# ASHISH SABHARWAL

Research Associate
Dept. of Computer Science
5160 Upson Hall, Cornell University
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http://www.cs.cornell.edu/~sabhar/jobapps

## CURRENT POSITION

**Cornell University**, Ithaca, NY, U.S.A.
RESEARCH ASSOCIATE — Sep 2008 – present
Dept. of Computer Science and Institute for Computational Sustainability (ICS)

## EDUCATION

**Cornell University**, Ithaca, NY, U.S.A.
Postdoctoral Associate, Intelligent Information Systems Institute (IISI) — Nov 2005 – Aug 2008
Supervisors: *Profs. Carla P. Gomes* and *Bart Selman*

**University of Washington**, Seattle, WA, U.S.A.
Ph.D., Computer Science and Engineering (GPA 3.89/4.0) — 2001 – 2005
M.S., Computer Science and Engineering — 1998 – 2001
Advisors: *Profs. Paul Beame* and *Henry Kautz*

**Indian Institute of Technology** (IIT), Kanpur, India
B.Tech., Computer Science and Engineering (CPA 9.4/10.0) — 1994 – 1998
Project Supervisor: *Dr. Manindra Agrawal*

## AWARDS AND ACHIEVEMENTS

Best Paper Awards

| | | |
|---|---|---|
| IJCAI-JAIR | Runner-up, best paper prize for 2003-2008 | 2008 |
| AAAI-06 | 21st National Conference on Artificial Intelligence, Boston, MA | 2006 |
| CP-06 | 12th Intl. Conference on Constraint Programming, Nantes, France | 2006 |

Best Paper Nominations

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|---|---|---|
| AAAI-07 | 22nd Conference on Artificial Intelligence, Vancouver, BC | 2007 |
| IJCAI-07 | 20th Intl. Joint Conference on Artificial Intelligence, Hyderabad, India | 2007 |
| UAI-07 | 23rd Conference on Uncertainty in Artificial Intelligence, Vancouver, BC | 2007 |
| ICAPS-06 | Intl. Conference on Automated Planning and Scheduling, Cumbria, U.K. | 2006 |

Scholarships and Other

| | |
|---|---|
| Jhamandas Watumull Scholarship, University of Washington, Seattle | 2002, 2005 |
| Research Assistantship and Teaching Assistantship, University of Washington, Seattle | 1998 – 2005 |
| National Talent Search Scholarship, India | 1992 – 1998 |
| Gold Medal, National Standard Examination in Physics, India | 1994 |
| Certificate of Merit in English, Mathematics, and Physics<br>awarded to 0.1% by Central Board of Secondary Education, India | 1994 |
| International Mathematics Olympiad Training and Selection Program, Mumbai, India | 1993 – 1994 |
| All India 24th Rank in IIT Entrance Examination (over 60,000 candidates) | 1994 |

## RESEARCH INTERESTS

My research is driven by combinatorial reasoning applications in Artificial Intelligence (AI), and draws upon an extensive background in Theoretical Computer Science. I am interested in developing scalable and robust automated reasoning technology that will allow computers to act intelligently in increasingly complex real-world settings and in competitive and uncertain environments.

*Focus areas*: combinatorial methods (SAT, CSP, QBF), probabilistic inference (BP, SP), multi-agent reasoning, constraint programming, connections to statistical physics, game theory, algorithm design, complexity

## PUBLICATIONS

### REFEREED PUBLICATIONS

[upcoming]

CPAIOR-09: *Backdoors to Combinatorial Optimization: Feasibility and Optimality.* B. Dilkina, C.P. Gomes, Y. Malitsky, A. Sabharwal, M. Sellmann. 6th Intl. Conf. on Integration of AI and OR Techniques in Constraint Programming, Pittsburgh, PA, May 2009.

SAC-09: *Message-Passing and Local Heuristics as Decimation Strategies for Satisfiability.* L. Kroc, A. Sabharwal, B. Selman. 24th Annual ACM Symp. on Applied Computing, Honolulu, HI, Mar 2009.

IJCAI-09 (under review): *Integrating Systematic and Local Search Paradigms: A New Strategy for MAX-SAT*. L. Kroc, A. Sabharwal, B. Selman. 21st Intl. Joint Conf. on AI. Under review.

SAT-09 (under review): *Relaxed DPLL Search for MaxSAT*. L. Kroc, A. Sabharwal, B. Selman. 12th Intl. Conf. on Theory & Applications of Satisfiability Testing. Under review.

SAT-09 (under review): *Backdoors in the Context of Learning*. B. Dilkina, C.P. Gomes, A. Sabharwal. 12th Intl. Conf. on Theory & Applications of Satisfiability Testing. Under review.

Constraints-09 (journal): *New Filtering Algorithms for Combinations of Among Constraints*. W.-J. van Hoeve, G. Pesant, L.-M. Rousseau, A. Sabharwal. Constraints Journal. In press.

CGTA-09 (journal): *Floodlight Illumination of Infinite Wedges*. M. Cary, A. Rudra, A. Sabharwal, E. Vee. Computational Geometry: Theory and Applications, journal. In press.

AMAI (journal, under review): *Tradeoffs in the Complexity of Backdoor Detection.* B. Dilkina, C.P. Gomes, A. Sabharwal. Annals of Mathematics and Artificial Intelligence. Under review.

AOR (journal, under review): *Leveraging Belief Propagation, Backtrack Search, and Statistics for Model Counting.* L. Kroc, A. Sabharwal, B. Selman. Annals of Operations Research. Under review.

AOR (journal, under review): *Bounds Consistency Filtering for Pair-Atmost1*. W.-J. van Hoeve, A. Sabharwal. Annals of Operations Research. Under review.

JAIR (journal, under review): *Friends or Foes? On Planning as Satisfiability and Abstract CNF Encodings*. C. Domshlak, J. Hoffmann, A. Sabharwal. Journal of Artificial Intelligence Research.

PNAS (journal, in preparation): *Reasoning About Solution Clusters Using Message Passing Algorithms*. L. Kroc, A. Sabharwal, B. Selman. In preparation for Proc. of the National Academy of Sciences.

*Filtering the Length-Lex Set Partition Constraint.* W.-J. van Hoeve, A. Sabharwal. In preparation.

[2008]

NIPS-08: *Counting Solution Clusters in Graph Coloring Problems Using Belief Propagation*. L. Kroc, A. Sabharwal, B. Selman. 22nd Conf. on Neural Info. Processing Systems, Vancouver, BC, Dec 2008.

CPAIOR-08: *Leveraging Belief Propagation, Backtrack Search, and Statistics for Model Counting.* L. Kroc, A. Sabharwal, B. Selman. 5th Intl. Conf. on Integration of AI and OR Techniques in Constraint Programming, Paris, France, May 2008. Also in ISAIM-08.

CPAIOR-08: *Connections in Networks: A Hybrid Approach*. C.P. Gomes, W.-J. van Hoeve, A. Sabharwal.

CPAIOR-08: *Filtering Atmost1 on Pairs of Set Variables*. W.-J. van Hoeve, A. Sabharwal.

Constraints-08 (journal): *SymChaff: Exploiting Symmetry in a Structure-Aware Satisfiability Solver*. A. Sabharwal. Constraints Journal. DOI: 10.1007/s10601-008-9060-1, SpringerLink, Oct 2008.

[2007]

CP-07: *Tradeoffs in the Complexity of Backdoor Detection.* B. Dilkina, C.P. Gomes, A. Sabharwal. 13th Intl. Conf. on Principles and Practice of Constraint Programming, Providence, RI, Sep 2007.

UAI-07: *Survey Propagation Revisited.* L. Kroc, A. Sabharwal, B. Selman. 23rd Conf. on Uncertainty in Artificial Intelligence, Vancouver, BC, July 2007.

AAAI-07: *Counting CSP Solutions Using Generalized XOR Constraints.* C.P. Gomes, W.-J. van Hoeve, A. Sabharwal, B. Selman. 22nd Conf. on Artificial Intelligence, Vancouver, BC, July 2007.

AAAI-07: *The Impact of Network Topology on Pure Nash Equilibria in Graphical Games.* B. Dilkina, C.P. Gomes, A. Sabharwal.

SAT-07: *Short XORs for Model Counting: From Theory to Practice.* C.P. Gomes, J. Hoffmann, A. Sabharwal, B. Selman. 10th Intl. Conf. Theory & Apps. of Sat. Test., Lisbon, Portugal, May 2007.

CPAIOR-07: *Connections in Networks: Hardness of Feasibility versus Optimality.* J. Conrad, C.P. Gomes, W.-J. van Hoeve, A. Sabharwal, J. Suter. 4th Intl. Conf. on Integration of AI and OR Techniques in Constraint Programming for Comb. Optimization Problems, Brussels, Belgium, May 2007.

IJCAI-07: *From Sampling to Model Counting*. C.P. Gomes, J. Hoffmann, A. Sabharwal, B. Selman. 20th Intl. Joint Conf. on Artificial Intelligence, Hyderabad, India, Jan 2007.

Complexity-07 (journal): *Resolution Complexity of Independent Sets and Vertex Covers in Random Graphs*. P. Beame, R. Impagliazzo, A. Sabharwal. Computational Complexity Journal, Dec 2007.

[2006]

NIPS-06: *Near-Uniform Sampling of Combinatorial Spaces Using XOR Constraints*. C.P. Gomes, A. Sabharwal, B. Selman. 20th Conf. on Neural Info. Processing Systems, Vancouver, BC, Dec 2006.

CP-06: *Revisiting the Sequence Constraint*. W.-J. van Hoeve, G. Pesant, L.-M. Rousseau, A. Sabharwal. 12th Intl. Conf. on Principles and Practice of Constraint Programming, Nantes, France, Sep 2006.
Best Paper Award.

SAT-06: *QBF Modeling: Exploiting Player Symmetry for Simplicity and Efficiency*. A. Sabharwal, C. Ansotegui, C.P. Gomes, J.W. Hart, B. Selman. 9th Intl. Conf. on Satisfiability, Seattle, Aug 2006.

AAAI-06: *Model Counting: A New Strategy for Obtaining Good Bounds*. C.P. Gomes, A. Sabharwal, B. Selman. 21st Natl. Conf. on Artificial Intelligence, Boston, MA, July 2006.
Outstanding Paper Award, two awards out of nearly 800 submissions.

ICAPS-06: *Friends or Foes? An AI Planning Perspective on Abstraction and Search*. J. Hoffmann, A. Sabharwal, C. Domshlak. 16th Intl. Conf. on Auto. Planning & Scheduling, Cumbria, U.K., 2006.

[2005 and earlier]

AAAI-05: *SymChaff: A Structure-Aware Satisfiability Solver*. A. Sabharwal. 20th Natl. Conf. on Artificial Intelligence, Pittsburgh, PA, July 2005.

JAIR-04 (journal): *Towards Understanding and Harnessing the Potential of Clause Learning*. P. Beame, H. Kautz, A. Sabharwal. Journal of Artificial Intelligence Research, Dec 2004.
Runner-up for IJCAI-JAIR Best Paper Prize for years 2003-2008,

SICOMP-04 (journal): *Bounded-Depth Frege Lower Bounds for Weaker Pigeonhole Principles*. J. Buresh-Oppenheim, P. Beame, T. Pitassi, R. Raz, A. Sabharwal. SIAM Journal on Computing, Dec 2004.

IJCAI-03: *Understanding the Power of Clause Learning*. P. Beame, H. Kautz, A. Sabharwal. 18th Intl. Joint Conf. on Artificial Intelligence, Acapulco, Mexico, Aug 2003.

SAT-03: *Using Problem Structure for Efficient Clause Learning*. A. Sabharwal, P. Beame, H. Kautz. 6th Intl. Conf. on Theory and Applications of Satisfiability Testing, Portofino, Italy, May 2003.

FOCS-02: *Bounded-depth Frege Lower Bounds for Weaker Pigeonhole Principles*. J. Buresh-Oppenheim, P. Beame, T. Pitassi, R. Raz, A. Sabharwal. 43rd Symp. Foundations of CS, Vancouver, Nov 2002.

CCC-01: *Resolution Complexity of Independent Sets in Random Graphs*. P. Beame, R. Impagliazzo, A. Sabharwal. 16th Annual Conf. on Computational Complexity, Chicago, IL, June 2001.

BOOK CHAPTERS AND SURVEYS

*Satisfiability Solvers*. C.P. Gomes, H. Kautz, A. Sabharwal, B. Selman. In Handbook of Knowledge Representation, in the series Foundations of Artificial Intelligence, vol. 3, editors F. van Harmelen, V. Lifschitz, B. Porter. Elsevier. 2008.

*Incomplete Algorithms (for Satisfiability).* H. Kautz, A. Sabharwal, B. Selman. In Handbook of Satisfiability, editors A. Biere, M. Heule, H. van Maaren, T. Walsh. IOS Press. 2009.

*Model Counting (for Satisfiability).* C.P. Gomes, A. Sabharwal, B. Selman. In Handbook of Satisfiability, editors A. Biere, M. Heule, H. van Maaren, T. Walsh. IOS Press. 2009.

*Exploiting Runtime Variation in Complete Solvers (for Satisfiability).* C.P. Gomes, A. Sabharwal. In Handbook of Satisfiability, editors A. Biere, M. Heule, H. van Maaren, T. Walsh. IOS Press. 2009.

*Artificial Intelligence and Complexity*. A. Sabharwal, B. Selman. In Encyclopedia of Complexity and Systems Science, editor R. Meyers. Springer. In preparation.

WORKSHOPS, INVITED TALKS, OTHER WORK

UBC, 2008 (invited talk): Laboratory of Computational Intelligence (LCI) Forum, University of British Columbia, Vancouver, BC, Dec 2008.

CMU, 2008 (invited talk): Carnegie Mellon University, Pittsburgh, PA, 2008.

UC Merced, 2008 (invited talk): University of California, Merced, CA, 2008.

PhysDIS, 2008 (invited talk): Workshop on Physics of Distributed Information Systems (PhysDIS), Nordic Institute for Theoretical Physics (NORDITA), Sweden, Stockholm, May 2008.

INFORMS-08: *Hidden Structure in Constraint Reasoning Problems*. B. Dilkina, C.P. Gomes, A. Sabharwal (presenter). INFORMS Annual Meeting, Washington, DC, Oct 2008.

INFORMS-08: *Solution Counting Methods for Combinatorial Problems.* C.P. Gomes, W.-J. van Hoeve, L. Kroc, A. Sabharwal (presenter), B. Selman.

INFORMS-08: *Counting CSP Solutions Using Generalized XOR Constraints.* C.P. Gomes, W.-J. van Hoeve (presenter), A. Sabharwal, B. Selman.

AAEA-08: Optimal Corridor Design for Grizzly Bear in the U.S. Northern Rockies. J.F. Suter (presenter), J. Conrad, C.P. Gomes, W.-J. van Hoeve, A. Sabharwal. American Agricultural Economics Association Annual Meeting, Orlando, FL, Jul 2008.

ISAIM-08: *Tradeoffs in Backdoors: Inconsistency Detection, Dynamic Simplification, and Preprocessing*. B. Dilkina, C.P. Gomes, A. Sabharwal. 10th Intl. Symp. on AI and Math, Ft. Lauderdale, FL, Jan 2008. Initial results at CP-07.

ModRef-07: *Two Set Constraints for Modeling and Efficiency*. W.-J. van Hoeve, A. Sabharwal. 6th Intl. Workshop on Constraint Modeling and Reformulation, at CP-07, Providence, RI, Sep 2007.

INFORMS-07: *Hidden Structure in Combinatorial Problems*. C.P. Gomes, A. Sabharwal (presenter). INFORMS Annual Meeting, Seattle, WA, Nov 2007.

INFORMS-07: *Filtering Algorithms for the Sequence Constraint*. W.-J. van Hoeve (presenter), G. Pesant, L.-M. Rousseau, A. Sabharwal.

INFORMS-06: *Streamlining Reasoning for Solution Finding and Counting.* C.P. Gomes (presenter), A. Sabharwal, M. Sellmann, B. Selman. INFORMS Annual Meeting. Pittsburgh, PA, Nov 2006.

ISWC-07: *Sampling and Soundness: Can We Have Both?* C.P. Gomes, J. Hoffmann, A. Sabharwal, B. Selman. 6th Intl. Semantic Web Conference, Busan, Korea, Nov 2007.

AISP-07: *Empirical Validation of the Relationship Between Survey Propagation and Covers in Random 3-SAT*. L. Kroc, A. Sabharwal, B. Selman. Workshop on Algorithms, Inference, and Statistical Physics, Santa Fe, NM, May 2007.

NESCAI-07: *Sparse Message Passing Algorithms for Weighted Max-SAT*. A. Culotta, A. McCallum, B. Selman, A. Sabharwal. 2nd North East Student Colloq. on AI, Ithaca, NY, Apr 2007.

PH.D. THESIS: *Algorithmic Applications of Propositional Proof Complexity*, October 2005.
Advisors: Prof. Paul Beame and Prof. Henry Kautz

*Model Checking: Two Decades of Novel Techniques and Trends*.
General Examination Report, University of Washington, Seattle, May 2002.

*Notes on Proof Complexity*. Scribed lectures for Summer School, Institute for Advanced Study / Park City Math. Inst. (IAS/PCMI), Princeton, Aug 2000, IAS/PCM Series, volume 10, pages 199-246, 2004.

## RESEARCH POSITIONS AND SUMMER WORK

RESEARCH ASSOCIATE, CORNELL UNIVERSITY, Ithaca, NY, U.S.A. Sep 2009 – present

Computational Sustainability (NSF): Funded by the National Science Foundation under the Expeditions in Computing program, this project, directed by Prof. Carla Gomes, has the overarching vision that computer scientists can — and should — play a key role in increasing the efficiency and effectiveness of the way we manage and allocate our natural resources, while enriching and transforming Computer Science. The project seeks to employ state-of-the-art computational methods to challenging problems in the arena of sustainability, ranging from wildlife preservation (e.g., by designing movement corridors or removing carefully selected fish passage barriers) to renewable energy (e.g., biofuels production and distribution) to balancing socio-economic demands and the environment (e.g., optimizing rotational opening and closing of fisheries).

POSTDOCTORAL ASSOCIATE, CORNELL UNIVERSITY, Ithaca, NY, U.S.A. Sep 2005 – Aug 2008

*Supervisors: Profs. Bart Selman and Carla P. Gomes*

Real-World Reasoning (DARPA): Funded by the Defense Advanced Research Projects Agency, this project seeks to significantly improve the scalability and robustness of general reasoning technology to address large-scale adversarial and contingency settings. This work achieved orders of magnitude improvement over prior technology by introducing novel problem modeling and solution techniques.

Beyond Traditional SAT Technology (NSF): Funded by the National Science Foundation under the Robust Intelligence program, this project aims at new scientific advances in automated reasoning systems that go beyond traditional combinatorial search and apply in competitive and unpredictable settings. This work explored connections with probabilistic reasoning and developed several state-of-the-art practical tools for counting and uniform sampling problems in intricate combinatorial spaces.

RESEARCH ASSISTANT, UNIVERSITY OF WASHINGTON, Seattle, WA, U.S.A. 2000 – 2005

*Advisors: Profs. Paul Beame and Henry A. Kautz*

Proof Complexity: Studied 'resolution' as a proof system and developed techniques to show that even approximately solving a majority of the instances of some natural structured problems are hard for this system. In separate work, contributed to proving lower bounds for a stronger proof system.

Satisfiability (SAT) Algorithms: Introduced the first formal framework capturing the most widely used class of complete algorithms for propositional satisfiability. Proposed and built a state-of-the-art solver called SymChaff for exploiting structural symmetry in reasoning problems.

PARTICIPANT AND SCRIBE, IAS/PCMI Summer School in Theoretical Computer Science Summer 2000
INSTITUTE FOR ADVANCED STUDY (IAS), Princeton, NJ, U.S.A.

INTERN, MICROSOFT RESEARCH (MSR), Redmond, WA, U.S.A. Summer 1999

*Supervisor: Dr. John Manferdelli,* Anti-Piracy Group

Digital Rights Management: Designed methods that use control- and data-flow analysis on binary program code to embed hard-to-break license authentication protocols in arbitrary programs.

VISITING STUDENTS RESEARCH PROGRAM Summer 1997
TATA INSTITUTE OF FUNDAMENTAL RESEARCH (TIFR), Mumbai, India

*Supervisor: Dr. Paritosh K. Pandya,* Theoretical Computer Science Group

Verification: Explored efficient monadic second order logic operators useful for verification, by exploiting connections between logic and automata-theoretic frameworks.

B.TECH. PROJECT, INDIAN INSTITUTE OF TECHNOLOGY (IIT), Kanpur, India 1997 – 1998

*Project Supervisor: Dr. Manindra Agrawal*

Circuit complexity: Proved lower bounds on the size of small depth monotone circuits for the 3-clique problem using combinatorial techniques.

## TEACHING EXPERIENCE

TUTORIAL PRESENTATIONS

Satisfied by Message Passing: Probabilistic Techniques for Combinatorial Probs.: AAAI Conference, 2008

Combinatorial Problems (series of 3 lectures) : Kavli Instt. for Theoretical Physics, China, 2008
I. Solving II. Counting and Sampling III. QBF Reasoning

Beyond Traditional SAT Reasoning : AAAI Conference, 2007
QBF, Model Counting, and Solution Sampling

Quantified Boolean Formula (QBF) Reasoning : DARPA, 2007

LECTURER, University of Washington, Seattle, WA, U.S.A. Fall 2003

Organized and taught with the help of two teaching assistants an undergraduate Data Structures course to a class of 46 students. Increased effectiveness of lectures by using a new tablet PC based interactive slide system. Was praised for enthusiasm and knowledge. Overall student evaluation rating: 4.2/5.0.

TEACHING ASSISTANT, University of Washington, Seattle, WA, U.S.A. 1998 – 2002

| | | |
|---|---|---|
| Graduate level courses | : | Design and Analysis of Algorithms, Applied Algorithms, Computability and Complexity |
| Courses involving teaching | : | Introduction to Computing, Data Structures, Machine Organization |
| Other courses | : | Introduction to Formal Models, Intro. to Compiler Construction, Algorithms and Computational Complexity |

TUTOR, University of Washington, Seattle, WA, U.S.A.

Provided one-on-one volunteer tutoring help to several undergraduate computer science students.

## PROFESSIONAL EXPERIENCE

Proposal Writing, Grant Management

National Science Foundation (NSF) [Robust Intelligence / Info & Intelligent Systems / Expeditions]
Defense Advanced Research Projects Agency (DARPA)
Air Force Office of Scientific Research (AFOSR)
Kodak Research Laboratories

Program Committees

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|---|---|
| IJCAI-09 | : Intl. Joint Conference on Artificial Intelligence |
| CPAIOR-09 | : Intl. Conference on Integration of AI and OR Techniques in Constraint Programming |
| CP-09 | : Intl. Conference on Principles and Practice of Constraint Programming |
| AAAI-08/07/06 | : Conference on Artificial Intelligence |
| Counting-08 | : Workshop on Counting Problems in CSP and SAT, and other Neighboring Problems |
| ISC-07 | : Intl. Symmetry Conference |
| SAT-06 | : Intl. Conference on Theory & Applications of Satisfiability Testing |

Journal Reviews

J. of Artificial Intelligence Research (JAIR), Artificial Intelligence J. (AIJ),
J. on Satisfiability, Boolean Modeling and Computation (JSAT),
Constraints J., Transactions on Computational Logic, Acta Informatica

Conference Reviews

AAMAS-09 AAAI-08/07/06/05 SAT-07/06 CPAIOR-07 CP-08/06 ISC-07 NESCAI-07/06
ISAIM-08 STACS-07 ITNG-07 PRICAI-06 CSR-06 SASIMI-06 ISVLSI-06 SAC-06

Member

Association for the Advancement of Artificial Intelligence (AAAI)
Constraint Programming Society in North America (CPNA)
New York Academy of Sciences (NYAS)

## PERSONAL INFORMATION

Nationality: Indian, currently on H-1B work visa in the U.S.
Non-academic interests: hiking, skiing, martial arts (karate black belt), classical music

## REFERENCES

*Prof. Carla P. Gomes* (Postdoc. co-supervisor)
Director, Institute for Computational Sustainability
Department of Computer Science — Ph: 607·255·9189
5133 Upson Hall, Cornell University — *gomes@cs.cornell.edu*
Ithaca, NY 14853-7501 — http://www.cs.cornell.edu/gomes

*Prof. Bart Selman* (Postdoc. co-supervisor)
Department of Computer Science — Ph: 607·255·5643
4148 Upson Hall, Cornell University — *selman@cs.cornell.edu*
Ithaca, NY 14853-7501 — http://www.cs.cornell.edu/selman

*Prof. Paul Beame* (Ph.D. co-advisor)
Computer Science and Engineering — Ph: 206·543·5114
University of Washington, Box 352350 — *beame@cs.washington.edu*
Seattle, WA 98195-2350 — http://www.cs.washington.edu/homes/beame

*Prof. Henry Kautz* (Ph.D. co-advisor)
Chair, Department of Computer Science — Ph: 585·275·5671
University of Rochester, Box 270226 — *kautz@cs.rochester.edu*
Rochester, NY 14627 — http://www.cs.rochester.edu/u/kautz

# Research Interests

**Ashish Sabharwal**
**Cornell University**

The goal of my research is to *develop scalable and robust automated reasoning technology* that will allow computers to act intelligently in increasingly complex real-world settings and in competitive and uncertain environments. My research is driven by central applications and techniques in Artificial Intelligence (AI), and draws upon an extensive background in Theoretical Computer Science. I study combinatorial problems in domains such as planning, adversarial reasoning, verification and diagnosis, scheduling, design automation, resource economics, e-commerce, discrete mathematics, and, most recently, computational sustainability. My work has strong ties with probabilistic inference methods and the whole gamut of related applications.

A distinguishing strength of my research approach is *a unique blend of rigorous analysis and principled experimentation*, which I believe are equally critical components of fundamental research leading to practically useful technology. I place a strong emphasis on studying a variety of challenging combinatorial problems with researchers from diverse backgrounds and with varying interests. This has resulted in a series of fruitful collaborations in the past few years with theoreticians and practitioners alike.[1]

Automated inference engines lie at the core of artificial intelligence, and are often embedded in systems ranging from car diagnosis tools to production planning software in the industry to complex control units in space missions. The vision of this technology is well exemplified by the DARPA Grand Challenge, where fully autonomous ground vehicles have relied on automated inference and control methods to successfully navigate over 100 miles of terrain without any human assistance. In 2007, the Urban Challenge took the setting from a desert course to an urban environment, safely navigating which revealed both the challenges in automated reasoning and decision making, as well as their tremendous potential in pushing the boundaries of computer science.

Combinatorial reasoning technology, in particular for propositional satisfiability (SAT), has witnessed an unprecedented growth. Starting with only a few hundred variable problems in the early 1990's, publicly available SAT solvers can now easily solve many large industrial problems with over 1 million variables and 5 million constraints. This research area promises to grow further in richness and impact as we begin to venture beyond basic combinatorial search, to problems such as *inferring properties of complex combinatorial spaces, and reasoning in multi-agent competitive environments.* This requires a shift in technology from NP-complete search problems to significantly more difficult #P- and PSPACE-complete problems. Efficient techniques for these problems are crucial for pushing automated inference engines to a level where they can address complex real-world systems. This poses many fundamental research challenges:

- *Scalability*: How can we overcome the high worst-case computational cost of solving these problems and scale them to the range of millions of variables demanded by real-world applications?
- *Robustness*: How can we obtain performance guarantees and have solutions that are robust against rare but catastrophic failures, such as power grids failures and stock markets crashes?
- *Synergy between exact and probabilistic inference*: How can we directly or indirectly use techniques developed for exact inference to solve problems in probabilistic inference, and vice versa?
- *Multi-agent reasoning*: How can we perform strategic decision making that will provably work in the presence of multiple agents and adversaries with competing interests?
- *Intelligent assistance*: How can the ability of computers to do fast exact inference on sub-problems be used to fruitfully assist humans in performing more complex tasks?
- *Representation and Balance*: How rich should the problem representation language be? How should we balance brute-force exploration vs. inference at each step of the search?

I believe addressing these issues will require a constant flow of ideas between foundational research and system design, and successful solutions will pave the road to a whole new range of applications.

[1] The work discussed here was a joint effort with Carlos Ansotegui, Paul Beame, Jon Conrad, Carmel Domshlak, Carla Gomes, Willem-Jan van Hoeve, Jörg Hoffmann, Russell Impagliazzo, Henry Kautz, Andrew McCallum, Gilles Pesant, Toniann Pitassi, Ron Raz, Louis-Martin Rousseau, Meinolf Sellmann, and Bart Selman; and (then) students: Josh Buresh-Oppenheim, Matthew Cary, Aron Culotta, Bistra Dilkina, Justin Hart, Lukas Kroc, Yuri Malitski, Atri Rudra, Jordan Suter, and Erik Vee.

## Main Research Themes

My research interests and methodology fall into three broad themes, which I discuss next along with a synopsis of my past work aligning with each theme.

### Developing Scalable Automated Reasoning Methods

A key focus of my work is on building fast practical methods for combinatorial reasoning, often based on non-traditional approaches. The application domains and annual competitions that have been the catalyst for the tremendous growth in SAT solver and related technology have also brought the discipline to the boundary between general scientific research and careful, detailed engineering to excel on specific benchmark problems. A substantial amount of work goes into fine-tuning and exploring variations of techniques already in place. While this undoubtedly has its own merit, it is also crucial to look at problems from a fresh perspective. *Can one address issues regularly encountered by researchers by introducing a fundamentally new way of solving, or even representing, the problem?* This has served as a constant motivating question for my research. Here are three examples of innovative approaches that I have introduced, all of which have pushed the limits of automated reasoning by orders of magnitude:

XOR-Streamlining for Model Counting and Sampling [AAAI-06/07, NIPS-06, IJCAI-07, SAT-07, ISAIM-08]: Implemented in a series of state-of-the-art tools (`MBound`, `SampleCount`, and `XorSample`) for counting and near-uniformly sampling solutions of combinatorial problems, xor-streamlining is a fundamentally different technique for attacking these #P-hard problems than the traditional ones based on DPLL-search and Markov Chain Monte Carlo (MCMC) methods. Inspired by work in complexity theory, this approach introduced the first effective and scalable method for using a complete or local search SAT-solver essentially *off-the-shelf*, and a new framework for obtaining bounds with probabilistic correctness guarantees. This work was recognized with an Outstanding Paper Award at the 21$^{st}$ National Conference on Artificial Intelligence, AAAI-06. My recent work broadens the scope of these ideas by incorporating message passing techniques from probabilistic inference (namely, Belief Propagation) as well as statistical estimation.

Dual Formulation for QBF solvers [SAT-07]: Implemented as the solver `Duaffle`, the method represents a departure from the commonly used cnf-based representation formalism for quantified Boolean formulas. By using a new dual cnf-dnf representation based on a two-player game perspective of QBF domains, this approach brings out the full power of dnf-based "solution learning" techniques and facilitates, for the first time, constraint propagation across quantifiers—a bottleneck for search-based QBF solvers.

Symmetry-Breaking and Reasoning Beyond Resolution [AAAI-05, Constraints J. 08]: Implemented in the structure-aware SAT solver `SymChaff`, this technique is again a departure from commonly used methods like "symmetry-breaking constraints" for SAT and CSP. By retaining and exploiting automatically generated contextual information about problem variables, it can achieve as much as (provably) exponential speed-ups over the best alternatives. The theme is the same as in the QBF work above: overcome limitations introduced by traditional cnf-based encodings by altering the representation formalism.

### Formal Analysis of Inference Techniques Used in Practice

Understanding inherent strengths and limitations of various methods used in practice plays a crucial role in further development and successful application of such methods. Following this philosophy, I have created formal frameworks for understanding and analyzing state-of-the-art approaches in satisfiability testing and AI planning, complementing empirical observations about when these approaches work well and when they don't. This has led to new ideas addressing fundamental limitations of known techniques. My methodology here has combined a mathematical analysis, often based on proof complexity theory, and systematic experimentation. Examples of my work in this direction include:

Resolution-Based Formal Framework for SAT Solvers [IJCAI-03, SAT-03, JAIR-04]: This work, recognized as the Runner-up for the IJCAI-JAIR Best Paper Prize for 2003-2008, introduced the first formal proof complexity based framework for a rigorous analysis of key techniques often engineered in DPLL-style SAT solver implementations. It revealed the inherent power of certain learning and restart techniques, by relating them to the 'resolution' proof system. This laid a much needed foundation, helping make these techniques an integral part of the next generation of solvers, and spawning further research and improvement.

Probabilistic Inference and Statistical Physics [UAI-07, NIPS-08, CPAIOR-08, ISAIM-08, SAC-09, in progress] A relatively recent message passing approach originating in statistical physics, namely Survey Propagation (SP), has turned out to be much more efficient than mainstream DPLL and local search methods for solving very hard random SAT instances. This work provided key insights into this somewhat mysterious technique, revealing through extensive experimentation what probabilistic information about the solution space does Survey Propagation effectively compute. The work also demonstrated how such properties of the solution space can be fruitfully exploited to obtain the number of solutions of these problems, and has recently provided the first clear formal connection between SP and statistics over "clusters" of solutions. This "cluster-centered" approach appears to be very promising for designing a new class of search algorithms.

Abstraction in AI Planning [ICAPS-06, JAIR (under review)]: Abstraction is a commonly employed technique, especially in model checking and planning, for improving efficiency by abstracting away non-critical details. Can abstraction methods really achieve any benefit in AI planning systems? This work provided a rather surprising *negative* answer for the best-case behavior of Resolution-based planners. This showed that the "informedness" of the search method must compete with the informedness of the abstraction heuristic, providing new insights into the design of abstraction techniques.

Hardness Profiles and Problem Structure [CPAIOR-07/08/09, CP-07, ISAIM-08]: CSPs often exhibit an intriguing pattern: an abrupt phase transition from being feasible to being infeasible as a key problem parameter is varied. This work, with direct application to "wildlife corridor" design for grizzly bears in the Northern Rockies, empirically revealed for the first time such phenomena—and a corresponding "easy-hard-easy" pattern—for problems that combine both constraint satisfaction and optimization aspects. In a different direction, my work has brought to light the fundamental strength of the notion of propagation-based "backdoor sets" used to characterize real-world structure in combinatorial problems and explain the astonishing scalability of SAT solvers on structured industrial benchmarks.

**Addressing Foundational Issues: Algorithm Design and Proof Complexity**

The third theme of my research involves addressing foundational issues underlying automated reasoning systems. Specifically, I design efficient algorithms for constraint solvers and characterize the strength of various "proof systems". This has resulted in the first polynomial time algorithms in some cases, and NP-completeness or hardness of approximation results in other. Two examples of my work in this area are:

Filtering Algorithms for Special Constraints [CP-06, Constraints J. 09]: This work introduced the first polynomial time filtering algorithm for a combinatorial constraint (the "sequence" constraint) that appears frequently in scheduling and design automation problems. This resolved a question that had been open for 10 years in the Constraint Programming (CP) community. This work was recognized with the Best Paper Award at the 12$^{\text{th}}$ International Conference on Principles and Practice of Constraint Programming, CP-06. In related work [ModRef-07, CPAIOR-08], our algorithms revealed exponential memory and runtime savings that higher-level set-based representations in CP can achieve.

Resolution Complexity and Hardness of Approximation [Complexity-01, Comp. Complexity J.-07, FOCS-02, SIAM J. Computing-04]: This proof complexity work showed that almost all instances of some interesting co-NP complete graph problems require exponential size Resolution proofs of infeasibility, even to approximate within significant factors, thus providing a large family of structured formulas hard for the Resolution proof system. The methodology involved combinatorial and probabilistic analysis. The work also showed that a natural class of approximate optimization algorithms for these problems must fail on almost all instances. In related work, we proved that even stronger proof systems, such as bounded-depth Frege systems described in many logic texts, require exponential size proofs even for very weak pigeonhole formulas, strengthening previously known results in this area.

## Other Interests

My broad interests have drawn me to many applications of combinatorial analysis spanning various areas in computer science, such as *game theory* [AAAI-07], *computational geometry* [J. CGTA (to appear)], *circuit complexity*, and *digital rights management* [MSR Internship]. Looking forward, I expect to continue this stimulating endeavor, and collaborate with researchers in these and other fields.

# Teaching Statement

**Ashish Sabharwal**
**Cornell University**

My goal as an educator is to introduce students to the fascinating concepts and challenges in Computer Science. Free flow of ideas is a cornerstone of academics. It appears in various forms during peer-to-peer communications, in advisor-advisee relationships, and most pervasively during student-teacher interactions. In a constantly evolving field at the forefront of technology, the task of an educator requires an active interest in ensuring that the concepts and the ways of imparting them stay fresh. I strongly believe that to be a successful teacher one must understand and go through *a constant cycle of preparation, implementation, and evaluation*. I share below my experiences with these, drawing upon several refreshing and enlightening teaching opportunities, particularly as a *lecturer* at the University of Washington and as a *tutorial presenter* at the Conferences on Artificial Intelligence (AAAI-07/08) as well as at the Kavli Institute for Theoretical Physics in China (2008).

**Preparation**: The preparation for teaching in a natural and clear manner begins by developing a deep understanding of the subject matter. Thankfully, both the graduate curriculum at the University of Washington as well as the rigorous coursework at the Indian Institutes of Technology emphasize *breadth of knowledge*. They require courses from a large number of diverse and important fields not necessarily related to a student's specific research interests, and have thus prepared me to comfortably teach a broad range of classes at the undergraduate level. My own research is in Artificial Intelligence, with strong connections to Theoretical Computer Science. Teaching standard as well as newly designed courses in this area will be a delightful opportunity to share my knowledge and enthusiasm. As another important step in long-term preparation, I have strived to *learn how to teach* because sufficient knowledge doesn't necessarily make one a good teacher. I have frequently worked with the Center for Instructional Development and Research (CIDR) at the University of Washington. I have participated in training programs and discussions on how to be effective in a classroom where students have varied backgrounds, expectations, and skill levels.

**Implementation**: As a graduate student, I took up a rare opportunity for hands on experience: teaching an undergraduate Data Structures course as a lecturer. The task involved lecturing and organizing a class of nearly fifty students and managing workload with two teaching assistants. My goal was to make this foundational course stimulating, exciting, and challenging for the students. I achieved this by using a new *tablet-PC based interactive slide projection system* being developed at the UW, along with partial handouts that we filled together as each lecture progressed. This encouraged interaction, at the same time providing students concrete course material to take home. Having *lively programming goals* like playing songs in reverse, solving mazes, and using word patterns to identify playwrights made traditional projects fun to work on. Group programming projects and joint quizzes were my tools to make students learn to work productively as a team, an asset for any professional. Pop quizzes at the beginning of lecture were a lesson in punctuality for some. I broke the monotony of the class by having guest speakers give a glimpse of intriguing new topics like Google searches and zero-knowledge data structures.

In retrospect, this was an invaluable experience. It helped me develop my own teaching style and philosophy, and evaluate its efficacy. Prior to this assignment, I have been a teaching assistant for a variety of undergraduate and graduate courses, where I enjoyed the challenge of presenting lecture material in alternative ways during sections. I have volunteered for a one-on-one tutoring program for undergraduate students in need, and have substituted for lectures as occasions arose. During the last two years, I have prepared and delivered extensive tutorials on subjects related to my own research area, namely, the latest in automated reasoning technology. These tutorials have been very well received. The experience has taught me how to put together scattered research ideas into a comprehensive introductory material on a subject.

**Evaluation**: The ability to mold one's teaching approach based on continuous feedback from students about their grasp and needs is crucial for effective teaching. Students' interest and understanding can be perceived indirectly from homework, attendance, and quality of questions raised in class. I personally like, in addition, the more active approach of feedback forms designed specifically for this purpose. One challenge in the latter method is to convince students that they are free to critique and that their comments will receive due attention. It is important, especially for beginning educators in my position, to clarify to the students that

we are in the classroom to teach as well as to learn as a teacher. For the Data Structures course I taught, I utilized the services of CIDR at the UW to obtain concrete comments from students in the middle of the quarter, and was able to make some immediate changes based on their needs. The final survey at the end of the quarter revealed that the students had liked aspects such as *instructor's enthusiasm and knowledge, relevance of course content, and availability of help* when needed. Their overall evaluation rating was quite high at 4.2 out of 5.0.

In addition to student feedback, one must also evaluate over time the course content itself. As computer science rapidly progresses, it is critical to scrutinize the relevance and comprehensiveness of the course material. I believe this is best done by incorporating into it *a flavor of recent research results* and by looking at the way the course is taught by other lecturers and at other places.

While the challenges and the approach to teaching vary to a great extent from one discipline to another, certain key aspects are of value irrespective of what one teaches and in what context. My own teaching philosophy has been influenced enormously by a seemingly unrelated subject—the practice of martial arts, which frequently requires me to lead groups of beginner students. Over the years, this has consistently emphasized *leadership, clarity, patience, and the ability to inspire passion* for the subject, qualities that are in my opinion essential for the success of any teacher. Advances in human society rely critically on the transfer of various kinds of knowledge and wisdom from one generation to another. To accomplish this goal is the responsibility of the teacher. I believe that I have prepared myself well for this task in the field of computer science, and I look forward to it.