THE UNIVERSITY OF UTAH
SCHOOL OF COMPUTING

2016 RESEARCH REPORT

THE UNIVERSITY OF UTAH®

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Director, School of Computing: Ross Whitaker
Associate Director, School of Computing: R. Michael Kirby II

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Message from the Director

It's a great time to be a computer scientist — and it's a wonderful time to be a computer scientist in Utah. The world is changing rapidly in so many ways, and a ubiquitous embrace of new computing devices, new software, and new communications infrastructure drives much of that change. As computer scientists, we get to be the leading edge of these changes; we see and appreciate these changes from a unique perspective. Meanwhile, our research expands basic capabilities in diverse fields such as machine learning, networking, security, high performance computing, human computer interaction, etc. It's a very satisfying job.

On the pages that follow you will see great examples of this impact in the form of new projects, centers, papers and awards. We are lucky to have extremely productive faculty and students who are excited about their creative work and these new opportunities. This shows, for example, in the research expenditures and the Ph.D. dissertations. Research expertise and productivity have had significant impacts on our teaching mission. For instance, data science research has dovetailed with new graduate programs and certificates, and research in algorithm bias was featured in this year's Praxis Lab in the Honors College. The relationships between our research and education missions are extensive and rewarding.

We are also very lucky to be in computer science at the University of Utah. There is a unique confluence of the State Legislature, local industry, and state universities. The software and IT industries in the Wasatch Front are booming, and Utah is fast becoming one of a very few information technology states in the U.S. The State Legislature, with the support of local industry, has recognized this opportunity and the growing demand for technology talent. Thus, they have passed the 2017 Engineering Initiative, which will help fuel the growth in our College and our School in the years to come. This means new faculty, new research ideas and initiatives, stronger relationships with our local software and IT industries, and, most importantly, a growing, vibrant, talented student body.

Indeed, it's a great time to be in Utah.

Ross Whitaker
Director, School of Computing

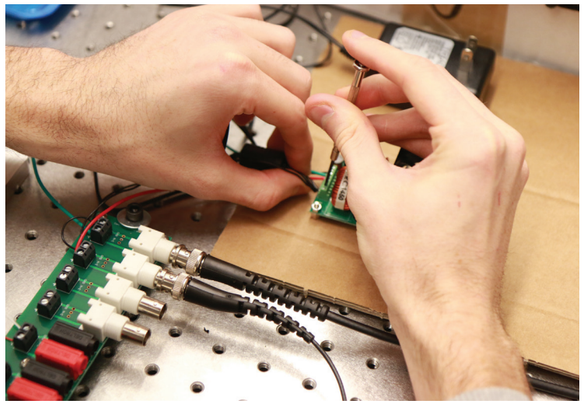
UTAH ROBOTICS CENTER

From the hulking Terminator to the lovable R2-D2, people's notion of what robots are has been shaped mostly by science fiction. But science fact is much different. Robotics can range from sophisticated tools on manufacturing lines to precise machines that perform delicate surgeries.

At the tip of robotics research are faculty members from the University of Utah's Department of Mechanical Engineering and the School of Computing who have been developing the next generation of autonomous machines. Now, their work will be receiving even more recognition in the future — the Utah State Board of Regents has approved the new University of Utah Robotics Center (UURC), the latest addition to the list of research centers for the U's College of Engineering.

"The advantages of this are really about visibility — you might say a sense of identity. It identifies us as a center of excellence as a robotics center in the state of Utah and elsewhere," said School of Computing professor John Hollerbach, co-director of the center and director of the school's robotics track. "It's our hope that our increased visibility with the center translates into higher goals in terms of funding and grants. We also hope it will attract more people, more students, more faculty and visitors."

The center is the consolidation of eight faculty-run labs researching a wide array of fields in robotics including medical robotics, machine learning, autonomous robots, self-driving cars, human motor control, drones, climbing robots, and robot vision. In addition to the individual labs, the center also received two larger lab spaces in the newly-refurbished Rio Tinto Kennecott Mechanical Engineering Building.



Another focus for the lab will be its continued outreach effort, promoting science and math for younger students throughout the state. That includes sponsoring summer computing camps for K-through-12 students as well as helping organize the regional FIRST Robotics and FIRST LEGO League competitions.

The UURC offers a master's degree and Ph.D. in the Robotics Track, a joint program of study. It was the second robotics program ever offered in the U.S. and has five faculty members from the mechanical engineering department and four from the School of Computing.

"The center will not only provide the foundation for the Robotics Track but also allows our research and curriculum to flourish even more," said U mechanical engineering associate professor Mark Minor, co-director of the center. "The center also provides a focal point for youth considering STEM careers."

http://robotics.coe.utah.edu/

SCHOOL OF COMPUTING

DATA GROUP

Research
The School of Computing Data Group's research touches on many areas of data science, ranging from large-scale management, to analysis and fairness issues. The group's strengths are in formalizing and proving key principles of data science and in collaborating on various scientific and engineering tasks involving large data sets.

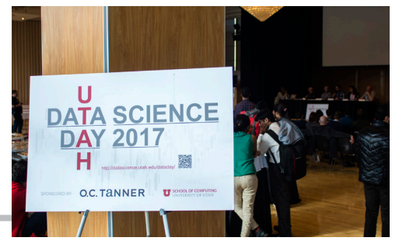
The group works cohesively, publishing at the cross section of data science in top conferences including: SIGMOD, VLDB, SODA, STOC, FOCS, KDD, NIPS and ICML.

Education
There are educational opportunities available for students interested in the areas of data management, data mining and machine learning.

Computing Degree Track - *Data Management and Analysis (MS and PhD)*
In the Data Management and Analysis track, students take advanced courses comprising the modern core of data science: in machine learning, data mining, databases, algorithms, and visualization. They supplement this core with their choice of specialized courses in these areas, hands on projects, and research experiences. Our graduates are in demand in data science and software engineering jobs at top companies in Utah, Silicon Valley, and Seattle.

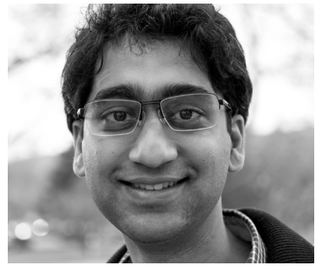
Big Data Certificate
For the Big Data certificate, students take the same core courses with tenure-track professors as the degree programs above. The courses have online lecture notes and streamed videos, making this modern material available to graduate students in non-computing disciplines as well as software engineers and other quants needing to modernize their skills. The hands-on material with a focus on the foundations, provides the students with the skills to evolve with this fast moving field.

Outreach
The Data Group is working to create a collaborative environment across campus. It is increasing its visibility and impact in data science through many research collaborations, weekly seminars, a student-focused data science club, and campus-wide events such as an annual Data Science Day.



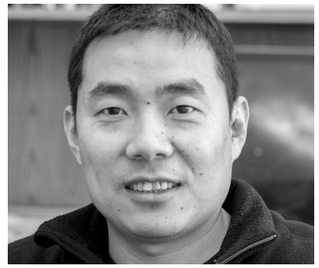
The data group faculty specialize in emerging and classic techniques for exploring and understanding the large and complex data; and it is an exciting time for the students to get involved in data science.

- Bei Wang-Phillips
Assistant Professor



Aditya Bhaskara
Assistant Professor

Theoretical computer science and machine learning. Approximation algorithms, spectral graph theory, algorithms with guarantees for learning problems like mixture models and multi-layer neural nets.



Feifei Li
Associate Professor

Database systems and large-scale data management, systems, and analytics. Security issues in data management and systems.

Jeff Phillips
Assistant Professor

Algorithms for Big Data Analytics: Geometric Data Analysis, Computational Geometry, Handling Uncertainty, Data Mining, Databases, Machine Learning, Computational Statistics.

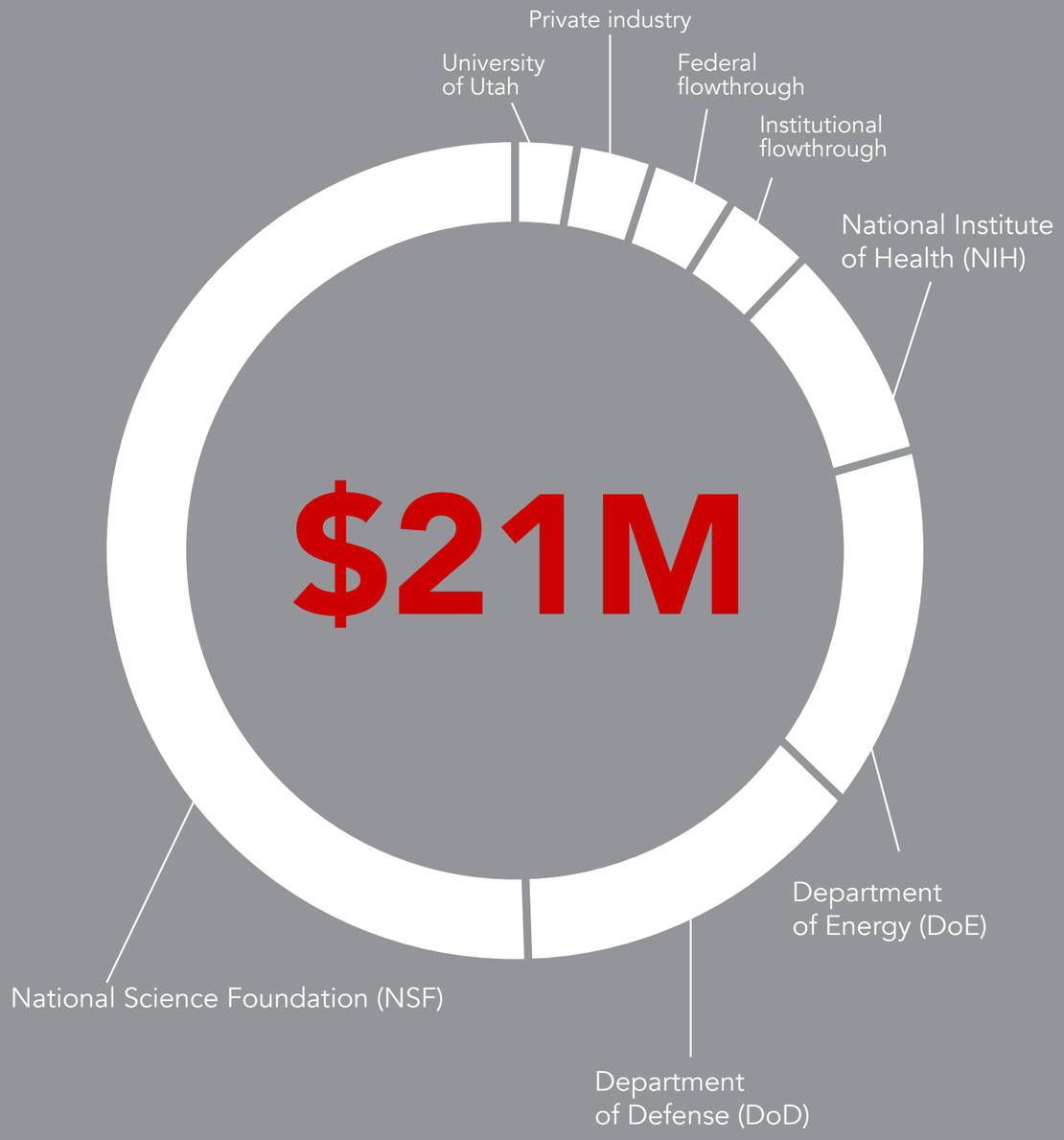
Suresh Venkatasubramanian
Associate Professor

Algorithms and computational geometry, with a current focus on data mining and large-data (and large-dimension) geometric questions.

Bei Wang-Phillips
Assistant Professor

Topological data analysis, scientific visualization, information visualization, computational topology, computational geometry, computational biology and bioinformatics, machine learning, and data mining.

RESEARCH SNAPSHOT



2016 RESEARCH EXPENDITURES

2016 GRANTS

Towards Complexity-Effective Intelligent Prefetchers
PI: Rajeev Balasubramonian
Intel

Neuromorphic Architectures
PI: Rajeev Balasubramonian
University of Utah Seed Grant

Portable Parallelism for Neptune
Martin Berzins and R. Michael Kirby
Engility Corporation

Design Responding to Engineering Analysis in Support of Manufacturing
PI: Elaine Cohen
DARPA

Beyond Diagnostic Classification of Autism
PI: Thomas Fletcher and Bei Wang-Phillips
National Institute of Health

EAGER: Application-Driven Data Precision Selection Methods
PI: Ganesh Gopalakrishnan and Mary Hall
National Science Foundation

Result Variability and Mitigation on OpenMp 4.0 Race-Induced Variability and Compiler-Caused Floating-Point Variability
PI: Ganesh Gopalakrishnan
Department of Energy

Software Infrastructure for Sustained Innovation
PI: Ganesh Gopalakrishnan
National Science Foundation

Autonomous Robot Manipulation of Object Collections
PI: Tucker Hermans
National Science Foundation

Auto-tuning Compiler Technology Across Architecture Transformation and Code Generation
PI: Mary Hall
Department of Energy

Center for Integrative Biomedical Computing
PI: Charles Hansen, Christopher Johnson, Ross Whitaker
National Institute of Health

Openspace: Dynamic Visualization
PI: Charles Hansen
American Museum of Natural History

The Best of Both
PI: R. Michael Kirby
National Science Foundation

Visual Analysis of Large Pat Cohorts
PI: Alexander Lex
Harvard University

Utah DIA
PI: Alexander Lex
Department of Defense

Data Science for Secure and Privacy –Aware Data Management and Mining
PI: Feifei Li
National Science Foundation

III: Small: Towards a Database Engine for Interactive and Online Sampling and Analytics
PI: Feifei Li
National Science Foundation

Storage Access Massive Imagery
PI: Valerio Pascucci
National Science Foundation

Secure and Resilient Architecture: Netsecops – Policy Drive, Knowledge-Centric, Holistic Network Security Operations
PI: Kobus Van der Merwe
National Science Foundation

SafeEdge – Dynamic Public Safety Response through a Municipal Software Definition
PI: Kobus Van der Merwe
National Science Foundation

Algorithmic Fairness: A Systemic and Foundational Treatment of Non-Discriminatory Data Mining
PI: Suresh Venkatasubramanian
National Science Foundation

Visualizing Alma Data Using TDA
PI: Bei Wang-Phillips and Christopher Johnson
National Science Foundation

Topological Data Analysis for Large Network Visualization
PI: Bei Wang-Phillips
National Science Foundation

Cyber-Attack Automated Unconventional Sensor Environment
PI: R. Michael Young
Charles River Analytics

Not a (micro)Second to Lose

Many of today's most interesting services rely on fast access to small pieces of information assembled in real-time; displaying a single Facebook page requires fetching data scattered across hundreds of machines. Making all of this happen in a fraction of a second means each machine involved must process requests for information quickly, and more importantly, predictably. Just one slow response from a single machine can drag down the performance of the whole.

That one slow server is what keeps Ryan Stutsman up at night. Stutsman heads the Scalable Computer Systems Lab at the University of Utah. He and his students are working on systems that spread data over hundreds of machines to provide access to terabytes of information but with access times more than a thousand times faster than conventional data-center storage systems. Stutsman helped engineer a fault-tolerant storage system that provides access to data over a network in just a few microseconds rather than the milliseconds most systems require.

"Lessons from building networks for supercomputers have made their way into conventional systems," says Stutsman. "But, realizing the gains wasn't as simple as plugging in new hardware."

Conventional operating systems evolved in the 1970s, and they aren't designed to provide fast access to hardware devices.

"Software layers built up over the years, which was okay when networks and devices were slow, but we saw software accounting for 90 percent of communication delay," he adds.

When those layers were stripped out, access times improved by nearly ten times.

Now, Stutsman and his team work to rebuild these software layers but retuned for the constants of modern hardware. Those layers are important. Systems need to tolerate loss of network messages and machine failures.

Recently, Stutsman's lab has been working on a new approach to moving data between servers to redistribute load but in a way that leaves the database online and minimizes impact on its ongoing operations.

"Our approach exploits new hardware capabilities of network cards to directly transmit data from database data structures, and it relies on multicore parallelism not just to speed migration but also to hide the performance impact of migration by operating fully in parallel with normal request processing."

Initial results show the approach migrates data nearly ten times faster than existing techniques that use conventional approaches while maintaining tighter worst-case response times.

The group is already applying this approach to other areas as well.

"Our initial success has turned our attention to the bigger question of how database servers should structure their data," Stutsman explains.

Historically, database students are taught to focus on hard disk I/O, but in the applications Stutsman is targeting, disks are largely irrelevant.

"RAM is now so large that the network interface is the primary I/O device the database has to deal with. It only makes sense that the network will begin to shape the layout of database records and how concurrent access to the records is managed," he says.

Stutsman's latest trick is integrating the network device into the way ordered indexes for in-memory databases are updated. Drawing techniques from "lock-free programming," these indexes will allow records to be read and modified even while the network card is transmitting copies of the records itself. The upshot is that nothing ever waits: any operation can be performed at any time regardless of what else is being done to the index. That results in less stalling, which translates to better CPU efficiency, especially for emerging massively multicore systems.

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TENURE-TRACK FACULTY

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LECTURING FACULTY

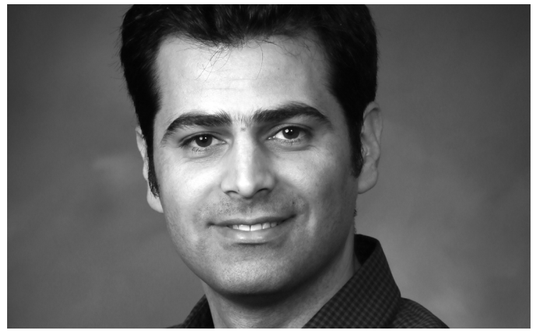
5

RESEARCH FACULTY

http://www.cs.utah.edu/people/faculty/

NEW FACULTY

Aditya Bhaskara, *Assistant Professor*
Aditya received his Ph.D. from Princeton University in 2012 and his undergraduate degree in Computer Science from the Indian Institute of Technology, Bombay. He was a post-doctoral researcher at EPFL, Switzerland and Google Research NYC before joining Utah as faculty. His recent research has been at the intersection of theoretical computer science and machine learning with the goal of designing novel learning algorithms that also come with guarantees.



Mahdi Nazm Bojnordi, *Assistant Professor*
Mahdi earned a bachelor's in computer engineering from Shiraz University in Iran, master's degrees in electrical and computer engineering from the University of Tehran in Iran and the University of Rochester in New York. He received a doctorate in computer architecture at the University of Rochester. His research interests are in computer architecture, new memory technologies, high-performance memory systems, and energy-efficient computing.

Ladislav Kavan, *Assistant Professor*
Ladislav received his bachelor's and master's degrees in mathematics and physics from Charles University in Prague. He then went on to complete his doctorate degree in computer science from Czech Technical University. Ladislav's research focuses on real-time computer graphics, physics-based animation, and geometry processing.

Bei Wang-Phillips, *Assistant Professor*
Bei earned a bachelor's in computer science and mathematics from the University of Bridgeport and a doctorate in computer science from Duke University. Her research is in topological data analysis, scientific visualization, information visualization, computational topology, computational geometry, bioinformatics, machine learning, and data mining.

Jason Wiese, *Assistant Professor*
Jason received a bachelor's in computer science from the University of California, San Diego, and a doctorate in human computer interaction from Carnegie Mellon University. His research is focused on personal data and human-computer interaction.

Michael Young, *Professor*
Michael received his bachelors in computer science at California State University, a master's in computer science at Stanford University and a doctorate in intelligent systems at the University of Pittsburgh. His research is focused on artificial intelligence, video games and interactive narrative.

FACULTY AWARDS

Distinguished Service Award
University of Utah, College of Engineering
David Johnson

Distinguished Alumni Award
University of Utah
Mariah Meyer

Research Highlight Award
ACM SIGMOD
Feifei Li

Pioneer Award in Solid Modeling
Symposium on Geometry Processing
Elaine Cohen

Top Researcher Honoree
University of Utah, College of Engineering
R. Michael Kirby

University of Utah Distinguished Mentor Award

Professor Valerio Pascucci was recipient of the 2016 University Distinguished Mentor award.

The University of Utah Distinguished Mentor Award was established by the Graduate School to honor faculty members who consistently serve as effective mentors of graduate students. The relationship between a graduate student or postdoctoral scholar and their faculty advisor is one that can have a profound, lifelong influence on both parties. The effective mentor serves as advisor, teacher, advocate, sponsor, and role model for students.

Valerio exemplifies each of these areas and is an outstanding researcher and teacher. He creates a supportive environment for students and scholars to take full advantage of academic and professional opportunities. He serves as an advocate for his students and has given countless hours in helping students to successfully complete their degrees.

PAPER AWARDS

Addressing Service Interruptions in Memory with Thread-to-Rank Assignment, *IEEE International Symposium on Performance Analysis of Systems and Software*, ISPASS 2016
Manjunath Shevgoor, **Rajeev Balasubramonian**, Niladrish Chatterjee, Jung-Sik Kim

Memristive Boltzmann Machine: A Hardware Accelerator for Combinatorial Optimization and Deep Learing, *IEEE High Performance Computer Architecture*, HPCA 2016
Mahdi Nazm Bojnordi and Engin Ipek

Memristive Boltzmann Machine: A Hardware Accelerator for Combinatorial Optimization and Deep Learing, *IEEE Micro Top Picks in Computer Architecture 2016*
Mahdi Nazm Bojnordi and Engin Ipek

Making Noise: Using Sound-Art to Explore Technological Fluency, ACM SIGCSE 2016
Erik Brunvand and Nina McCurdy

Demo: Repeatable mobile networking research with PhantomNet, *International Conference on Mobile Computing and Networking (MobiCom) 2016 - MobiCom '16 Best Demo Award*
Junguk Cho, Jonathon Duerig, **Eric Eide,** Binh Nguyen, **Robert Ricci**, Aisha Syed, **Jacobus Van der Merwe,** Kirk Webb, and Gary Wong.

Pathways for Theoretical Advances in Visualization, *IEEE Visualization Conference 2016*
Chris Johnson, Min Chen, Georges Grinstein, Jessie Kennedy, Tamara Munzner, and Melanie Tory
Dynamic Sparse-Matrix Allocation on GPUs, *International SuperComputing*, PRACE-ISC 2016
James King, Thomas Gilray, **Robert M. Kirby** and **Matthew Might**

Wander Join: Online Aggregation via Random Walks, *ACM SIGMOD International Conference on Management of Data*, SIGMOD 2016
Feifei Li, Bin Wu, Ke Yi, Zhuoyue Zhao

ISAAC: A Convolutional Neural Network Accelerator with In-Situ Analog Arithmetic in Crossbars, *ACM/IEEE International Symposium on Computer Architecture*, ISCA 2016
Ali Shafiee, Anirban Nag, Naveen Muralimanohar, **Rajeev Balasubramonian**, John Paul Strachen, Miao Hu, R. Stanely Williams, **Vivek Srikumar**

Critical Point Cancellation in 3D Vector Fields: Robustness and Discussion, *IEEE Pacific Visualization Symposium*, PacificVis 2016
Primoz Skraba, Paul Rosen, **Bei Wang**, Guoning Chen, Harsh Bhatia, **Valerio Pascucci**

Introducing Configuration Management Capabilities into CloudLab Experiments, *International Workshop on Computer and Networking Experimental Research Using Testbeds (CNERT) 2016*
Dmitry Duplyakin and **Robert Ricci**

To Catch a Wireless Thief

We crowdsource for business startups, art projects, inventions, even families in need. So why not ask cellphone users to contribute in helping catch high-tech thieves?

University of Utah School of Computing professor Sneha Kumar Kasera and his team of researchers are tasked with creating a system that allows cellphone and laptop users to help detect and locate someone who is stealing bandwidth on radio frequency waves. The team has received a three-year, $1-million grant from the National Science Foundation (NSF) to devise the system to help tighten security of the nation's radio spectrum, a valuable resource used for satellite communication and for commercial, public safety and military applications.

The problem of stealing radio frequencies for private use — what Kasera calls "unauthorized spectrum use" — is expected to become much more serious when more cellphones, laptops and other mobile devices utilize what's called "software-defined radio" technology, a fast-rising technology in which you can change the functions of a radio device by simply updating its software instead of making more costly hardware changes.

Once more devices turn to this technology for better flexibility, it is likely that hackers then will use it to create software to steal radio bandwidth, or worse, create malware for phones and computers meant to disrupt radio and satellite communications. For example, imagine terrorists using malware to attack software-defined radios that clog up emergency-services radio frequencies in the time of a crisis.

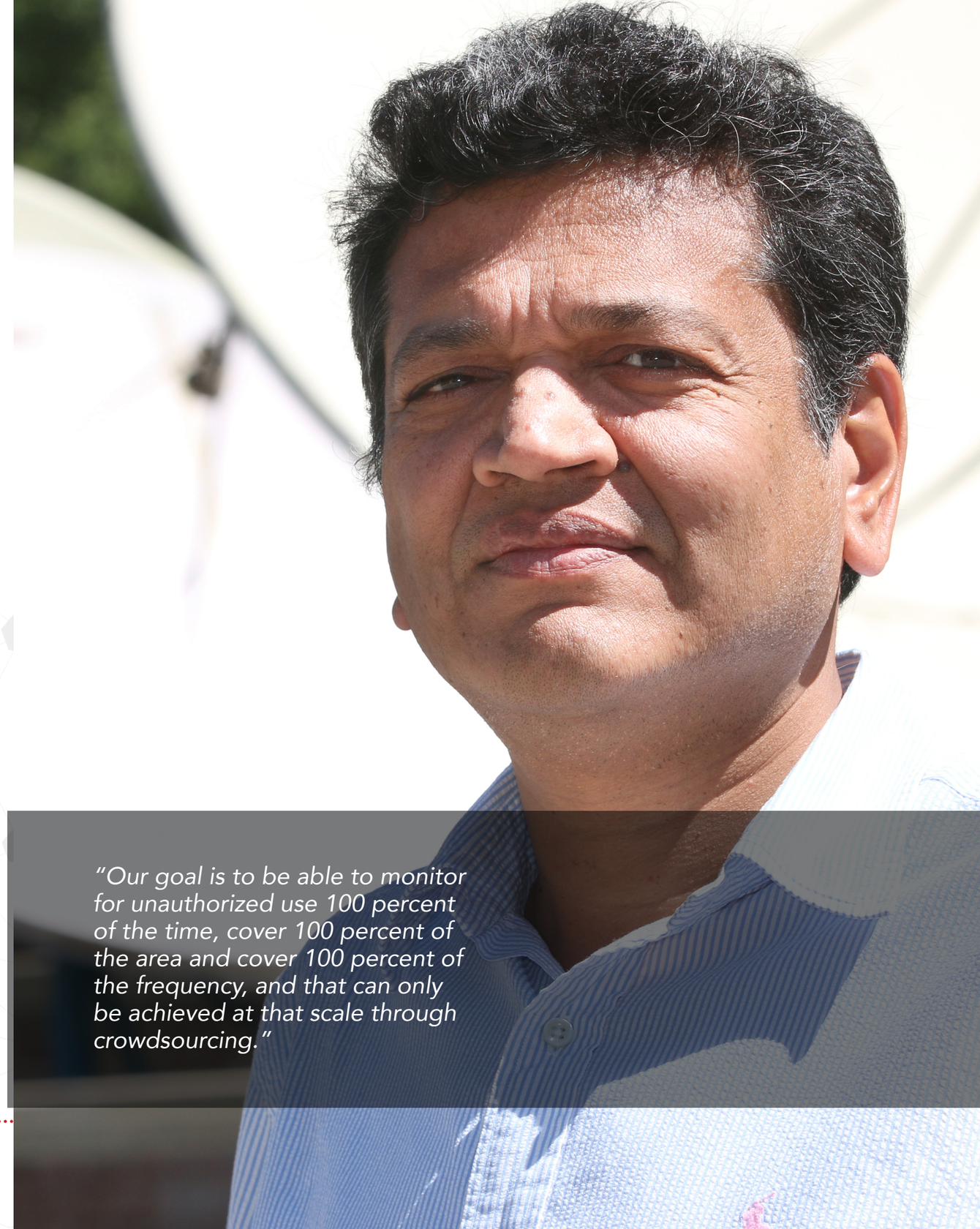
"It's not fully understood yet as to what scale this problem currently exists. But this is in anticipation that with more software-defined radios this will become a much bigger problem," says Kasera.

Kasera has come up with the idea that everyday users of cellphones and laptops could aid authorities in catching these kinds of hackers. He is researching a system in which people could download an app or piece of software for their devices that can detect if an unauthorized radio frequency is being used and where the offender might be located.

All devices with built-in radios can receive signals within a certain frequency range. When someone with a phone or laptop briefly runs Kasera's software, it could tell authorities if a hacker is using unauthorized bandwidth of a certain frequency range and at what strength it's being transmitted. If enough people in the area are simultaneously running the program, the system also could help locate the thief by triangulating the signal.

Currently, the Federal Communications Commission has an enforcement bureau that detects unauthorized use of radio frequencies whenever it receives complaints, Kasera says, but it's an arduous manual process, and they do not have enough resources to cover all areas.

"We thought that there should be a better way of doing this, and then we started thinking of ideas about crowdsourcing," he says. "Our goal is to be able to monitor for unauthorized use 100 percent of the time, cover 100 percent of the area and cover 100 percent of the frequency, and that can only be achieved at that scale through crowdsourcing."



DISSERTATIONS

Ray Tracing From a Data Movement Perspective
Daniel Kopta
Advisor – Erik Brunvand

Bounds for Nearest Neighbor Algorithms and EmbeddingsBOUNDS
Amirali Abdullah
Advisor – Suresh Venkatasubramanian

Designing Novel, Efficient Future Communication Systems Leveraging Network and Application Collaboration
Arijit Banerjee
Advisor – Sneha Kasera

Compiler Optimizations and Autotuning for Stencils and Geometric Multigrid
Protonu Basu
Advisor – Mary Hall

Course Transformation: Content, Structure and Effectiveness Analysis
Linda DuHadway
Advisor – Thomas Henderson

GPU- Enabled Surface Visualization
Mark Kim
Advisor – Charles Hansen

A Scalable and Turnable Adaptive Resolution Parallel I/O Framework
Sidharth Kumar
Advisor – Valerio Pascucci

Enabling Big Memory with Emerging Technologies
Manjunath Shevgoor
Advisor – Rajeev Balasubramonian

Investigating Depth of Field in Volume Rendering, and Distributed Volume Rendering on High Performance Computing Systems
Pascal Grosset
Advisor – Charles Hansen

Image Segmentation with Hierarchical Models
Ting Liu
Advisor – Tolga Tasdizen

Acquiring Knowledge For Affective State Recognition in Social Media
Ashequl Qadir
Advisor – Ellen Riloff

A Composable Framework for Program Analysis
Sriram Aanthakrishnan
Advisor – Ganesh Gopalakrishnan

Dissertation Award

Anand Venkat (Ph.D.'16), a University of Utah computer science graduate, was awarded the College of Engineering Outstanding Dissertation for 2016 for his dissertation entitled "An Integrated Compiler and Runtime Framework for Sparse Matrix Codes." Anand's advisor is Mary Hall.

Anand's breakthrough research has greatly expanded the capability of parallelizing compiler technology for high-performance computing. The results were made available in an open-source format, allowing entire communities of researchers to advance such work.

Anand has published four top-tier papers from his dissertation and was a Best Paper Finalist at the ACM/IEEE International Conference on Supercomputing, Network, Storage and Analysis in 2016. At the time he was nominated, his work had already garnered 73 citations, and this number continues to grow. Anand's research has led to a newly-funded NSF project at the University of Utah that will be the foundation for more dissertation projects.

Anand is now a Research Scientist at Intel Research in Santa Clara, CA where his work will continue to impact the field for many years to come.

Abstractions and Autotuning Techniques for Adaptive Programming
Saurav Muralidharan
Advisor – Mary Hall

An Integrated Compiler and Runtime Framework for Sparse Matrix Codes
Anand Venkat
Advisor – Mary Hall

WPCA: The Wreath Product Cognitive Architecture
Anshul Joshi
Advisor – Thomas Henderson

Surface- Based Image Segmentation Using Application-Specific Priors
Veni Gopalakrishna
Advisor – Ross Whitaker

Reducing Irregularities in Control Flow and Memory Access on GPU Architectures
James King
Advisor – R. Michael Kirby

Towards Building Efficient Error Detectors for Improving System Resilience
Vishal Sharma
Advisor – Ganesh Gopalakrishnan

Kernals and Geometry of Machine Learning
John Moeller
Advisor – Suresh Venkatasubramanian

Efficient Floating-point Error Testing and Rigorous Mixed Precision Tuning
Wei-Fan Chiang
Advisor – Ganesh Gopalakrishnan

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