now at U. Washington.
- 1998 Vishnu Patankar, CMU ECE. Now at Amazon.
- 1994 Samir Jain, CMU ECE. Now at Honeywell.
- 1984 Michael Schuster, Caltech CS. Now at Adobe Systems.
- 1984 Wen-Chi Chen, Caltech CS. Now President of VIA Technologies, Inc., Taiwan.
- 1984 Yen-Jen Oyang, Caltech CS. Now on the faculty at National Taiwan University.
- 1983 Jimmy Lam, Caltech CS.

## Thesis Committees

- 2013 Will Klieber, CMU CS Ph.D.
- 2013 Thangavel Bhuvaneshwari, Multimedia University, Melaka, Malaysia, CS Ph.D.
- 2012 Sicun Gao, CMU Pure and Applied Logic Ph.D.
- 2008 David Brumley, CMU CS Ph.D.
- 2007 Pankaj Chauhan, CMU CS Ph.D.
- 2006 Murali Talupur, CMU CS Ph.D.
- 2006 Anubhav Gupta, CMU CS Ph.D.
- 2006 Alberto Oliveras, Technical University of Catalonia, Barcelona Spain, CS Ph.D.
- 2006 Zhong Xiu, CMU ECE Ph.D.
- 2005 Sagar Chaki, CMU CS Ph.D.
- 2004 Hui Xu, CMU ECE Ph.D.
- 2003 Noppanunt Utamaphethai, CMU ECE Ph.D.
- 2003 Dong Wang, CMU ECE Ph.D.
- 2003 Chris Wilson, Stanford University, CS Ph.D.
- 2001 Sergei Berezin, CMU CS Ph.D.
- 2001 Marius Minea, CMU CS Ph.D.
- 2000 Yuan Lu, CMU ECE Ph.D.
- 2000 Rony Kay, CMU ECE Ph.D.
- 1999 Bwolen Yang, CMU CS Ph.D.
- 1998 Margaret Reid-Miller, CMU CS Ph.D.
- 1997 Mukund Sivaraman, CMU ECE Ph.D.
- 1997 Derek Noonburg, CMU ECE Ph.D.
- 1997 Denis Zampuniéris, Universitaires Notre-Dame de la Paix, Namur, Belgium, CS Ph.D.
- 1996 Xudong Zhao, CMU CS Ph.D.
- 1994 Samir Naik, CMU ECE Ph.D.
- 1994 Aarti Gupta, CMU CS Ph.D.
- 1993 Ken McMillan, CMU CS Ph.D.
- 1993 Jean-Christophe Madre, Habilitation, Université Joseph Fourier, Grenoble, France.
- 1993 David Long, CMU CS Ph.D.
- 1991 Tom Storey, CMU ECE Ph.D.
- 1991 John Willis, CMU ECE Ph.D.
- 1991 Jerry Burch, CMU CS Ph.D.

- 1991 Erik Brunvand, CMU CS Ph.D.
- 1990 Phil Nigh, CMU ECE Ph.D.
- 1990 Jean-Christophe Madre, Ph.D., Ecole Nationale Supérieure de Télécommunication, Paris, France.
- 1989 Larry Pillage, CMU ECE Ph.D.
- 1989 David Geiger, CMU ECE Ph.D.
- 1989 David Dill, CMU CS Ph.D.
- 1987 Carl Seger, Univ. Waterloo, Canada, CS Ph.D.
- 1986 William Dally, Caltech CS Ph.D.
- 1985 Ed Frank, CMU CS Ph.D.
- 1984 Tzu-Mu Lin, Caltech CS Ph.D.
- 1983 Erik P. DeBenedictis, Caltech CS Ph.D.
- 1982 Charles Lang, Caltech CS Ph.D.

## **Community Service**

- 2020–present Board of Directors, Bach Choir of Pittsburgh
- 2015–present Member of Bass Section, Bach Choir of Pittsburgh
- 2011–2014 Member of Bass Section, Pittsburgh Gospel Choir
- 2001–2014 Board of Directors, Steel City Rowing Club, Pittsburgh, PA. Board president 2005–2014.
- 1998–2000, 2003–2006, 2017–present Board of Session, Bellefield Presbyterian Church, Pittsburgh, PA.
- 1986–1990 Board of Trustees, Bellefield Presbyterian Church, Pittsburgh, PA.