Illinois Computer Science

Research Overview
Spring 2021

Overview

Illinois Computer Science faculty are engaged in research that spans, and often expands, the spectrum of computing. We reflect this spectrum by organizing ourselves into 11 different research areas (list below). These areas have evolved over time in response to the development of the field and the interests of our faculty, with the addition of three new areas since 2015. To be responsive to the constantly evolving research interests of our faculty, area membership is updated annually, with faculty self-identifying as members of an area and many faculty being members of more than one area. In addition to providing research communities within the department that manage activities such as specialized area seminars or events, advocate for (shared) research infrastructure, and coordinate faculty and grad student recruiting, the areas provide a structure and a home for the graduate students in the department, and the PhD students select one of the areas in which to do their qualifying exams. The areas vary in size in terms of number of faculty and students, but each has a designated faculty Area Chair (who has a two-year term) and is supported by a staff Area Assistant. At the end of this section, each area is described in detail including the faculty (both core CS and affiliates) identifying with an area and an overview of the research activity of the area.

- Architecture, Compilers, and Parallel Computing
- Artificial Intelligence
- Bioinformatics and Computational Biology (established in 2015)
- Computers and Education (established in 2018)
- Data and Information Systems
- Interactive Computing
- Programming Languages, Formal Methods, and Software Engineering
- Scientific Computing
- Security and Privacy (established in 2019)
- Systems and Networking
- Theory and Algorithms

Interdisciplinary research is a hallmark of the University of Illinois and computer science faculty have long been an integral component of these activities. The university and college include a number of major Interdisciplinary Research Units (IRUs) that have dedicated space (often entire buildings), bring together faculty from many departments, and enjoy positions of prominence in the university administrative structure in many ways equivalent to academic departments. Computer science faculty are deeply engaged in these activities and are currently leading some of these IRUs (e.g., NCSA and the Coordinated Science Lab, or CSL) and play leadership roles in others (e.g., as theme leads in the Institute for Genomic Biology, or IGB).

The department's faculty lead or have significant engagement in several interdisciplinary centers and institutes, including:

- Center for Digital Agriculture
- C3.ai Digital Transformation Institute with Berkeley, C3.ai, Microsoft and others
- Genomics and Eco-evolution of Multi-Scale Symbioses
- Center for Just Infrastructure
- Center for Cognitive Computer Systems Research (C3SR) with IBM
- Internet of Battlefield Things (IoBT)
- Strategic Research Alliance Center on Computer Security with Intel
- Center for Networked Intelligent Components and Environments (C-NICE) with Foxconn Internet Technology

CS faculty are actively pursuing large research projects and have had some recent notable successes, including two of the initial NSF AI Research Institutes (AIFARMS and Molecule Maker Lab) and the DOE-funded Center for Exascale-enabled Scramjet Design. To support the faculty in these activities, the department has recently added an Associate Head for Research and has hired an Assistant Director for our Grants and Contracts. We organize proposal development workshops for junior faculty, assist in forming teams for collaborative projects, and are working to develop a strategy to seek corporate sponsors for our research areas in a more organized manner.

Collaborations

While we have substantial research activity focused on core problems in computer science, we also have a significant interest in applications of computer science to problems in other disciplines. This interest is reflected in the broad engagement of our core and affiliate faculty in other departments and units across campus. For example, our core faculty have affiliate positions in other departments within the Grainger College of Engineering (most notably Electrical & Computer Engineering) as well as in units and departments across campus. These engagements have resulted in many collaborations between faculty in CS and other departments on campus. One metric of this activity is the number of collaborative proposals, as shown in Figure 1.

The departmental faculty and their research advisees (i.e., postdocs, graduate students and undergraduate researchers) are also actively involved in research collaborations with researchers across the globe, as shown in Figures 2 and 3.

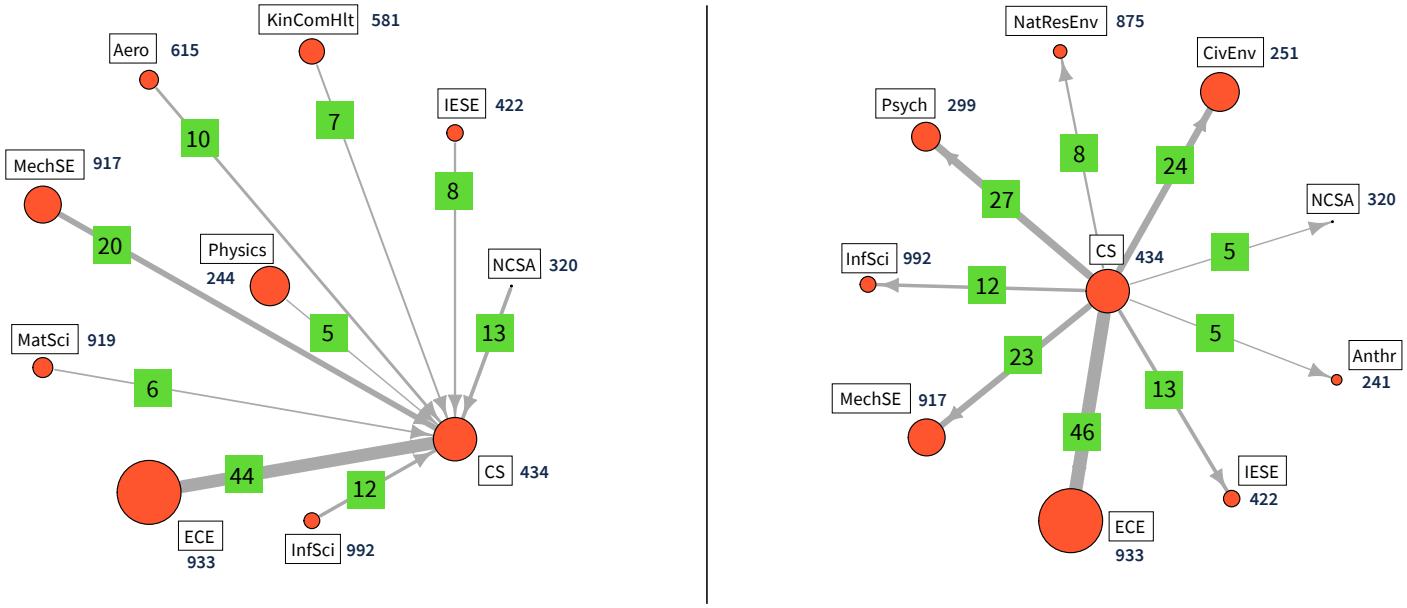


Figure 1: Interdepartmental collaborations within UIUC. Proposals submitted between 2016 and 2021 that include CS faculty as PI (left) or Co-PI (right) and faculty in some other department. Green numbers are proposal counts; blue numbers are department codes. Edge thickness α Number of proposals (minimum 5). Node size α approximate count of tenure-track faculty whose home department corresponds to the node label.

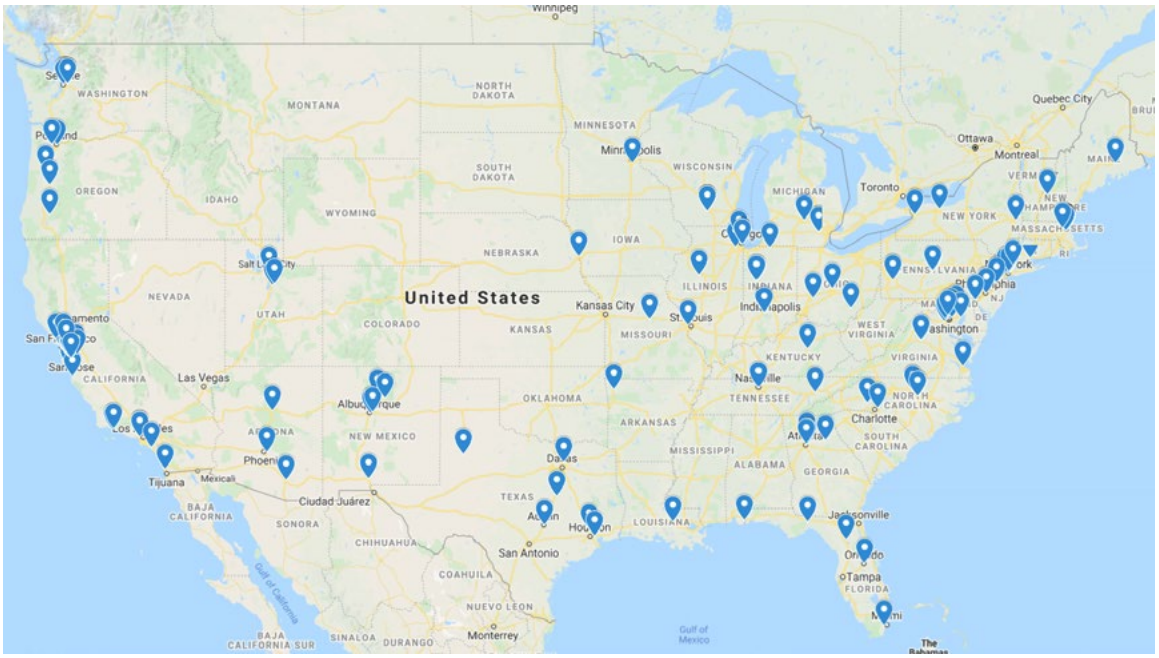
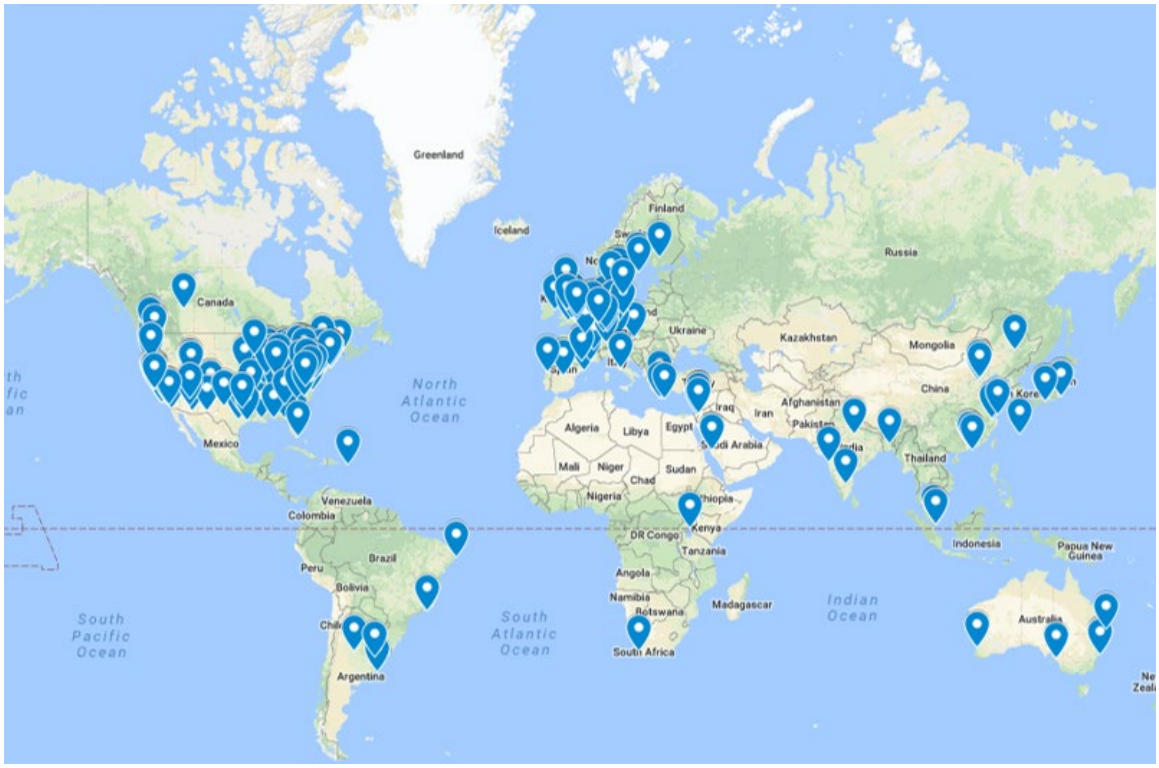


Figure 2: Collaborations between UIUC CS faculty and researchers at other institutions in the USA.

Figure 3: Collaborations between UIUC CS faculty and researchers at other institutions across the globe.



Technology Transfer and Entrepreneurship

The University has a variety of resources and organizations to facilitate technology transfer and entrepreneurship, including the University of Illinois Research Park, Office of Technology Management (OTM), EnterpriseWorks incubator, Illinois MakerLab, and the Technology Entrepreneur Center (TEC). This ecosystem provides Illinois CS faculty and students with training, support, working space, and experience to help them explore their options. Both Crunchbase (8th) and Pitchbook (10th) rank the university among the top schools in terms of entrepreneurs receiving venture capital funding. See https://entrepreneurship.illinois.edu/startups/ for a comprehensive list of startups related to the university.

Research Park is an award-winning technology hub located south of campus, which currently has more than 120 companies engaging faculty and students with research and internship opportunities, from names like Abbott Laboratories, Archer Daniels Midland, BP America, Capital One, Caterpillar, and Nvidia to the dozens of startups taking their first steps. TEC offers courses on entrepreneurship, hosts venture and product competitions, and organizes workshops and other events to explore technology innovation and market adoption. Some of TEC's opportunities are offered in partnership with the University of Chicago's Booth School of Business.

The department also expects to benefit from the Discovery Partners Institute (DPI), which is led by the University of Illinois System and located in Chicago. DPI's mission is to help build businesses and grow Chicago's tech ecosystem, while also training people for jobs in technology and conducting applied research and development.

In recent years, CS faculty have started or helped students to start a number of companies. Faculty startups include Cazoodle, Charmworks, EarthSense, Embedor Technologies, Reconstruct (2016 Turner Innovation Award), Runtime Verification, and Veriflow (purchased by VMware in 2019). Recent startups launched by enrolled students have included Adrenaline Mobility, Caterva, FlipWord, Lightform, Malwarebytes, Pattern Insight, Revery.AI, and ZeroPercent.

The department's active Corporate Relations Program also helps bring industry representatives to campus, and CS faculty have strong relationships with major companies, such as Adobe, Amazon, Boeing, Google, Intel, IBM, C3.ai, Microsoft, and NVidia.

Computer Science

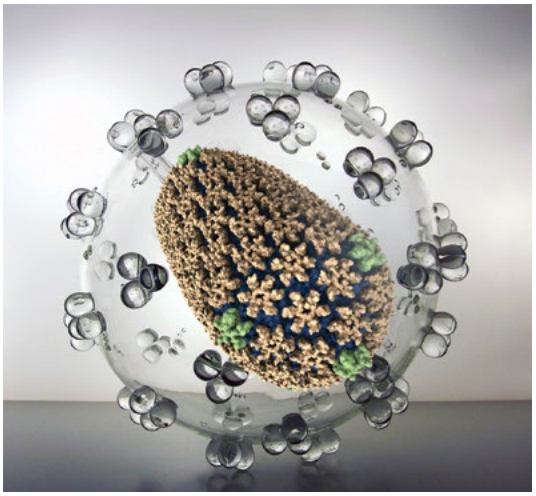
ARCHITECTURE, COMPILERS, AND PARALLEL COMPUTING

This is an area that includes many researchers and a variety of topics. There is a core set of faculty who work in the areas of computer architecture, compilers, and parallel computing. There is also a set of faculty who work in the neighboring areas of numerical computing, distributed systems, and parallel algorithms. In addition, there are affiliated faculty from Electrical & Computer Engineering and NCSA who work on very similar topics; we see ourselves as a single research group.

The research topics that the area covers are wide. As we approach the end of Moore's Law, and as mobile devices and cloud computing become pervasive, all aspects of system design—circuits, processors, memory, compilers, programming environments—must become more energy efficient, resilient, and programmable. Our research groups explore energy efficiency via low-voltage design techniques, specialized hardware accelerators, adaptive runtime techniques in high performance computing, efficient memory architectures for heterogeneous mobile systems, novel architectures for exascale systems, and other projects. We also examine resilience through tolerating variation during chip fabrication, failure-tolerant processor architectures, scalable resilience protocols, and automated software debugging and recovery techniques. We explore programmability through architectural support for synchronization, automatic parallelization and vectorization, performance-portability for heterogeneous mobile systems, high-performance implementations of scripting languages, and highly scalable parallel run-time systems. Work in high-performance computing includes communication libraries and High Performance Storage (HPS). Current libraries are not well adapted to irregular applications in emerging fields, such as graph analytics, and to emerging asynchronous task programming models. We work on new HPS frameworks for identifying crash consistency bugs in parallel storage systems.

Recent research efforts include research on data-centric computer architectures that can offer orders of magnitude improvements in energy efficiency, software and hardware architecture techniques for security, and machine learning architectures. They also include work on complete hardware-compiler-runtime system stacks and testbeds for domain-specific interactive edge systems for applications such as extended reality, autonomous vehicles, and agricultural robots.

In addition to collaborating with major companies on a wide range of research projects, our software artifacts and technologies like LLVM (2012 ACM Software System Award), Charm++, and the C++ and Java memory models are widely used by researchers and practitioners in industry, government labs, and academia.



An illustration of the structure of the HIV capsid, featured on the cover of *Nature* in 2013. Illinois researchers mapped the capsid's structure using the NAMD biomolecular modeling software, which is written using Charm++.

Strengths and Impact

Recent highlights since our last review approximately ten years ago include many national honors and awards to our faculty. This includes election to the National Academy of Engineering for Bill Gropp; NSF CAREER Awards to Christopher Fletcher, Sasa Misailovic, and Edgar Solomonik; ACM/IEEE Kennedy Award and election to the American Academy of Arts and Sciences for Sarita Adve; IEEE Computer Society Harry H. Goode Memorial Award to David Padua (2015) and to Josep Torrellas (2021); the election of Bill Gropp to IEEE Computer Society President; and the award of a national AI Research Institute (AIFRAMS) to Illinois and led by Vikram Adve.

The faculty in this area are very active in the professional community. They participate in many program committees, organize workshops, and give lectures. They publish in the most competitive venues of the area, often making the University of Illinois the most represented institution in the top conferences. They also receive many Best Paper Awards every year (e.g., Top Picks from Computer Architecture). The faculty also develop software that they distribute to the community.

The faculty are active in large grants from NSF, DARPA, and industry. For example, large ongoing grants include the Center for Cognitive Computer Systems Research (C3SR) with IBM, the Strategic Research Alliance Center on Computer Security with Intel, and participation in the SRC-DARPA JUMP center efforts and DARPA Electronic Resurgence Initiative programs. There are also many collaborations with computer companies and laboratories.

The area is also known for placing its PhD students in top academic and research positions in the United States. Recent successes include placing students in tenure-track Assistant Professor positions at MIT, CMU, and Wisconsin. There is a large number of graduates from this area in the faculty of top departments in the nation, including MIT, CMU, Cornell, Princeton, U of Washington, Georgia Tech, U of Michigan, and U of Wisconsin, to name a few. In addition, many of the area's graduates are in leading positions at IBM, Intel, Microsoft, and other companies.

FACULTY AND THEIR RESEARCH INTERESTS

Sarita Adve
Computer Architecture, Parallel Computing, Memory Systems, Domain-Specific and Heterogeneous Systems, Resiliency, Approximate Computing

Vikram Adve
Compilers, Parallel Computing, Heterogeneous Parallel Systems, Hardware-Software Codesign, Edge Computing

Nancy M. Amato
Parallel Algorithms and Libraries, Parallel Graph Algorithms, Performance Modeling

Christopher Fletcher
Architectures for Security and Machine Learning

Saugata Ghose
Data-Oriented Architectures, Processing-in-Memory, Memory/Storage Systems, Hardware/Software Co-Design, Architectures for Emerging Domains

William Gropp
Programming Models and Systems for Parallel Computing, Parallel I/O

Laxmikant Kale
Large-Scale Parallel Systems; Runtime Systems, Tools; and Frameworks for High-Performance Computing

Charith Mendis
Compilers and Code Generation, Machine Learning based Compiler Optimizations, Autotuning, Neural Network Optimizations, Program Analysis, Domain Specific Languages

Sasa Misailovic
Program Optimization Systems, Probabilisitic Programming, Approximate Computing Techniques

Klara Nahrstedt
Quality of Experience, Tele-Immersion, Multi-View Visualization, Embedded Sensors, Distributed and Parallel Systems

Luke Olson
Parallel Numerical Algorithms, Performance Modeling

David Padua
Compiler Techniques for Parallel Computing, Compiler Evaluation and Testing, Autotuning Strategies and Systems

Lawrence Rauchwerger
Parallel Computing, Compilers for Parallel Computing, Parallel Generic and Graph Libraries, Parallel Architecture, Exascale Computing

Marc Snir
Large-Scale Parallel Systems, Algorithms, Libraries

Edgar Solomonik
High-Performance Computing, Communication Cost Analysis, Tensor Computations, Quantum Simulation

Josep Torrellas
Computer Architecture, Parallel Computing, Energy-Efficient Architectures, Hardware/Software Co-Design, Programmability, Graph Architectures, Secure Architectures

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

Deming Chen
Electrical & Computer Engineering
Hardware/Software Co-Design for System-On-Chip; Reconfigurable Computing; GPU Computing and Optimization

Jian Huang
Electrical & Computer Engineering
Computer Systems, Systems Architecture, Systems Security, Memory and Storage Systems

Wen-mei Hwu
Electrical & Computer Engineering
HPC and Parallel Systems, Compilers, GPU Programming

Nam Sung Kim
Electrical & Computer Engineering
Non-Conventional Computer Architecture: Bio-Inspired, Molecular, Cellular, and Analog-Digital Hybrid Computing

Volodymyr Kindratenko
National Center for Supercomputing Applications
HPC, Reconfigurable Computing, GPU Computing and Optimization

Rakesh Kumar
Electrical & Computer Engineering
Power- and Reliability-Aware Architectures, Approximate Computing

Steve Lumetta
Electrical & Computer Engineering
Parallel Computing, Architecture, Reliability, Architectures for Genomic Applications

Sanjay Patel
Electrical & Computer Engineering
High-Performance and Parallel Systems

Shobha Vasudevan
Electrical & Computer Engineering
System Verification and Security; Analog and Digital Hardware Validation

Martin Wong
Electrical & Computer Engineering
Computer-Aided Design of Integrated Circuits

Professor Sarita Adve (wearing the purple jacket) and members of her research group.

Computer Science

ARTIFICIAL INTELLIGENCE

Artificial Intelligence (AI), defined broadly as the study of systems that behave intelligently, includes several key areas where our faculty have been recognized leaders for decades: machine learning, computer vision, natural language processing, machine listening, and robotics.

Crucial to modern AI, **machine learning** methods exploit training data or experiences in order to improve performance for prediction or decision tasks. **Computer vision** systems can understand images and video, for example, building extensive geometric and physical models of cities from video, or warning construction workers about nearby dangers. **Natural language processing** systems understand written and spoken language; possibilities include automatic translation of text from one language to another, or understanding text on Wikipedia to produce knowledge about the world. **Machine listening** systems understand audio signals, with applications like speech recognition, acoustic monitoring, or transcribing polyphonic music automatically. **Robotics** puts AI into practice by designing embodied agents that perceive and interact with the physical world.

Over the last decade, spurred by advances in deep learning, AI has become one of the most dynamic and fast-growing disciplines in CS, with extensive interdisciplinary connections and collaboration opportunities. Accordingly, the Illinois CS AI group has grown rapidly in recent years, maintaining its leadership in the above-mentioned “traditional” areas as well as expanding into cutting-edge areas at the intersection of AI and security, bioinformatics, distributed computing, as well as applications to medicine and agriculture.

Strengths and Impact

The AI group at Illinois is strong, diverse, and growing. It combines expertise in core strengths with promising new research directions.

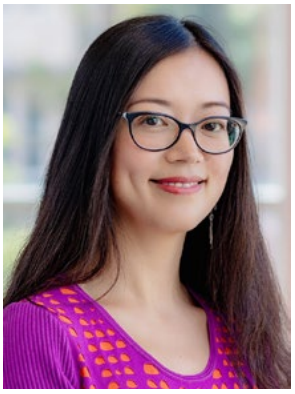
In **machine learning**, AI group faculty are studying theoretical foundations of deep and reinforcement learning; developing novel models and algorithms for deep neural networks, federated and distributed learning; as well as investigating issues related to scalability, security, privacy, and fairness of learning systems. **Computer vision** faculty are developing novel approaches for 2D and 3D scene understanding from still images and video; joint understanding of images and language; low-shot learning (recognition of rare or previously unseen categories); transfer learning and domain adaptation (adapting pre-trained systems to a changing data distribution); and image generation and editing approaches based on generative neural networks. **Natural language processing** faculty are working on topics such as grounded language understanding, information extraction and text mining, and knowledge-driven natural language generation for applications such as scientific discovery. **Machine listening** faculty are working on sound and speech understanding, source separation, and enhancement, as well as applications in music and computing. **Robotics** faculty are developing novel planning algorithms for grasping, locomotion, and navigation; investigating multi-robot systems; as well as pursuing high-impact applications of robotics to medicine, agriculture, home care, and autonomous driving.

The excellence and impact of the AI group's research has been recognized by a number of awards, including NSF CAREER (Amato, Hauser, Hockenmaier, Hoiem, Ji, Koyejo, Lazebnik, Smaragdis, Telgarsky), Sloan Research Fellowship (Hoiem, Koyejo, Lazebnik), Microsoft Research Faculty Fellowship (Lazebnik), AFOSR Young Investigator (Chowdhary), IEEE PAMI Significant Young Researcher Award (Hoiem), MIT TR-35 (Li, Smaragdis), Intel Rising Star Award (Li), "Young Scientist" selected by World Economic Forum (Ji), "AI's Top 10 to Watch" Award by IEEE Intelligent Systems (Ji), ACM Fellow (Amato, Forsyth, Warnow), IEEE Fellow (Amato, Forsyth, Lazebnik, Smaragdis), IEEE Technical Achievement Award (Forsyth), and Packard Fellowship (Warnow).

In the last few years, AI group members received a number of best paper awards, including: IEEE Signal Processing Society Best Paper Award (Smaragdis, 2018 and 2020), IEEE MLSP Best Paper Award (Smaragdis, 2017), Best Demo Paper Award at the 58th Annual Meeting of the Association for Computational Linguistics (Ji, 2020).

AI group research has led to a number of startups. Hoiem is co-founder and CTO of Reconstruct, which visually documents construction sites, matching images to plans and analyzing productivity and risk for delay. Chowdhary is co-founder and CTO of EarthSense, a startup creating machine learning and robotics solutions for agriculture, whose work was featured in a 2020 *New York Times* article. Forsyth advises a number of startups focusing on augmented reality and image synthesis, including Lightform, Revery, and Depix.

AI faculty are playing key roles in two $20 million AI institutes recently funded by the National Science Foundation and the U.S. Department of Agriculture's National Institute of Food and Agriculture. The AI Institute for Future Agricultural Resilience, Management, and Sustainability (AIFARMS), led by Vikram Adve from CS, features Chowdhary as Associate Director of Research, with other investigators including Schwing, Driggs-Campbell, Gupta, Hauser, Hockenmaier, Ji, Koyejo, and Smaragdis. The AI Institute for Molecular Discovery, Synthetic Strategy, and Manufacturing, led by Huimin Zhao from Chemical Engineering, involves Ji and Peng as investigators.



Professor Heng Ji is leading a multi-institution team of researchers to create a next generation framework for event understanding systems. The project has been awarded $12.3 million by DARPA.

FACULTY AND THEIR RESEARCH INTERESTS

Nancy M. Amato
Robot Motion and Task Planning, Multi-Agent Systems, Crowd Simulation

Arindam Banerjee
Machine Learning, Learning Theory, Optimization, Generative Models, Sequential Decision Making, Physics-Guided Machine Learning, Differential Privacy

Kevin C. Chang
Machine Learning, AI Applications, Data Management Support for AI

Girish Chowdhary
Control, Autonomy and Decision Making, Vision and LIDAR Based Perception, GPS Denied Navigation

Payam Delgosha
Graphs, Information Theory, Algorithms, Machine Learning

Margaret Fleck
Computational Linguistics, Programming Language Tools

David A. Forsyth
Computer Vision, Object Recognition, Scene Understanding

Liangyan Gui
Computer Vision, Machine Learning, Motion Analysis, Robotics

Jiawei Han
Machine Learning, Natural Language-Based Text Analysis, Text Summarization

Kris Hauser
Motion Planning, Optimal Control, Integrated Planning and Learning, Robot Systems

Julia Hockenmaier
Natural Language Processing, Computational Linguistics

Derek Hoiem
Computer Vision, Object Recognition, Spatial Understanding, Scene Interpretation

Heng Ji
Natural Language Processing, especially on Information Extraction and Knowledge Base Population, as well as its Connections with Computer Vision and Natural Language Generation

Nan Jiang
Reinforcement Learning, Machine Learning, Sample Complexity Analyses

Karrie Karahalios
Human-Computer Interaction for Machine Learning, Artificial Intelligence Explainability

Sanmi Koyejo
Machine Learning, Neuroscience, Neuroimaging

Steven M. LaValle
Robotics, Motion Planning, Virtual Reality

Svetlana Lazebnik
Computer Vision, Scene Understanding, Visual Learning, Vision and Language

Bo Li
Adversarial Machine Learning, Robust Learning

Marco Morales
Motion Planning and Control, Autonomous Robots

Jian Peng
Machine Learning and Optimization

Gagandeep Singh
Certified AI, Adversarial Robustness, Neural Network Verification, Safe Deep Learning

Paris Smaragdis
Machine Learning for Audio, Speech, and Music; Signal Processing; Source Separation; Sound Recognition & Classification

Jimeng Sun
Deep Learning for Drug Discovery, Clinical Trial Optimization, Computational Phenotyping, Clinical Predictive Modeling, Mobile Health and Health Monitoring, Tensor Factorization, and Graph Mining

Matus Telgarsky
Machine Learning Theory

Hanghang Tong
Explainable AI, Fairness in AI, Adversarial Maching Learning

Shenlong Wang
Computer Vision, Robotics

Yuxiong Wang
Computer Vision, Machine Learning, Meta-Learning, Robotics

Tandy Warnow
Machine Learning in Computational Genomics

Han Zhao
Machine Learning, Representation Learning, Algorithmic Fairness, Probabilistic Methods

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

Mark A. Anastasio
Bioengineering
Machine Learning Methods for Imaging Science, Image Reconstruction, Deep Learning for Inverse Problems

Timothy Bretl
Aerospace Engineering
Motion Planning and Control

Jana Diesner
School of Information Sciences
Social Network Analysis, Natural Language Processing, Machine Learning

Minh N. Do
Electrical & Computer Engineering
Signal Processing, Computational Imaging, Geometric Vision, Data Science

Katherine Driggs-Campbell
Electrical & Computer Engineering
Autonomous Vehicles, Validating Autonomous Systems, Interactive Control Policies for Intelligent Systems in Multi-Agent Settings

Roxana Girju
Linguistics
Computational Linguistics

Mani Golparvar-Fard
Civil Engineering
Computer Vision Analytics for Building and Construction Performance Monitoring

Saurabh Gupta
Electrical & Computer Engineering
Computer Vision, Robotics, Machine Learning

Mark Hasegawa-Johnson
Electrical & Computer Engineering
Statistical Speech Technology

Ravi Iyer
Electrical & Computer Engineering
Probabilistic Graphical Models, Deep Learning, Data Science, Health Analytics

Volodymyr Kindratenko
National Center for Supercomputing Appplications
Cyberinfrastructure for Machine Learning, Maching Learning Systems Research, Deep Learning Applications

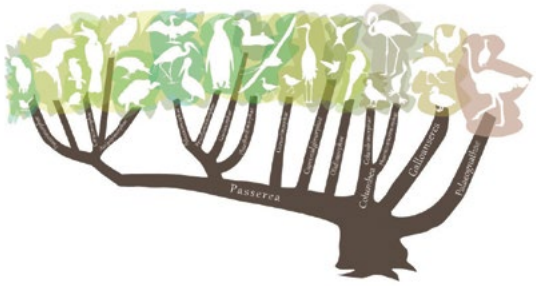
Kenton McHenry
National Center for Supercomputing Applications
Cyberinfrastructure for Digital Preservation, Auto-Curation, and Managing Unstructured Digital Collections

Lane Oscar Schwartz
Linguistics
Machine Translation, Computational Morphology & Syntax

Alexander Schwing
Electrical & Computer Engineering
Machine Learning, Computer Vision

Computer Science

BIOINFORMATICS AND COMPUTATIONAL BIOLOGY



Until 2014, only one person (Saurabh Sinha) at UIUC CS was a full-time researcher in bioinformatics and computational biology. Tandy Warnow joined in 2014 and Jian Peng joined in 2015, which led to the establishment of the BCB research area in 2015. Mohammed El-Kebir joined in 2018, bringing this group of core computational biology researchers to 4. Our group now includes 10 CS faculty (4 of whom consider themselves primarily in BCB) and 2 affiliate faculty. We also have active collaborations and affiliations with different departments and institutes across the University of Illinois, and in particular with the Carl R. Woese Institute for Genomic Biology (IGB), where Sinha serves as the Director of Computational Genomics.

The main focus of the BCB group is in core computational biology-related problems in genomics, proteomics, metagenomics, and phylogenomics. We develop novel techniques that combine ideas from mathematics, computer science, probability, statistics, and physics, and we help identify and formalize computational challenges in the biological domain, while experimentally validating novel hypotheses generated by our analyses. Importantly, we also collaborate with biologists in analyzing data, in formulating new computational problems, and in making biological discoveries. We are developing algorithms with improved accuracy for large-scale and complex estimation problems in phylogenomics (genome-scale phylogeny estimation), multiple sequence alignment, and metagenomics. We are exploring gene regulation-developing advanced techniques to predict the diverse function of noncoding parts of DNA and to relate interspecies and interpersonal differences in DNA to differences in the organism's form and function. We are designing algorithms for molecular and structural biology including predicting protein structure and function and mining biological insights from molecular networks. We work broadly in cancer genomics and human disease biology, with research spanning the areas of tumor phylogeny; cancer systems biology; neurodegenerative diseases; and infectious diseases. Other research in the BCB group includes biomedical literature text mining, clinical medicine support systems, compressive genomics, protein folding, drug discovery, health informatics, and personalized medicine.

Strengths and Impact

Recent highlights from the last five years include several honors and awards to our BCB faculty, including the Sloan Research Fellowship and Chris Overton Prize (highest award given by the International Society for Computational Biology (ISCB) to a junior researcher) to Jian Peng; election as ACM Fellow and ISCB Fellow, and award of the Grainger Distinguished Chair in Engineering to Tandy Warnow, CAREER award to Mohammed El-Kebir; and award of the Founder Professor in Engineering to Saurabh Sinha.

The BCB group has particular strengths in cancer genomics, which is the main focus of Mohammed El-Kebir and also of interest to Jian Peng. El-Kebir has made important advances in the theoretical foundations of cancer phylogenetics and developed methods for the estimation of cancer phylogenies from sequencing data of tumors. Recent breakthroughs include PhyDOSE (Weber et al., PLOS Computational Biology 2020), a method to design cost-effective single-cell DNA sequencing experiments of tumors, and RECAP (Christensen et al., ECCB 2020), a method to detect repeated patterns of tumor evolution in cancer patient cohort data.

Another strength in the group is protein structure and function prediction, which is the main focus of Jian Peng. His method, DeepContact (Liu et al. Cell Systems 2018), which is based on deep learning, has been a strong performer in the bi-annual community-wide Critical Assessment of protein Structure Prediction (CASP) competition, and became the foundation for the recent breakthrough in this field. His group also developed a few popular function prediction algorithms, including Mashup for network integration (Cho et al. Cell Systems 2016), DTINet for protein-drug interaction prediction (Luo et al. Nature Communications 2017) and TransposeNet for studying gene function in neurodegenerative diseases (Khurana et al. Cell Systems 2017).

Regulatory genomics refers to the study of gene regulation and Saurabh Sinha's group develops computational techniques for this field. His group recently showed how multi-omics data can be analyzed through a probabilistic model to reveal key regulators of colorectal cancer progression (Ghaffari et al. Genome Biology 2021). Another study from the group developed a state-of-the-art simulator for single-cell expression data based on given gene regulatory networks (Dibaeinia & Sinha, Cell Systems 2020).

A team of Illinois and Mayo Clinic scientists led by Professor Saurabh Sinha has created the Knowledge Engine for Genomics (KnowEnG), a first-of-its-kind analytical platform that guides researchers through the process of interpreting complex genomic datasets. Their paper in PLOS Biology shares the culmination of five years of research.

Phylogenomics, which is the estimation of evolutionary histories, is another important strength in the group, and the main focus of Tandy Warnow. Recent breakthroughs include MAGUS (Smirnov and Warnow, Bioinformatics 2020), a method for large-scale multiple sequence alignment that is more accurate than the previous best methods (PASTA and UPP), and the first proofs of statistical consistency (Legried et al., RECOMB 2020 and Molloy & Warnow, ISMB 2020) for methods for species tree estimation that address gene duplication and loss.

Finally, the BCB group has been fully committed to the placement of its PhD students and postdocs in top academic and research positions in the United States and abroad. Erin Molloy from the Warnow's group has accepted a faculty position in the CS department at the University of Maryland starting Fall 2021. From the Sinha group, Jaebum Kim is now a faculty member at the Konkuk University in Korea, Xin He is an assistant professor at the University of Chicago, Jin Tae Kwak is a faculty member at the Korea University, Majid Kazemian is an assistant professor at the Purdue University, Md. Abul Hassan Samee is an assistant professor at Baylor College of Medicine, and Amin Emad is an assistant professor at McGill University. Sheng Wang from Peng's group is now an assistant professor at the University of Washington at Seattle.

A consortium of researchers has released gene sequences for more than 1,100 plant species, the culmination of a nine-year research project published in Nature. Due to the massive scope of the project, Professor Tandy Warnow and collaborators developed new computational tools for sequence assembly and phylogenetic analysis.

FACULTY AND THEIR RESEARCH INTERESTS

Nancy M. Amato
Modeling Molecular Motions, Protein Folding, Protein/Ligand Binding

Mohammed El-Kebir
Bioinformatics, Cancer Genomics, Cancer Phylogenetics, Phylodynamics, Phylogeography, Information Visualization

Jiawei Han
Mining Biological Text, Biological Named Entity and Relation Extraction

Michael Nowak
Bioinformatics, Healthcare Informatics

Jian Peng
Bioinformatics, Protein Function and Structure, Systems Biology, Machine Learning and Optimization

Saurabh Sinha
Bioinformatics, Genomics, Modeling, Sequence Analysis, Machine Learning, Probabilistic Methods, Cancer, Behavior

Jimeng Sun
Deep Learning for Drug Discovery, Molecule Property Prediction and Generation, Genomic and Phenotypic Modeling

Tandy Warnow
Graph Algorithms, Statistical Estimation, Heuristics for NP-Hard Optimization Problems, Phylogenomics, Metagenomics, Multiple Sequence Alignment

Tiffani Williams
Genomics, Computational Phylogenetics, High-Performance Computing

ChengXiang Zhai
Intelligent Biomedical Decision Support Systems, Analysis of Electronic Medical Records, Biomedical Literature Retrieval and Mining

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

Ravi Iyer
Electrical & Computer Engineering
Variant Calling, Individualized Medicine, Health Data Analytics, Probabilistic Graphical Models, Neuroscience

Olgica Milenkovic
Electrical & Computer Engineering
Compressive Genomics, Information Theory

Computer Science

COMPUTERS AND EDUCATION

Computing has a large and growing impact on education. It is improving classroom interactivity, increasing accessibility, facilitating personalized learning inside and outside the classroom, and providing a platform for exploring fundamental questions about how people learn.

At the same time, demand for computer science education is skyrocketing world-wide. Reaching larger and more diverse audiences requires both understanding how people learn computer science, removing barriers that limit access, and creating best practices for teaching specific computing topics.

Our faculty study broadly in both of these facets of computers and education: how computers can enrich education and how to enrich computer science education. We build new systems, run them at scale, design interfaces, and study the human impacts of technology in the classroom. We gather and analyze data about student behavior to better understand the learning process using both data science techniques and qualitative research.

Strengths and Impact

The Computers and Education research area provides training for PhD students in a CS department, which makes it one of the first in the US and internationally. The area admitted its first PhD students to explicitly focus their research in the area in the 2019-20 academic school year and hired its first tenure-track assistant professor in 2020. The area has diverse research interests, examining how students learn computing, broadening participation in computing, K-12 CS Education, scaling and spreading teaching innovations, using computing resources to improve students' learning, and improving accessibility of education. While only three tenure-line faculty list this as their primary research area, the area is highly collaborative, incorporating many teaching faculty into research projects and providing support for teaching faculty to publish and mentor graduate students when there is interest. The research area has been helping the department and the College of Education navigate the process of creating new CS + Education undergraduate degrees that will help establish one of the first K-12 computer science licensure programs in the state of Illinois.

Although relatively new, the research area has already begun to distinguish itself in the Computing Education Research community. Faculty have won Best Paper Awards in the Research Track at the ACM SIGCSE annual conference (Nguyen & Lewis, 2020. https://doi.org/10.1145/3328778.3366805) the ACM International Computing Education Research conference (Lewis, 2012. https://doi.org/10.1145/2361276.2361301), the American Society for Engineering Education IL/IN section (2018), and the ACM SIGCSE best paper in

Teaching Associate Professor Geoffrey Herman was the recipient of the IEEE Education Society's Mac Van Valkenburg Early Career Teaching Award in 2020, "for his dedication to teaching, for his expertise in bridging research and practice in engineering education, and for his ability to inspire students and colleagues alike."

the first 50 years of SIGCSE (Kaczmarczyk, Petrick, East, & Herman, 2019. https://doi.org/10.1145/3324900). Faculty in the area have been recognized as leaders in the field, serving as invited authors for both the Cambridge Handbook of Computing Education Research and the Cambridge Handbook of Engineering Education Research. The research area has also been recognized for its excellence in teaching and promoting diversity in computing with awards such as the 2010 and 2020 Mac Van Valkenburg Early Career Teaching Awards from the IEEE Education Society and the 2016 Denice Denton Emerging Leader Award from AnitaB.org. One PhD student has been awarded a Graduate Research Fellowship from the NSF. Faculty in the research area have been funded by NSF, NSA, Microsoft, and Google.

The research area is also making significant technological contributions that are creating infrastructure for new educational best practices. For example, PrairieLearn provides an open-source platform that promotes mastery-based learning and makes this possible at scale. It is currently adopted in over 100 courses, impacting more than 15,000 students a semester. The platform is now being adopted at other institutions such as University of California Berkeley, University of British Columbia (UBC), University of Maryland, Michigan State University, Grand Valley State University, and Detroit Mercy University. The platform is being expanded to also support computer-supported collaborative learning and other teaching best practices. Additionally, the Computer Based Testing Facility provides critical support for faculty in the administration of exams, especially for large courses. The Computer Based Testing Facility supports the administration of over 50,000 exams per semester at the University of Illinois alone and is being adopted by other institutions.

FACULTY AND THEIR RESEARCH INTERESTS

Abdussalam Alawini
Active Learning in Large Classrooms, Teamwork and Collaboration, Computer-Based Assessment, Instructional Technologies

Lawrence Angrave
Success Factors of Underrepresented Students in Online Courses, Universal Access, Crowd-Based Course Curation

Mattox Beckman
Process-Oriented /Guided Inquiry Learning, Training Graduate Teaching Assistants, Scalable Education, Semantics-Based Autograders

Geoffrey Challen
Technology to Improve Classroom Interactivity and Outcomes, Data-Driven Approaches to Teaching and Learning

Neal Davis
Incentivizing Productive Student Behaviors, Open Source Curricula, Assessment, Learning Analytics

G. Carl Evans
Outcomes Assessment

Wade Fagen-Ulmschneider
Data Discovery, Social Media, Open-Ended Creative Assessments

Elsa Gunter
Scalable Education, Automated Interactive Assessment, Blended Learning

John Hart
Learning at Scale

Geoffrey Herman
How Students Learn Computing, Studying How to Design Effective Instructional Visualization, Teaching at Scale, Assessing Student Learning

Colleen Lewis
Broadening Participation in Computing, K-12 CS Education, Conceptual Change in CS, Cultural and Structural Barriers in CS, Anti-Racist CS Education

Michael Nowak
Automated Interactive Assessment, Learning Analytics, Scalable Education, Pedagogy

Eric Shaffer
Teaching at Scale, Outcomes Assessment, Learning Analytics

Mariana Silva
Teaching at Scale, Assessment, Collaborative Learning, Online Learning Platforms

Tiffani Williams
Pedagogy, Inclusive Classrooms, Adult and Multiple Pathways Computing Education

ChengXiang Zhai
Intelligent Education Systems, Scalable Education, Applications of Data Science in Education

Craig Zilles
Learning Analytics, Pedagogy, Computer-Based Testing, Assessment, Asynchronous Exams, Item Generation, Concept Inventories, Plagiarism Detection

COLLABORATORS AND THEIR RESEARCH INTERESTS

Gabrielle Allen
Astronomy/College of Education
STEM Education

Carolyn Anderson
Educational Psychology, Psychology, and Statistics
Underrepresented STEM Students, Multi-level Statistics

Suma Bhat
Electrical & Computer Engineering
Online Spaces to Support Underrepresented STEM Students

Tim Bretl
Aerospace Engineering
Online Learning Platforms, Outcomes Assessment, Prison Education, Pedagogy

Bill Cope
Education Policy, Organization & Leadership
e-Learning Platforms

Jennifer Cromley
Educational Psychology
STEM Students' Achievement and Retention

Sebastian Kelle
Computer Science Instructional Development Team
Serious Games, Virtual Reality Learning, Interactive Storytelling, Instructional Design

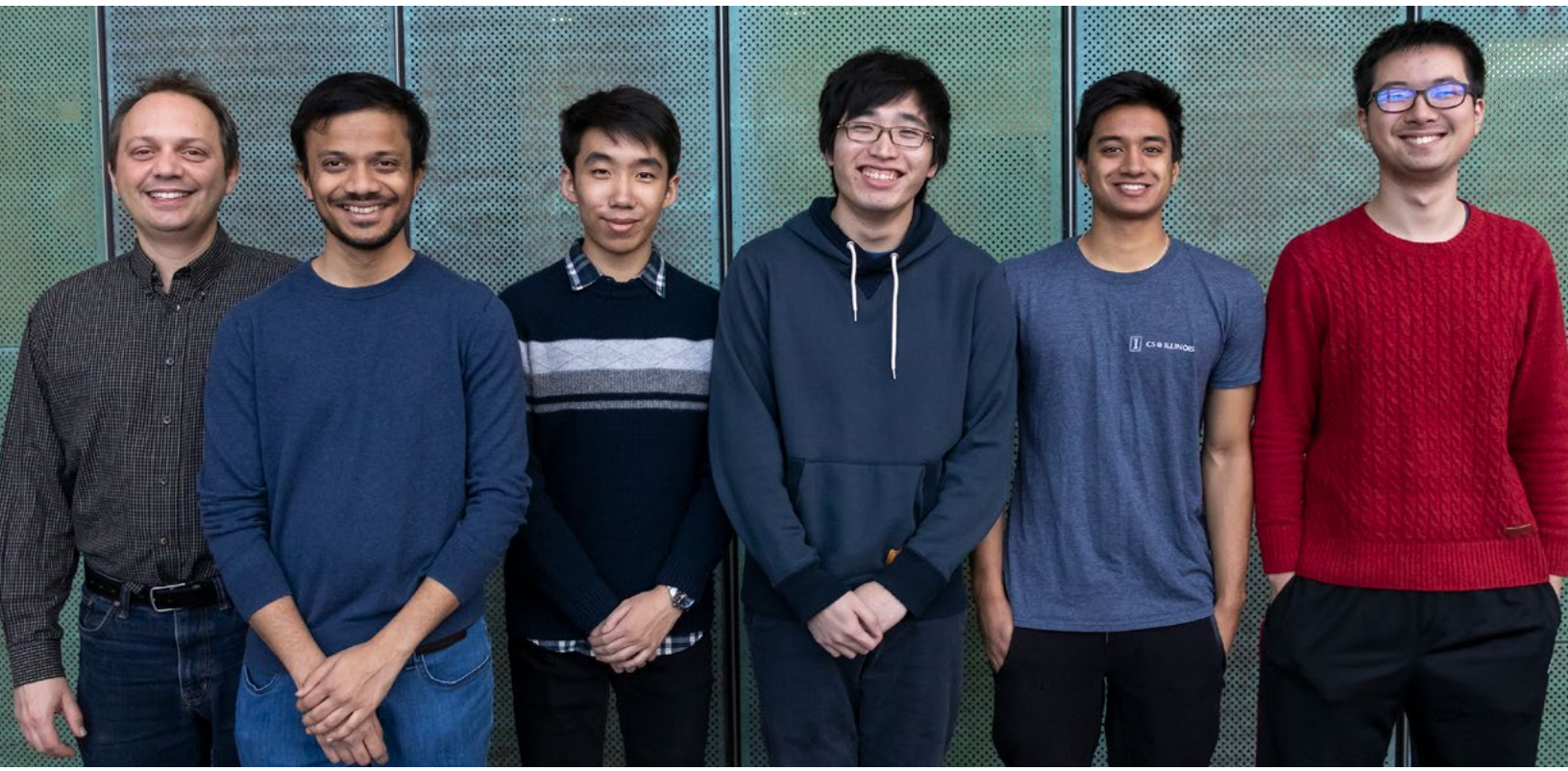
H. Chad Lane
Educational Psychology
Artificial Inteligence in Education, Educational Games, Informal CS Education

Robb Lindgren
Curriculum & Instruction
Learning in Emerging Platforms (e.g., Simulations, Virtual Environments)

Luc Paquette
Curriculum & Instruction
Modeling Student Behavior, Educational Data Mining, Learning Analytics

Michelle Perry
Educational Psychology
Online Spaces to Support Underrepresented STEM Students

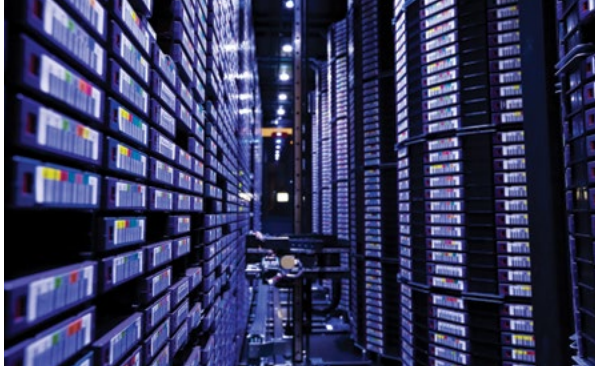
Matthew West
Mechanical Science & Engineering
Online Learning Platforms, Learning Analytics, Computer-Based Testing



Teaching Professor Lawrence Angrave (left) and members of the ClassTranscribe team. ClassTranscribe translates speech to text in real-time in order to improve disabled students' access to lecture content.

Computer Science

DATA AND INFORMATION SYSTEMS



The rapid growth of big data has created unprecedented demand and opportunities for developing powerful intelligent data and information systems that help people organize, search, explore, analyze, and manage data, information, and knowledge.

Our faculty work on a wide range of research problems, tackling the many challenges associated with developing such intelligent data and information systems and their applications. Research includes structuring and organizing massive data and information, helping people search and find relevant data and information; mining actionable knowledge from massive, heterogeneous structured and unstructured data; optimizing the entire workflow of data access, analytics, and exploration; analyzing and mining large social and/or information networks; organizing, exploring and mining scientific data including biomedical data, chemistry data, ecology and climate science data, and health information data; optimizing human-computer collaboration centered on data; and exploring broad data-intensive applications, including social media analysis, online learning, biomedical and healthcare, data/information organization and analysis in chemistry and agriculture (for newly funded NSF AI Centers).

Our faculty work closely with industry, and many of our algorithms are used in a wide range of information system applications, especially in database and data analytics systems, data mining systems, search engines, and web information service systems.

Strengths and Impact

DAIS faculty have created an active, dynamic and collaborative research environment, leading a large group of graduate students, pioneering research in the frontiers of database systems, data mining, information retrieval, Web information systems, as well as their social and scientific applications, and generating impactful results. They have graduated a good number of PhDs. Many of them are professors in major U.S. or international universities (e.g., Georgia Tech, Univ. of Michigan, UCLA, UCSD, UCSB, USC, Penn State, Purdue, Notre Dame, Univ of Virginia, Vanderbilt) and industry research labs (e.g., Google Research, IBM Research, Microsoft Research, Adobe Research), and major industry (e.g., Google, Facebook, Microsoft) and received prominent awards (e.g., NSF Career awards, KDD/SIGMOD Dissertation Awards, KDD innovation awards). The research results generated by the DAIS groups have been highly cited and some results have been popularly used in industry and academia and collected in textbooks. DAIS faculty have been highly active in the corresponding international research communities, winning many research paper awards, major research awards, and student awards, invited to deliver keynote conference speeches and conference tutorials, and claim competition awards on multiple occasions.

Some of the most impactful research contributions made by DAIS group include:

- Mining structures from massive unstructured text data with embedding and weak supervision (received three SIGKDD Dissertation awards/runner-ups in 2018, 2019 and 2020, three Google PhD Fellowships

and one Microsoft Research PhD Fellowship, with three PhDs joined USC, Georgia Tech and UCSD respectively)

- Heterogeneous information networks: Modeling, construction and analysis (attracted $16+M ARL-funded Information Network Academic Research Center (2009-2019) and $10+M NIH Funded BD2K Research Center (2014-2018) and received two SIGKDD Dissertation Awards in 2013 and 2015 respectively, two IBM PhD Fellowships and one Microsoft Research PhD Fellowship, with PhDs joined UCLA (2), Purdue, Notre Dame, Emory, Google Research, IBM Research and Microsoft Research).
- Systems for large-scale analytics: A platform-independent optimizer for data warehouses received a SIGMOD Dissertation award runner-up. Its research prototype was used in several large enterprises (e.g., Walmart and Dunnhumby). Currently, the system is commercialized by Keebo, a company funded by venture capital firms.
- Fast algorithms and tool for graph proximity (received two best paper awards and a 'test-of-time' award)
- Theories and algorithms for graph connectivity optimization (received one best paper award and an NSF career award)
- Data analysis and predictive modeling for scientific problems in ecology and climate sciences, two Best Paper Awards (SDM 2012, 2013), top tier scientific publications (PNAS, GEB, J. Climate), multiple research grants (NSF HDR, Expeditions in Computing, BII).
- General Information retrieval models for optimizing ranking and diversification of search results (received three ACM SIGIR Test-of-Time awards).

FACULTY AND THEIR RESEARCH INTERESTS

Abdussalam Alawini
Data Provenance, Scientific Data Management, Data Citation, Workflow Management, Machine Learning

Arindam Banerjee
Data Mining, Spatio-temporal Data Analysis, High-dimensional Models, Applications in Climate Science, Ecology, Recommendation Systems

George Chacko
Scientometrics, Knowledge Diffusion, Data Mining, Network Analysis

Kevin C. Chang
Data Mining, Database Systems, Information Retrieval, Web Search/Mining, Social Media Analytics

Jiawei Han
Data Mining, Text Mining, Information Networks, Database Systems, Data Analytics, Data Science Applications

Heng Ji
Natural Language Processing, especially on Information Extraction, Knowledge-driven Natural Language Generation, Text Mining, and Knowledge Graph Construction for Scientific Discovery

Yongjoo Park
Database Systems, Big Data Analytics, Approximate Computing, Machine Learning for Systems

Jimeng Sun
Deep Learning for Drug Discovery, Clinical Trial Optimization, Computational Phenotyping, Clinical Predictive Modeling, Mobile Health and Health Monitoring, Tensor Factorization, and Graph Mining

Hari Sundaram
Network Analysis, Behavioral Modeling, Applications of Game Theory

Hanghang Tong
Data Mining, Network and Graph Mining

Tandy Warnow
Scientometrics, Bibliometrics, Data Science, Statistical Inference, Graph Algorithms, Historical Linguistics

ChengXiang Zhai
Intelligent Information Systems, Information Retrieval, Data Mining, Big Data Applications

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

Catherine Blake
School of Information Sciences
Text Mining, Information Synthesis, Collaborative Information Behaviors, Recognizing Textual Entailment, Summarization, Evidence-Based Discovery, Meta-Analysis, Socio-Technical Systems

Robert Brunner
Astronomy
Cosmological Data Mining

Wendy Cho
Political Science
Computational Social Science, Data Science, Machine Learning

Jana Diesner
School of Information Sciences
Social Computing, Computational Social Science, Human-Centered Data Science

Roxana Girju
Linguistics
Natural Language Processing/Computational Linguistics, especially Semantics and Pragmatics (language use) with application to Conversational AI, Dialogue Systems, Behavior Analytics, Affective Computing

Jingrui He
School of Information Sciences
Data Mining, Heterogeneous Learning, Rare Category Analysis, Healthcare

Daniel S. Katz
National Center for Supercomputing Applications
Resilience and Fault-Tolerance, Many-Task Computing, Parallel and Distributed Computing, Sustainable and Open Science Software

Bertram Ludascher
School of Information Sciences
Data and Knowledge Management, Scientific Workflow Systems, Data Curation

Bruce Schatz
Medical Information Science
Medical Informatics, Mobile Health

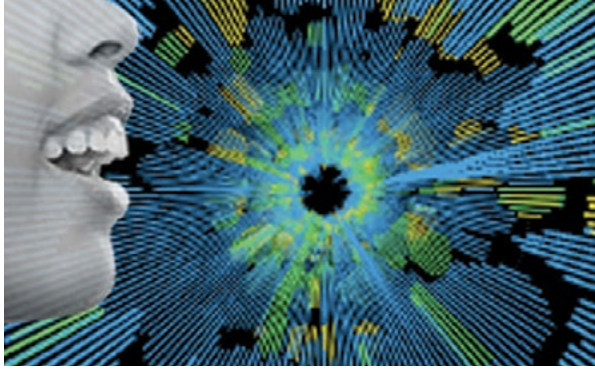
Shaowen Wang
Geography & Geographic Information Science
Computational and Geographic Information Science; CyberGIS; Multi-Scale Geospatial Problem Solving

Ouri Wolfson
Department of Computer Science, University of Illinois Chicago
Spatial Databases, Computational Transportation, Location-Based Services, Mobile Data Management, Connectomics

In 2019, Professor Jiawei Han was invested as a Michael Aiken Chair, one of the campus's top honors, in recognition of his contributions to data mining.

Computer Science

INTERACTIVE COMPUTING



Interacting with computers and with devices with embedded information technology is an important part of modern life, from driving a car safely to using all the features your phone can deliver, to being able to work productively and creatively. Interactive computing studies how computers and people can cooperate effectively on any number of tasks in a broad range of contexts.

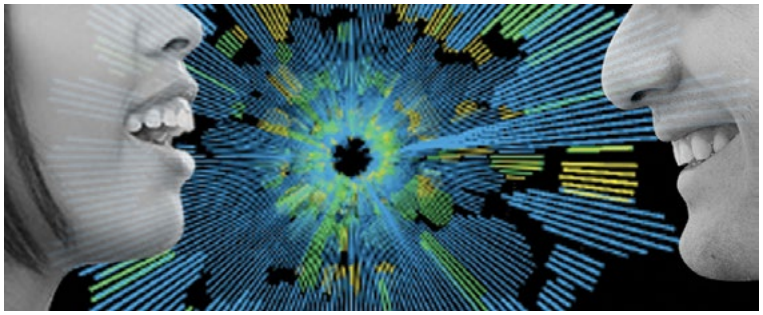
Our work targets foundational and emerging problems in human-computer interaction, computer graphics, and visualization. For example, we study the transparency of algorithms controlling social media feeds, the use of robotics in domestic environments to support aging in place, and the application of crowd and artificial intelligence to enable new methods of creative work. Working at times with companies like Adobe, Facebook, Google, Intel, Microsoft, NVidia, and Tableau, our research synthesizes knowledge from machine learning, psychology, design, and the learning sciences to invent and study new genres of interactive technology that address important problems in society. We also work on the presentation of and interaction with information, ranging from dashboards of visualizations to virtual reality displays of photorealistic video games.

Strengths and Impact

The interactive computing area comprises scholars with diverse preparation, methodologies, and perspectives spanning interaction design, visualization, applied machine learning, decision sciences, and social computing. These scholars share the common goal of designing computational artifacts and developing pedagogy to address important questions that arise when algorithms mediate (and influence) individual and group decision-making; team formation or collectives; interaction design; and mechanisms that influence online behavioral norms. The group's intellectual diversity is critical to address these questions, provides group synergies, and facilitates meaningful collaboration with scholars across other units across campus.

The interactive computing group's groundbreaking research develops algorithms, designs experiments, and builds systems to answer research questions at different scales: individuals, small groups, and large groups. At the individual level, the group has examined research questions around personal health, supporting work, and, more broadly, the design of just, equitable infrastructures. Our focus on individual health has led to the creation of tools to elicit communication in children and adults diagnosed with Autism Spectrum Disorders (ASD); the creation of environments to support adherence to medical regimens for children with asthma; the development of embodied, mixed-reality rehabilitation systems; the design of algorithmic synthesis of messages; and the development of domestic robots to help aging-in-place. Our research on work environments has resulted in the development of algorithms for opportune notification management, design of decision control and automation systems; the design of visual analytics engines; and the creation of virtual environments for safety. Our emphasis on equity and justice has led to the development of contestable machine learning systems; the design of interfaces to communicate algorithmic knowledge and process; the creation of tools that democratize visualization for non-experts; methods to hide on the

internet; and the design of adversarial bargaining systems. Our work has led to the creation of the term "algorithmic auditing", and an increased focus on the ethical implications of the use of algorithms in online platforms.



A visualization of a group discussion made by Conversation Clock.

At the small group level, we have examined algorithmic team formation, visualization of group conversations, and public visualizations that incentivize workplace collaboration. At a large scale, our work has examined crowdsourced design critiques and develops educational technologies for remote learning and identifying coordinated behavior. We are exploring novel approaches to online moderation and developing new AI-backed socio-technical systems. Our research pioneered the concept of design mining: using data mining and machine learning to capture and index large repositories of existing designs and correlate the design patterns found in these repositories with performance metrics to understand best practices. We are also building novel data-driven tools for creating and evaluating digital design (developing generative model approaches for predictive design; designing effective user experiences powered by machine learning models; how the design of ranking and rating systems on social platforms can incentivize users to engage more meaningfully with content, to the benefit of everyone).

The group, which comprises senior, mid-career, and junior faculty, including three ACM distinguished members, shows leadership in research, teaching, and service to the community. We publish at leading human-computer interaction and social computing conferences, and the community has recognized our work with best-paper awards and honorable mentions at these conferences. Our scholarship has also been recognized through highly visible external fellowships and with prominent awards within the university. Funding from federal agencies and industry support our work. The group has received acclaim for its teaching and student mentoring. Our faculty have been honored with teaching excellence awards within the university. Our mentoring efforts have led to our undergraduates receiving CRA honorable mentions and our PhD students taking faculty positions at top-tier peer institutions and prominent industry research labs. As part of broader service to the community, we help organize major conferences, associate editors of prominent journals in the field, and as series editors of distinguished academic book collections. Our faculty are leading the Just Infrastructure center that interrogates the complex interactions between people, systems, and algorithms. Our senior faculty are also in leadership positions within the university and have been instrumental in developing the online master's data science program.

Our public engagement has led to creating public datasets, startups, and to changes in online governance. As part of a collaboration with Google, our faculty have released and maintained the Rico dataset—the largest repository of mobile app designs collected to date—comprising more than 72k unique UI screens and 3M UI elements mined from 9.7k Android apps. This dataset's scale and its semantic classification of UI components have made it possible for researchers in academia and industry to train deep neural models for mobile task automation, app testing, and UI layout generation. Our work on design mining the Web led to a startup (Apropose, Inc.) that raised significant capital from prominent venture capital funds. We have worked with large-scale Internet platforms, including Twitter, Reddit, and Facebook, to improve online governance. This work led to the ban of hate groups in several online forums and received considerable press coverage—e.g., *The New York Times*, *The Verge*, *MIT Technology Review*, *TechCrunch* and *Motherboard*.

FACULTY AND THEIR RESEARCH INTERESTS

Brian P. Bailey
Human-Computer Interfaces, Design Thinking, Creativity, Crowdsourcing, Teamwork

Eshwar Chandrasekharan
Social Computing, Human-Centered AI, Data Science, Online Moderation

David A. Forsyth
Graphics, Projection Mapping

John Hart
Data Visualization, Computer Graphics, Virtual Reality

Karrie Karahalios
Social Computing, Human Computer Interaction, Social Visualization, Assistive Technologies, Fairness and Bias in Computing

Alex Kirlik
Human-Computer Interaction, Human Factors, Cognitive Science and Engineering, Modeling and Supporting Human Judgment and Decision Making, Human-Automation Interaction

Ranjitha Kumar
Data-Driven Design, Design Mining, User-Centered Machine Learning, UI/UX, Mobile/Web Applications, Social Networks, Fashion, Emoji

Steven M. LaValle
Virtual Reality, Human Perception

Klara Nahrstedt
Quality of Experience, Tele-Immersion, Multi-View Visualization, Embedded Sensors, Distributed and Parallel Systems

Hari Sundaram
Voting, Improving Individual and Collective Decision Making, Information Asymmetry, MOOCs

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

Donna Cox
National Center for Supercomputing Applications and the School of Art & Design
Scientific Visualization, Computer Graphics, Information Design

Yun Huang
School of Information Sciences
Social Computing, Mobile Computing, Computer Supported Cooperative Work, Croudsourcing

H. Chad Lane
Educational Psychology
AI in Education, Educational Games, Affective Computing, Intelligent Tutoring Systems

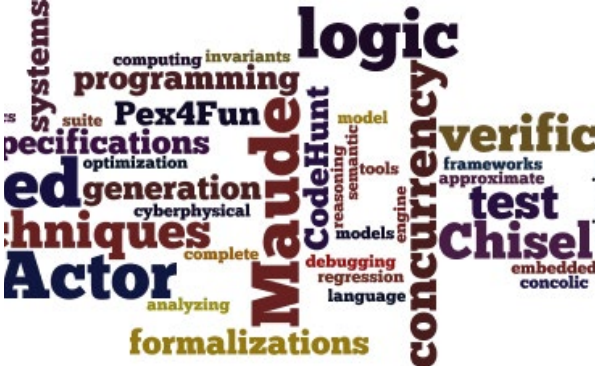
Michael Twidale
School of Information Sciences
Computer Supported Collaboration

Yang Wang
School of Information Sciences
Usable Privacy and Security, Social Computing, Accessibility, Explainable Artificial Inteligence

Associate Professor Ranjitha Kumar has released Rico, the largest database of mobile app interfaces, to help researchers mine and build machine learning models for good design.

Computer Science

PROGRAMMING LANGUAGES, FORMAL METHODS, AND SOFTWARE ENGINEERING



The broad area of programming languages, formal methods and software engineering includes 17 department faculty and 2 affiliate faculty. With three recent hires, Reyhaneh Jabbarvand, Gagandeep Singh, and Lingming Zhang, we now have a reasonably good coverage of all the major areas and subareas of our field.

Strengths and Impact

There are several thrusts of research in our area, their common denominator being the harmony we keep between theory and system development. Compilers, compiler optimizations, and program transformation are traditional topics, but we approach them using novel techniques and tools, which not only get the job done but also do it with a high level of correctness confidence, sometimes even provably correctly. Parallel computing and models for concurrency are complex areas where we have unique expertise. Several of our faculty push conventional formal methods and verification into the realm of cyber-physical systems, which have both discrete and continuous behaviors, as well as into probabilistic and approximate models of computation. Software testing is one of our core strengths in software engineering; it is often the case that 10% or more of all the papers in top testing conferences are authored by Illinois faculty. In programming languages, we cover semantics and logics for program reasoning very well, proposing frameworks and foundations that are significantly better than the state-of-the-art. Our research covers a broad spectrum, from foundationally advanced interactive theorem proving and category and type theory, to practical software engineering such as test selection and energy consumption. Security is also one of our strengths, being known for one of the most prominent attacker models in the security community, as well as for using modern programming language and formal methods and software engineering techniques to detect security flaws and improve system security. Importantly, we are actively investigating ideas and success stories from other areas, such as operating systems, numerical analysis, artificial intelligence, machine learning, and natural language processing, to propose innovative synergies between these fields and our area and specific scientific interests.

Awards

The excellence and impact of the area's research has been recognized by several awards, including NSF CAREER (all non-junior tenured faculty in our area), ACM Fellow (Adve, Agha, Meseguer), IEEE Fellow (Rosu, Xie), AAAS Fellow (Xie). Our area members received a number of paper and system awards, including ACM Software System Award (Adve), test-of-time or 10-year or 15-year Most Influential Paper awards from ASE (Marinov, Rosu) and ACM SIGSOFT (Agha, Marinov, Rosu) and CGO (Adve) and RV (Rosu), more than 10 ACM SIGSOFT/SIGPLAN Distinguished Paper Awards, the CHI Best Paper Award, the OSDI

Professor José Meseguer was named a 2020 ACM Fellow for "the development of logical methods for design and verification of computational systems.

Audience Choice Paper Award, and more. Besides the usual funding streams, we have also received funding specific to faculty accomplishments which is regarded as awards as well, such as several Facebook faculty awards, Google faculty research awards, IBM faculty awards, Microsoft faculty awards, Qualcomm faculty awards, Samsung GRO faculty awards, the Alibaba innovative research award, the NSF CRII award, and many more. Our students have also obtained prominent awards and honorable mentions, such as the ACM Software System Award, SIGPLAN Distinguished Dissertation Award, SIGOPS Dennis M. Ritchie Outstanding Dissertation Award, ACM Outstanding Dissertation Award.

Student Placements

The area has placed several PhD students in top academic and research positions in the United States and abroad. Recent successes include placing students in tenure-track Assistant Professor positions at Cornell, UT Austin, Purdue, Rice University, U of Rochester, University of Illinois at Chicago, East Carolina University, Kennesaw State University, University of Sheffield and National University of Singapore. There are a number of Illinois graduates from our area in the faculty of top departments, including Toronto, UC Berkeley, and UT Austin, to name a few. In addition, many of the Illinois graduates joined leading companies and research institutes including Apple, Facebook, Google, Microsoft, Amazon, VMware, VISA, NASA, Galois, and more.

Outreach

We actively work with industrial collaborators to promote and transition the technology that we develop in our research groups to their institutions and the broader community, to power products that are used by masses of developers. Examples include Adve with transitioning LLVM to companies like Apple and many others, Marinov with transitioning regression testing to Google and others, Rosu with transitioning token formal verification to blockchains like Ethereum and others, Zhang with transitioning automated bug fixing to Alibaba. Such activities have often brought our department in the news. Adve is working with Tuskegee University (one of the most successful HBCUs in both Engineering and Agriculture) in AIFARMS research and education. This includes TU graduate students and faculty joining AIFARMS research projects, and a summer REU program for 2021 in development to fund TU undergraduates to participate in AIFARMS projects.

FACULTY AND THEIR RESEARCH INTERESTS

Vikram Adve
Programming Languages, Compilers, Parallel Programming, Domain-Specific Languages, Automated Debugging, Formal Verification, Software Repositories

Gul Agha
Models for Concurrent Computation, Parallel and Distributed Algorithms

Mattox Beckman
Parsers and Parser Generators, Clone Detection, Functional Programming and Type Classes, Matching Logic, Category Theory

Elsa Gunter
Formal Methods, Programming Languages, Software Engineering, Semantics, Interactive Theorem Proving, Model Checking, Type Systems, Program Verification, Compiler Correctness

Reyhaneh Jabbarvand
Software Testing and Analysis, Mobile Apps Energy and Security Assessment, Machine Learning for Software Engineering, Search-Based Software Engineering

Darko Marinov
Software Engineering, Software Testing

Jose Meseguer
Formal Executable Specification and Verification, Software Architecture

Sasa Misailovic
Program Optimization Systems, Probabilistic Programming, Approximate Computing Techniques

David Padua
Program Analysis, Transformation, Optimization

Madhusudan Parthasarathy
Formal Methods, Software Verification, Model Checking, Decidable Logics

Lawrence Rauchwerger
Languages for Parallel Computing, Run-Time Systems for Parallel Computing, Compilers for Domain Specific Parallel Languages

Grigore Rosu
Software, Design, Semantics and Implementation of Programming Specification Languages

Gagandeep Singh
Numerical Program Analysis, Formal Verification, Abstract Interpretation, System Verification, Formal Automated Reasoning

Mahesh Viswanathan
Model Checking, Logic, Cyberphysical Systems, Software, Security

Tao Xie
Software Engineering, Software Testing, Program Analysis, Software Analytics

Tianyin Xu
Operating Systems, Cloud and Datacenter Systems, System Reliability and Resilience, Large-Scale System Management, Configuration Management, Reliability Engineering

Lingming Zhang
Software Engineering, Software Testing and Debugging, Automated Program Repair, Program Analysis, Synergy between AI/FM and Software Engineering

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

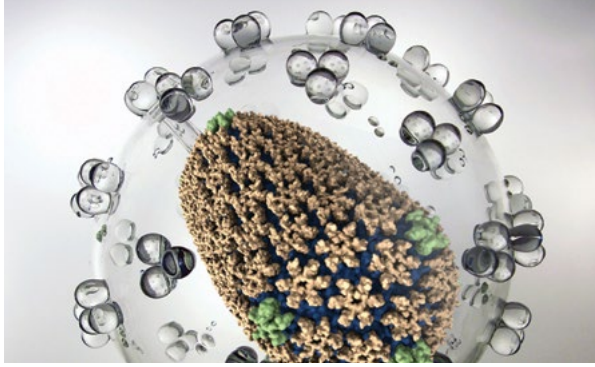
Andrew Miller
Electrical & Computer Engineering
Design of Secure Decentralized Systems and Cryptocurrencies

Sayan Mitra
Electrical & Computer Engineering
Formal Methods, Automated Reasoning

Illinois CS faculty members (l to r) Tarek Abdelzaher, Svetlana Lazebnik, and Grigore Rosu were among the 2021 class of IEEE Fellows.

Computer Science

SCIENTIFIC COMPUTING



Simulation plays a major role in nearly every area of science and engineering — from data analysis to physical models, computation plays a key role in discovery. Our faculty design, build, and analyze numerical algorithms to ensure that numerical methods are accurate and that implementations are efficient.

We design and analyze the accuracy of methods, developing numerical approximations to partial differential equations with advanced finite element methods and integral equations. We also develop solvers for these problems, including techniques based on numerical linear algebra, iterative subspace methods, and multigrid methods. Our research explores the efficiency of these methods on a range of architectures and environments, from high-concurrency nodes, such as GPUs, to large-scale supercomputing systems. We explore parallel scalability and analyze performance in computing kernels from graph algorithms to sparse linear algebra. We collaborate with application scientists to ensure that our innovations have impact.

Strengths and Impact

The scientific computing group at the University of Illinois has had a long history of research and education in numerical analysis dating to the 1960s and the early years of parallel computing at the University. The group is widely recognized for its deep contributions in the field and as a leader in breakthroughs and advances in the latest methods and algorithms in numerical computing. Scientific computing is home to researchers with established collaborations within the department, from machine learning to theory and algorithms to architecture and parallel computing. Moreover, the faculty in this area have deep collaborations with researchers across The Grainger College of Engineering and campus in a range of scientific domains in the engineering, math, and physical sciences. The group is nationally considered a center for research and education in scientific computing, with highly recognized alumni in national labs, industry, and academia, both in computer science and in mathematics.

The research focus of the group is broad in application and follows several themes of research.

Numerical methods for partial differential equations: The group has had extensive impact in advancing numerical computation in this area, foremost in the area of finite element methods. Faculty have led the development of novel approaches in spectral element, discontinuous Galerkin, and least-squares finite element methods. Moreover, the group has been leading the development of new methods and tools for integral equations. The advances in this area are not purely theoretical—

In 2017, MPICH (top) and PETSc (bottom) were both named to the Department of Energy Office of Science's list of 40 Years of Research Milestones.

researchers in the group have also been adept at applying these schemes on some of the most complex and largest scientific simulations in the world, from fluid flows to solid mechanics.

Numerical linear algebra: The group has gained wide recognition for advances in numerical linear algebra, particularly for use in parallel environments. By advancing the state-of-the-art in core numerical linear algebra routines that are used in a variety of scientific codes and establishing new theory and methods in emerging areas such as tensor computations, the research in the group continues to push the edge of innovation in computational mathematics. The group has also gained attention for impact in the area of sparse iterative methods for solving large scale linear systems. Advances in multigrid methods, domain decomposition methods, and other subspace methods are at the forefront of research in this area.

Parallel numerical algorithms: Research in the group has also led to impactful contributions to the MPI standard and supporting tools, developing methods and algorithms to handle communication and heterogeneous computing at scale. In addition, the group has made key contributions in performance modeling and the analysis of parallel scalability.

With a focus on methods and algorithms in numerical simulation, the group has a range of software contributions and supporting tools in this area as well. nek5000 is a highly efficient and scalable library for computational fluid dynamics (led by Fischer); the MPICH implementation of Message Passing Interface (MPI) and the Portable Extensible Toolkit for Scientific Computation (PETSc) have received numerous awards (Gropp); pycuda, pyopencl, loopy, and potentially provide an arc of performant numerical computing in Python (Kloeckner), pyamg, raptor, cedar, and cusp implement a range of multigrid methods on different platforms (Olson), and the Cyclops Tensor Framework (CTS) is gaining attention for high performance tensor computations (Solomonik).

The core faculty in scientific computing continue to work on and lead large projects and centers with national notoriety and impact. These include (1) the National Center for Supercomputing Applications (NCSA) at Illinois, a world renowned center for large scale computing (Gropp, Director); (2) Computational Science and Engineering (CSE) at Illinois, an interdisciplinary program in the Grainger College of Engineering that is advancing interdisciplinary scientific computing and computational science (Olson, Director); (3) the Center for Efficient Exascale Discretizations, a Department of Energy Exascale Computing Project (Fischer, Deputy Director); and (4) the Center for Exascale-enabled Scramjet Design (CEESD), a Department of Energy Predictive Science Academic Alliance Program Centers of Excellence (Gropp, Co-Director; Kloeckner, Olson, executive committee; Fischer, PI).

Highlights (noting faculty involvement)

- Solving large scale systems at extreme scales (Fischer)
  Scalable low-order finite element preconditioners for high-order spectral element Poisson solvers SISC, 2019
- State-of-the-art simulation of PDEs on supercomputer (Fischer)
  Scalability of high-performance PDE solvers IJHPCA, 2020
- A new method for model reduction in fluid flows (Fischer)
  Towards model order reduction for fluid-thermal analysis Nucl. Eng. Des, 2020
- Impact and advances in MPI (Gropp)
  Scalability challenges in current MPI one-sided implementations, ISPDC 2016
- A novel method for highly accurate quadrature (Klöckner)
  A Fast Algorithm for Quadrature by Expansion in Three Dimensions. JCP, July 2019
- Theoretical advances in the use of conformal mappings (Klöckner)
  Conformal Mapping via a Density Correspondence for the Double-Layer Potential, SISC, 2018

- A new tool for transforming numerical code for performance (Klöckner)
  Array Program Transformation with Loo.py by Example: High-Order Finite Elements ARRAY 2016
- A new, accurate finite element method for reduced basis models (Olson)
  A Least-Squares Finite Element Reduced Basis Method, SISC, 2020
- Projection and roadmaps for solver performance at exascale (Gropp, Olson)
  FFT, FMM, and multigrid on the road to exascale: Performance challenges and opportunities, JPDC, 2020
- Significant reduction in communication cost for sparse kernels (Gropp, Olson)
  Node aware sparse matrix–vector multiplication, JPDC, 2019
- A new, general method for robust algebraic multigrid solvers (Olson)
  A root-node based algebraic multigrid method, SIAM SISC, 2017
- Fast sparse matrix multiplication on GPUs (Olson)
  Optimizing Sparse Matrix—Matrix Multiplication for the GPU, ACM TOMS, 2015
- Advancing the field of tensor calculations (Solomonik)
  Distributed-memory DMRG via sparse and dense parallel tensor contractions SC 2020
- A new parallel algorithm for eigenvalue problems (Solomonik)
  A communication-avoiding parallel algorithm for the symmetric eigenvalue problem, SPAA, 2017
- Highly efficient calculations on graphs (Solomonik)
  To push or to pull: On reducing communication and synchronization in graph computations, HPDC 2017
- Fast QR factorization on parallel machines (Solomonik)
  Reconstructing householder vectors from tall-skinny QR, JPDC 2015

CS FACULTY AND THEIR RESEARCH INTERESTS

Nancy M. Amato
Parallel Algorithms and Libraries, Parallel Graph Algorithms, Performance Modeling

Paul Fischer
High-Order Numerical Methods for Partial Differential Equations, Scalable Parallel Algorithms, Iterative Solvers, Parallel Computing, Spectral Element Methods, Computational Fluid Dynamics

William Gropp
High Performance Scientific Computing, Scalable Numerical Algorithms for PDEs, Numerical Software, Performance Analysis

Laxmikant Kale
Simulation Software, Numerical Libraries, Numerical Algorithms

Andreas Kloeckner
Integral Equation Methods For PDEs, High-Order Finite Element Methods for Hyperbolic PDEs, Tools and Languages for High-Performance Computing, Time Integration

William Kramer
Extreme-Scale Computing and Analytics, Performance Evaluation, Data and Storage Techniques

Luke Olson
Numerical Analysis, Scientific Computing, Large-Scale Simulation, Multigrid and Iterative Methods, Finite Element Methods

Lawrence Rauchwerger
Parallel Computing, Compilers, Parallel Libraries, High Performance Computing, Parallel Architecture, Exascale Computing

Marc Snir
Large-Scale Parallel Systems, Algorithms, Libraries

Edgar Solomonik
Numerical Linear Algebra, Tensor Computations, Parallel Algorithms, Quantum Chemistry, Quantum Simulation

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

Mark A. Anastasio
Bioengineering
Computational Inverse Problems, Image Reconstruction, Wave Physics Modeling in Imaging

Daniel S. Katz
NCSA
Resilience and Fault-Tolerance, Many-Task Computing, Parallel and Distributed Computing, Sustainable and Open Science Software

Computer Science

SECURITY AND PRIVACY

With the growth of the Internet and increasing importance of data managed there, security and privacy developed as academic subjects around 2000. The University of Illinois CS department began to offer courses around that time and carved out a role for itself through the establishment of the Information Trust Institute (ITI) and the development of the first academic center focused on security for electric power grids. This catalyzed a variety of initiatives to address security concerns in critical infrastructures. A resulting critical mass of activity and investment in this and other technology areas led to the formation of the Security and Privacy Research at Illinois (SPR@I) and, in 2019, the establishment of the Security and Privacy Area (S&P) in the CS Department. S&P primarily occupies a collection of offices on the fourth floor of the Siebel Center that collaborates closely through SPR@I with its sister group of researchers in security and privacy in ECE, who are mainly located in CSL.

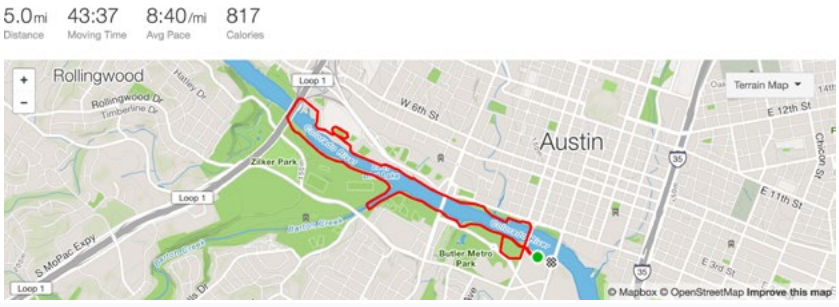
Security and privacy are topics that arise in many areas either as problems (such as denial of service attacks on the Internet) or potential solutions (such as using machine learning to detect such attacks). Hence S&P has strong connections with many other areas in CS including the areas of Systems and Networking; Theory and Algorithms; Artificial Intelligence; and Architecture, Compilers, and Parallel Computing.

Strengths and Impact

S&P is a young CS area consisting mainly of Assistant Professors. It has great energy, productivity, variety, and potential. The following sample of contributions captures the diversity and depth of the contributions in three general areas where security and privacy techniques are applied or developed.

Systems

Achievements in systems included the following: revealed and addressed a series of issues with permissions in smartphones and IoT leading to revisions in the Android OS; developed advanced techniques for detecting and investigating intrusions into large organizations' computer networks based on the concept of data provenance; studied privacy of popular fitness tracking applications available on mobile phones and wearable devices leading to integrated tools now available to millions of users; developed novel attacks microarchitecture and trusted execution environment abstractions; developed comprehensive defenses against microarchitectural attacks, addressing challenges at the programming stack, ISA and hardware levels.



Using fitness apps, runners can share their route, but this poses a security risk. A team led by Assistant Professor Adam Bates has worked with Strava and Garmin Connect on modifications to better protect their customers.

Sample publications in systems include:

- Analysis of Privacy Protections in Fitness Tracking Social Networks-or-You can run, but can you hide? Wajih Ul Hassan, Saad Hussain, and Adam Bates. USENIX Security 2018.
- Data Oblivious ISA Extensions for Side Channel-Resistant and High Performance Computing, Jiyong Yu, Lucas Hsiung, Mohamad El Hajj, and Christopher W. Fletcher, NDSS, 2019.
- Resolving the Predicament of Android Custom Permissions, Güliz Seray Tuncay, Soteris Demetriou, Karan Ganju, and Carl A. Gunter. NDSS 2018.

Theory

Achievements in theory included the following: designed the first secure multi-party computation protocols with provable security against quantum adversaries, and simplified the required cryptographic primitives; established the hardness of finding a Nash equilibrium for two-player zero-sum games based on standard assumptions; developed novel non-malleable commitment protocols to provably defend against man-in-the-middle attacks; designed practical Byzantine fault tolerant protocols with minority corruption; advanced understanding of optimal communication complexity of Byzantine agreement.

Sample publications in theory include:

- One-way Functions Imply Secure Computation in a Quantum World, James Bartusek, Andrea Coladangelo, Dakshita Khurana and Fermi Ma. QIP 2021.
- Communication complexity of Byzantine agreement, revisited, Ittai Abraham, TH Chan, Danny Dolev, Kartik Nayak, Rafael Pass, Ling Ren, and Elaine Shi. PODC, 2019.

Learning

Achievements in machine learning included the following: developed a range of novel neural network techniques to detect membership and attribute inference violations; made the first application of machine learning on hardware performance counters to detect illegitimate Bitcoin mining; developed adversarial ML attack algorithms against machine learning models, including classifiers, object detectors and reinforcement learning algorithms in both digital and physical worlds under whitebox and blackbox settings; designed robust machine learning systems against both training and testing time attacks, and provided certified robustness for given machine learning models; designed a robust federated learning system which is able to tolerate backdoor attacks during training effectively by smoothing and clipping the model weights.

Assistant Professor Bo Li was named to *MIT Technology Review's* 2020 List of Innovators Under 35. Li uses adversarial attacks to make AI systems more robust.

Sample publications in machine learning include:

- Property inference attacks on fully connected neural networks using permutation invariant representations, Ganju, Karan, Qi Wang, Wei Yang, Carl A. Gunter, and Nikita Borisov. CCS 2018.
- Detecting AI Trojans Using Meta Neural Analysis, Xiaojun Xu, Qi Wang, Huichen Li, Nikita Borisov, Carl A. Gunter, Bo Li. IEEE Symposium on Security and Privacy 2021.
- Nonlinear Projection Based Gradient Estimation for Query Efficient Blackbox Attacks, Huichen Li, Linyi Li, Xiaojun Xu, Xiaolu Zhang, Shuang Yang, Bo Li. AISTATS 2021.
- CADE: Detecting and Explaining Concept Drift Samples for Security Applications. Limin Yang, Wenbo Guo, Qingying Hao, Arridhana Ciptadi, Ali Ahmadzadeh, Xinyu Xing, and Gang Wang. USENIX Security Symposium. 2021.

Education

S&P has made strong progress on developing education in CS at UIUC. This is especially reflected in the number and quality of PhD students produced by members of the area and the development of a new qualifier format that covers both breadth and depth. The SPR@I group holds regular meetings to vet graduate student presentations of their works accepted for publication. Progress is also reflected by course design. For instance, S&P faculty Bates and Ren taught our flagship basic course in security (CS461) in the Fall 2020 and refined the content in a way that got very positive feedback from a sizable class of students. Khurana and Miller worked together on getting approval for our new 400-level cryptography course and have set up plans to develop a 500-level course as well. Li and Wang have proposed a novel topics course in machine learning and security that will look at both uses of ML to detect security breaches and adversarial techniques that aim to disguise attacks. Gunter has run a course on analyzing adverse impacts of computer technology (the “cyber-dystopia” course) that has been rated as excellent by students for each of the three years it has been offered and is now under consideration for becoming a topics course in societal impacts of computer technology.

CS FACULTY AND THEIR RESEARCH INTERESTS

Vikram Adve
Secure Compilation, Program Analysis, Software Security, Debloating

Adam Bates
Systems and Networks, Auditing, Internet of Things Security

Matthew Caesar
Network Verification, Software Resilience, Model Checking

Roy H. Campbell
Cloud Computing, Big Data, Ubiquitous Computing, Microkernels

Christopher Fletcher
Hardware Security, Applied Cryptography

Brighten Godfrey
Network Infrastructure Security and Verification

Carl A. Gunter
Internet of Things, Privacy, Data Science, Healthcare, Power Grid

Dakshita Khurana
Secure Computation, Cryptography, Privacy

Robin Kravets
Mobile Privacy, Wireless Security

Bo Li
Machine Learning, Privacy Preserving Generative Models

Sasa Misailovic
Approximate Computing across Full System Stack

Sibin Mohan
Real-Time and Cyber-Physical Systems, Internet of Things, Cloud Computing

Klara Nahrstedt
Mobile, Multi-Sensory Systems, Quality and Resource Management, Energy Systems

Ling Ren
Computer Security, Applied Cryptography, Blockchain

Gang Wang
Security and Privacy, Internet Measurement, Human Factors

Tao Xie
Mobile, Text Analytics, Testing, Program Analysis

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

Michael Bailey
Electrical & Computer Engineering
Networks

Nikita Borisov
Electrical & Computer Engineering
Privacy and Networks

Jian Huang
Electrical & Computer Engineering
Systems Security, Memory/Storage Security

Ravi Iyer
Electrical & Computer Engineering
Measures and Models

Kirill Levchenko
Electrical & Computer Engineering
E-Crime and Cyber-Physical Systems

Andrew Miller
Electrical & Computer Engineering
Distributed Computing and Cryptography

David Nicol
Electrical & Computer Engineering
Modeling and Simulation

Yang Wang
School of Information Science
Usable Privacy and Security

Computer Science

SYSTEMS AND NETWORKING

The Systems and Networking area comprises twenty one faculty working across a broad spectrum of challenges in the areas of cloud computing, big data, software defined networks, data center networking, mobile and wireless computing, Internet of Things, wearable computing, security and privacy, health care engineering, multimedia systems, real-time systems, system reliability, and cyber-physical systems. Our research spans the spectrum of low-level physical-layer computing all the way up to the applications and systems that bring advanced functions to emerging computing platforms. We are creative but also technically skilled, with extensive expertise on applying deep learning, coding theory, distributed algorithms, and formal methods to provide solutions that are rigorous and complete.

Our research is not only broad but deep, having resulted in a plethora of startups and technologies that form key foundations of the modern Internet, commonly used operating systems, and more.

Strengths and Impact

The Systems and Networking group at UIUC shaped several research fields with particular contributions to Mobile Computing, Internet of Things, Networked Sensing, Cyber-physical Systems, Multimedia Systems, Networking, and Distributed Systems, among others. While there is a lot that could be highlighted, this report will focus on a few key contributions that may be particularly noteworthy.

A key impact indicator of the group has been its success at technology transition and commercialization over the years. Recently, our faculty and grad students, including Prof. Brighten Godfrey and Prof. Matthew Caesar, pioneered the area of network verification, which applies the concept of formal, mathematical logic comprehensively model an entire network and provably determine if the network meets security and availability goals. This UIUC research directly inspired use of the technology at Microsoft Azure, and related technology has now been deployed by Google, Amazon, and Cisco, among others. It also led to a UIUC spinout startup, Veriflow, led by Godfrey and Caesar which commercialized the technology, growing from three co-founders to a team of over thirty. Veriflow was acquired by VMware in 2019 and its technology was released as part of VMware's network management platform in Fall 2020. Other prominent startup examples founded by Systems and Networking faculty (and/or their graduate students, or directly commercializing their research) include Pattern Insight led by Prof. Yuanyuan Zhou (for software bug detection and log analysis, acquired by VMware), Adrenaline Mobility (back-end support for mobile apps, acquired by Twitter), Caterva (a real-time social media marketing platform, acquired by Infochimps, started by Hieu Le, a PhD student in Prof. Tarek Abdelzaher's group), and Compira Labs (commercializing Godfrey's research in congestion control to improve video delivery). These startups continue the tradition of Systems/Networking-oriented companies emerging from CS at Illinois, such as Netscape, YouTube, C3.ai, Yelp, PayPal, and others.

In the areas of mobile computing and multimedia computing, the group significantly contributed to the scientific community and research on quality of service, privacy/trust, IoT, energy management for multi-modal mobile systems, teleimmersive systems, video 360 systems, networked sensing, and edge AI. Few examples of the various contributions are: Prof Tarek Abdelzaher started the International Conference

on Internet of Things Design and Implementation (IoTDI) that has become a top venue for IoT research publications and engaged in multiple leadership and service activities in the field. In the past four years, Prof. Klara Nahrstedt has served on multiple advisory boards (including Washington University St. Louis, Iowa State University, TECoSA, University of Minnesota, and NSF CISE), has achieved Fellow status of both ACM, AAAS, and IEEE, served on the organizing committees for ACM Multimedia, ACM MMSys, ACM NOSSDAV, ACM SEC, and continues to serve as the Director of Coordinated Science Laboratory (CSL), all while authoring numerous papers in highly prestigious venues. Klara also continues to regularly teach her widely-renowned class on Multimedia Systems, which teaches students the technologies behind YouTube, teleimmersion, 360 video systems, AR glasses, video games, and so many other graphical technologies that make up our modern world.

A traditional area of strength in the Systems and Networking group is Real-time and Cyber-Physical Systems, where group members have made many seminal contributions. Former Illinois CS faculty David C. L. Liu invented schedulability analysis algorithms that have become the foundation of modern real-time computing theory. Building on this foundation, Prof. Lui Sha's contributions to fundamental theory, practice, and standardization of real-time systems received the IEEE Simon Ramo Medal, which is the IEEE's highest honor for system science and engineering. He also served on the National Academy of Science's Committee on certifiably dependable software and the NASA Advisory Council. The group's work was and still is the only analytic real-time scheduling method approved by the FAA for safety critical flight-control applications; their technology was used to fix Mars Pathfinder's software when the Pathfinder was millions of miles away on Mars and its software kept crashing; they enabled software upgrades to GPS satellites in orbit, leading to continuous improvements in GPS services for navigation; and they allowed International Space Station computers *"to budget their time, to choose between a variety of tasks, and decide not only which one to do first but how much time to spend in the process,"* wrote Aaron Cohen, Deputy Administrator of NASA.

With the recent re-emergence of AI, and its integration with myriads of applications from autonomous systems to ubiquitous computing and network sensing, recent contributions of this group include social sensing, medical best-practice guidance systems (using computational pathophysiology-guided AI in cooperation with Carle Foundation Hospital), safe autonomy using physical model-guided AI, and defense systems. For example, Tarek Abdelzaher leads a $25M Research Alliance on the Internet of Battlefield Things (IoBT), funded by the Army Research Labs, where he is applying AI and IoT concepts to revolutionize the military capabilities of the US Army. Other contributions include real-time virtual synchrony and the physically asynchronous logically synchronous protocol that won IEEE's and AIAA's David Lubkowski memorial award for the Advancement of Digital Avionics.

As a reflection of the growing multidisciplinarity of Computer Science, the Systems and Networking area continues to be highly collaborative, both with other groups in the department and across campus. Collaborations within the department include work with critical areas such as (but not limited to) Formal Verification, AI/ML, Architecture, HCI, Security, and others. For instance, Prof. Indranil Gupta co-founded the "Center for Just Infrastructures" in 2020 with faculty in CS and the I-School to explore overlap areas between the three pillars of distributed systems, AI, and society. The Center for Just Infrastructures received funding from both industry and campus. The Just Infrastructure seminar series is attracting 500+ attendees over the country, and is receiving national attention. This multidisciplinary nature has also led to significant industry funding obtained by all faculty in the area from companies such as (but not limited to) Microsoft, Google, Facebook, Cisco, Capital One, Schlumberger, JP Morgan Chase, VMware, Boeing, AT&T, and many others.

We will now highlight some other successes in the group. Tarek Abdelzaher has been in the news for his studies on opinion polarization and COVID-19. Matthew Caesar has been in the news for his analyses on Amazon AWS IoT deployments. Robin Kravets' recent research on proximity networking and IoT has been

funded by the National Science Foundation (NSF) and a Google Focused research grant. Tianyin Xu has had his research adopted by several open-source projects such as the Linux kernel, and has won multiple awards including the Facebook Distributed Systems Research Award. Deepak Vasisht received the ACM SIGCOMM Doctoral Dissertation award. He has also created a new graduate class on wireless systems for IoT, expanding upon his great experience in applying new wireless technologies to applications such as digital agriculture and healthcare. He has also been publishing seminal papers on IoT, including his recent acceptance to NSDI (Decimeter-Level Localization with a Single Wifi Access Point), in which he makes yet another fundamentally new insight into how we can leverage wireless physical-layer properties to do new, amazing things. Brighten Godfrey has received the prestigious Alfred P. Sloan Research Fellowship and the ACM SIGCOMM Rising Star Award. It is also worth noting that every faculty member in our area has received the NSF CAREER award.

Apart from our regular on-campus teaching, the Systems and Networking group teaches several high impact MOOC courses (Massive Open Online Courses) on Coursera. This includes a Cloud Computing Specialization that includes Cloud Applications, Cloud Computing Concepts, Cloud Networking, and a Cloud Capstone. These are offered as full MOOCs, as well as concentrated courses in our MCS Coursera program (both are significant sources of revenue for the department, college, and campus). These courses have had a significant impact on industry, with typically 60-80% of students being full time employees. Each of these courses is massive in size, e.g., the Cloud Computing Concepts course itself has been visited by 650K students since 2015.

CS FACULTY AND THEIR RESEARCH INTERESTS

Tarek Abdelzaher
Networked Sensing, Intelligent Internet-of-Things (IoT) Applications, IoT and Big Data, Embedded (Cyber-physical) and Real-Time Systems, Machine Learning for CPS, Crowdsensing/ Social Sensing, Social Media Analysis, Social Networks in the Age of Information Overload

Gul Agha
Distributed Systems, Wireless Embedded Sensor Networks, Multi-Agent Systems

Adam Bates
Security

Matthew Caesar
Design, Analysis, and Verification of Wide-Area Networks and Distributed Systems

Roy H. Campbell
Cloud Computing, Deep Learning Systems, Big Data, Security, Ubiquitous Computing, Micro kernels, Quantum Computing Systems, Health Data Analytics

Brighten Godfrey
Cloud Networking, Network Verification, Machine Learning for Networks, Internet Architecture and Algorithms

Carl A. Gunter
Security, Internet Architecture and Protocols, Smartphones and Internet of Things

Indranil Gupta
Distributed Systems, Cloud Computing, Internet of Things Distributed Machine Learning, Industry Production Systems

Robin Kravets
Networking, Wireless Networking, Mobile Computing, Internet of Things

Sibin Mohan
Real-Time and Embedded Systems, Cyber-Physical Systems, Internet of Things, Cloud Computing, Software-Defined Networks, Resiliency, Security

Klara Nahrstedt
Quality of Service and Quality of Experience, Tele-Immersion, Video 360 Systems, Distributed and Parallel Systems; Real-Time Security in Industry Control Systems, Key Management Protocols, Privacy-Preserving Systems

Ling Ren
Applied Cryptography, Computer Security and Distributed Algorithms

Lui Sha
Real-Time Systems and Scheduling, Cyberphysical Systems, Medical Systems Engineering

Deepak Vasisht
Mobile Computing, Wireless Networking, Internet Of Things, Ubiquitous Computing

Tianyin Xu
Operating Systems, Cloud and Datacenter Systems, System Reliability and Resilience, Large-Scale System Management, Configuration Management, and Reliability Engineering

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

Haitham Al-Hassanieh
Electrical & Computer Engineering
Wireless Networking, Internet-of-Things (IoT), 5G Networks, Algorithms

Michael Bailey
Electrical & Computer Engineering
Security and Availability of Complex Distributed Systems

Nikita Borisov
Electrical & Computer Engineering
Security and Privacy, Distributed Systems

Geir Dullerud
Mechanical Science & Engineering
Networked, Distributed, and Multirate Hybrid Control Systems

Yih-Chun Hu
Electrical & Computer Engineering
Secure Systems and Mobile Communications

Jian Huang
Electrical & Computer Engineering
Computer Systems, Systems Architecture, Systems Security, Memory and Storage Systems

Ravi Iyer
Electrical & Computer Engineering
Reliable and Secure Networks and Systems; Measurement and Modeling; Architectures for Genomic Applications

Radhika Mittal
Electrical & Computer Engineering
Improving Performance and Manageability of Networked Systems

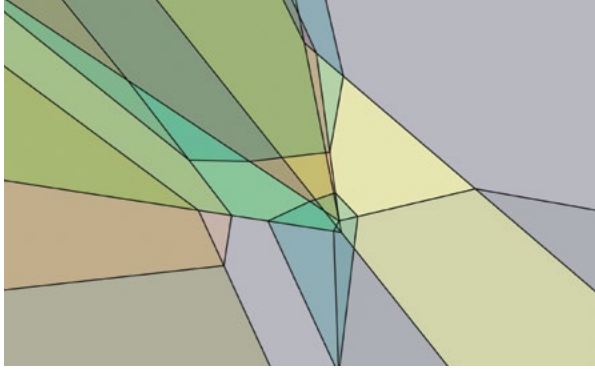
David Nicol
Electrical & Computer Engineering
Security, Privacy, and Information Trust for Computer and Communication Systems

Romit Roy Choudhury
Electrical & Computer Engineering
Wireless Networking, Mobile Computing, Sensing Systems

Professor Klara Nahrstedt and her collaborators won a best paper award at the recent 2020 IEEE International Symposium on Multimedia for their paper, "SEAWARE: Semantic-Award View Prediction System for 360-degree Video Streaming."

Computer Science

THEORY AND ALGORITHMS



Theoretical Computer Science studies the foundations of computing from a rigorous and mathematical point of view. Core topics include models of computing, design and analysis of algorithms, data structures, protocols and mechanisms, and lower bounds. The theory group at University of Illinois grew from traditional strengths in computational geometry to considerably broaden its activities in TCS. The group has also forged strong connections to other areas in Computer Science, and faculty in other departments on campus.

Our faculty study algorithms in several diverse areas (computational geometry & topology, graphs, optimization, approximation, randomization), data structures, cryptography and secure computation, economics and computation, complexity theory, foundations of machine learning, and applications to several areas including operations research, computational biology, parallel & distributed computing, and networking to name a few. Our research, in addition to its fundamental importance, has many near and long-term applications in computer science, operations research, discrete mathematics and beyond.

Strengths and Impact

The core theory group has a long standing and strong presence in algorithms and data structures with a traditional focus in the area of computational geometry. Over the last fifteen years, and more recently, the group has expanded considerably with new faculty in graph algorithms, combinatorial optimization, economics and computation, cryptography and security, complexity theory, and machine learning theory. Several faculty members in the CS department, and several in the Industrial and Enterprise Engineering (ISE) department have strong overlap with TCS (some are CS affiliate faculty). The footprint of the group is broad, deep and growing.

The algorithms group has multiple faculty members in computational geometry and topology, and is one of the strongest in the world. The recent accomplishments in this area include (1) improved data structures for fundamental geometric problems such as nearest neighbors, closest pair, point location, and range searching (2) derandomization of approximate nearest neighbor search in high dimensions (3) improved and fast geometric approximation algorithms in the plane and in low dimensions (4) efficient and fast algorithms for fundamental problems on graphs including shortest paths, flows and cuts on graphs embeddable in low-genus surfaces.

In graph algorithms, combinatorial optimization, and approximation, recent accomplishments include (1) approximation algorithms for disjoint paths and related routing problems, (2) a polynomial bound for the grid-minor theorem that resolved a long-standing open problem in graph theory via algorithmic tools, (3) fast and parallel approximation algorithms for constrained submodular function maximization, (4) near-linear time approximation algorithms for solving LP relaxations of several fundamental problems including the Held-Karp relaxation for Metric-TSP, and (5) first polynomial time randomized and deterministic algorithms for hypergraph k-cut.

In the area of economics and computation, our faculty have resolved fundamental questions on computational aspects of games including lower bounds and algorithms in worst-case and beyond worst-case models. Notable recent results include (1) establishing first polynomial smoothed complexity for a class of games relevant for social networks, (2) first impossibility results under the powerful algorithmic framework of sum-of-squares, (3) the first strongly polynomial-time algorithm for linear exchange markets, and (4) establishing that envy free allocations (up to any item) exist for three agents.

Faculty in the group have made significant contributions to complexity theory, cryptography, and their interaction with other topics including game theory, quantum computing, and fine-grained complexity of algorithms. Some recent highlights include (1) novel pseudorandom generators for space bounded computation that are secure even under an adversarial choice of input ordering, (2) best known deterministic algorithm for zero-testing algebraic expressions that are expressible as a limit of succinctly describable expressions, (3) the feasibility of secure computation over quantum channels under the simple cryptographic assumption that one-way functions exist, (4) proving that finding a Nash equilibrium in two-player zero-sum games is hard under standard cryptographic assumptions, and (5) improved results on the fine-grained complexity of 3SUM, APSP and related problems.

Faculty in operations research have focused on optimal decision-making under uncertainty and computational optimization, with applications in public policy and public health with recent accomplishments include advances in multi-level optimization algorithms for political redistricting and new methods to evaluate gerrymandering.

Machine learning theory faculty are officially part of the AI group but they overlap significantly with the theory group and have made fundamental contributions to deep learning theory via the analysis of gradient descent and its variants, sample complexity bounds for various models in reinforcement learning and online learning just to mention a few.

Collaborative research between two CS faculty, theoretician Dakshita Khurana (left) and AI researcher Sanmi Koyejo (right) earned a grant from C3.ai DTI to focus on federated learning as a way for healthcare systems to use predictive analysis in response to the COVID-19 pandemic.

The group has an outstanding and prolific publication record in the top conferences and journals of TCS. The faculty have received several best paper awards and mentions. Some recent highlights of faculty awards: (1) ACM Fellow (Amato, Chan, Warnow), (2) AAAS Fellow (Jacobson), (3) George E Kimball Medal from INFORMS (Jacobson), (5) David F Baker Distinguished Research Award from Institute of Industrial and Systems Engineering (IISE) (Jacobson), (6) NSF CAREER Award (Garg, Mehta, Solomonik, Telgarsky), and (7) Chairs or Professorships (Chan, Chekuri, Erickson, Jacobson, Warnow).

The group has graduated several doctoral students who have gone onto excellent careers in academia and industrial research. The more recent academic cohort includes: Hsien-chih Chang (Dartmouth), Alina Ene (Boston U, NSF CAREER, Sloan Fellowship), Kyle Fox (UT Dallas, NSF CAREER), Sungjin Im (UC Merced, NSF CAREER), Nirman Kumar (U of Memphis), Hemanta Maji (Purdue), Ben Moseley (CMU, NSF CAREER), Amir Nayyeri (Oregon State U, NSF CAREER), Kent Quanrud (Purdue), Ben Raichel (UT Dallas, NSF CAREER), Jason Sauppe (U Wisconsin at La Crosse).

CS FACULTY AND THEIR RESEARCH INTERESTS

Nancy M. Amato
Geometry, Parallel Algorithms, Computational Biology

Timothy M. Chan
Computational Geometry, Algorithms, Data Structures

Chandra Chekuri
Algorithms, Combinatorial Optimization, Mathematical Programming, Graphs

Payam Delgosha
Graphs, Information Theory, Algorithms, Machine Learning

Mohammed El-Kebir
Combinatorial Optimization, Integer Linear Programming, Computational Biology

Jeff Erickson
Computational Geometry and Topology, Algorithms

Michael A. Forbes
Pseudorandomness, Algebraic Computation, Computational Complexity

Brighten Godfrey
Algorithms for and Analysis of Networks and Distributed Systems

Sariel Har-Peled
Computational Geometry, Geometric Approximation Algorithms

Sheldon Jacobson
Optimization, Operations Research

Nan Jiang
Reinforcement Learning Theory, Machine Learning, Sample Complexity Analysis

Dakshita Khurana
Cryptography, Secure Computation, Zero-Knowledge, Differential Privacy

Ruta Mehta
Algorithmic Game Theory, Mathematical Economics, Efficient Algorithms

Ling Ren
Cryptography, Distributed Algorithms

Edgar Solomonik
Parallel Algorithms, Numerical Methods, Communication Cost Analysis, Quantum Computation

Matus Telgarsky
Machine Learning Theory

Mahesh Viswanathan
Model Checking, Logic, Cyberphysical Systems, Software, Security

Tandy Warnow
Graph Algorithms, Statistical Estimation, Heuristics for NP-Hard Optimization Problems, Experimental Algorithmics, Applications to Grand Challenges in Biology and Historical Linguistics

Han Zhao
Machine Learning, Information Theory, Representation Learning

AFFILIATE FACULTY AND THEIR RESEARCH INTERESTS

Karthik Chandrasekaran
Industrial & Enterprise Systems Engineering
Combinatorial Optimization, Integer Programming, Probabilistic Methods and Analysis, Randomized Algorithms

Jugal Garg
Industrial & Enterprise Systems Engineering
Algorithms, Game Theory, Fair Division

Rakesh Nagi
Industrial & Enterprise Systems Engineering
Social Networks, Graph Algorithms, Applied Operations Research, Discrete Optimization

Yuan Zhou
Industrial & Enterprise Systems Engineering
Maching Learning Theory, Operations Research, Combinatorial Optimization