leveraging the
computational
perspective

Hariri Institute for Computing

Unleashing Computing at BU:
Highlights from 2014

The remarkable and transformational impact of the Hariri Institute for Computing

In less than three years after its April 2012 inauguration, the Hariri Institute for Computing can point to achievements that could not have been imagined a few years ago. This report summarizes some of these achievements.

- Energizing a vibrant community of scholars by connecting junior and senior fellows and by attracting distinguished visiting fellows from academia and industry

- Seeding collaborations that promise to transform entire disciplines, from business to art history, and precision medicine to smart-city applications

- Funding translational research that has led to patent-pending software certification technology and $1M of investments from major research laboratories

> The BU Hariri Institute for Computing "was created to turn a computational lens on an array of disciplines" for a better society.
> - *New York Times*, April 30, 2012

- Leading multi-university collaborations at national scale as exemplified by a $10M NSF Frontier project on cloud cyber security that positions BU as a leader in this critically important area of R&D

- Continuing research funding in excess of $18M for Institute-led projects and in excess of $60M for sponsored research by affiliated faculty for 2014

- Leading BU's Data Science Initiative to strengthen and grow the base of talented faculty who conduct research in data-science

- Hosting BU's Digital Learning Initiative to leverage online educational technologies in a residential setting

- Commanding major media coverage, not only of the research findings of its fellows, but also of the fresh model of academic research that it puts forth

- Incubating a visionary project that has matured in less than three years into a $30M regional initiative anchored at BU to revolutionize both the technology and business of cloud computing

- Exploring new connections by presenting a coherent, integrated view of computing at BU and by connecting researchers and projects with prospective industrial partners both nationally and internationally

Empowering an interdisciplinary community of like-minded scholars

The core work of the Hariri Institute for Computing focuses on people by empowering a community of scholars who advance our collective knowledge, enabled by rapid advances in computational and data- driven techniques. The Institute modus operandi is that innovation happens when people mix and when conversations go beyond disciplinary silos. Creating those connections is a critical function of the Institute and the true catalyst of its success.

To that end, the Institute supports several types of activities, including: seed funding of new, atypical collaborations to pursue computational and data-driven research (e.g., a joint project between faculty in statistics and in political science); hosting seminars and workshops that focus on thematic areas (e.g., computational immunology, information security, and privacy); holding the thought-provoking Wednesdays @Hariri talk series to stimulate discussion about challenges in computational and data-driven research (e.g., privacy and public policy, data journalism, and crowdsourcing); hosting roundtable discussions on broad or deep topics in computational and data-driven research (e.g., educational technology, cyber warfare and international relations, and precision oncology);

hosting forums and hackathons focused on the development of an entrepreneurial culture among students (e.g., Global App Initiative meetings and hackathons).

As of December of 2014, the Institute community consists of over 120 Faculty Affiliates from 41 departments in 11 schools and colleges, including most of the departments in the College of Arts and Sciences, the College of Engineering, and the Questrom School of Business. Such breadth highlights the importance of computing in nearly every research field, and underscores the critical role of the Institute in catalyzing research through the development and application of computational techniques with a wide range of uses. Of this broad base of Institute affiliates, 18 Faculty Fellows are involved more closely with projects pursued at or directly funded by the Institute. The Institute has also created a program to recognize the achievements and accelerate the careers of outstanding junior faculty members, by connecting them with the larger Institute community at BU. Since 2011, 23 Hariri Junior Fellows have been selected for this honor, with a new cohort chosen annually through a competitive nomination process. The Institute also acts as a home base at BU for nine Visiting Fellows and six Postdoctoral Fellows from other academic and industrial institutions who collaborate with the Institute community on specific projects or activities. Last but not least, the Institute also engages Student Fellows at all levels through research experiences and through summer internships at the Institute. The following are few examples of achievements by members of the Institute community in 2014.

- Research by Hariri Fellow John Byers (Computer Science) and Hariri Junior Fellow Giorgos Zervas (Questrom) was prominently featured in a New York Times article on the sharing economy, specifically Airbnb. The research was also featured many other outlets, including The Economist and The Atlantic.

- Research by Hariri Fellow and Microbiology Professor Tom Kepler, in partnership with labs at Duke and Harvard universities, and with NIH support, yielded computational methods to select combinations of immunogens to use in vaccines against HIV, influenza, and anthrax.

- The Hariri-funded Levantine Ceramics portal project by Faculty Fellow, Archeology Professor Andrea Berlin, was credited by the CSA "transforming the discipline," and quoting a scholar's experience with the portal: "I feel like I just spent three days in the future."

- Institute Faculty Fellow and Professor of Renaissance art, Jodi Cranston, and her students developed an interactive guide to the work of the master painter Titan. This Hariri-funded project led to a significant Kress Foundation award to extend this effort.

- Support of Hariri Faculty Fellow and Clinical Professor of Journalism Maggie Mulvihill has led to development of "Storytelling with Data at BU," a hands-on workshop offered through COM that introduces participants to the tools and techniques, increasingly used by data storytellers.

- Institute Director and Professor of Computer Science Azer Bestavros was named Board Member of the Cloud Computing Caucus a non-partisan coalition of stakeholders, focused on raising awareness and educating lawmakers on issues associated with cloud computing.

- Hariri Executive Steering Committee member and Chair of Computer Science Mark Crovella was named BU's 2014 Innovator of the Year for his work in performance evaluation of computer systems, Internet measurement, and network science.

- Institute Faculty Fellow and Director of Reliable Information Systems and Cyber Security Center, Ran Canetti, was named as Fellow of the International Association for Cryptologic Research for numerous contributions to the foundations of cryptography, most importantly the Universal Composability framework.

- Institute Faculty Fellow and Professor of Computer Science, Leonid Levin, was inducted into the American Academy of Arts and Sciences, which enlists leaders from the academic, business, and government sectors to respond to the challenges facing the nation and the world.

- Research by Hariri Junior Fellow and computer science Professor Jonathan Appavoo in collaboration with Boston's Children Hospital has demonstrated the feasibility of interactive supercomputing in the cloud, enabling the first real-time 3D clinical imaging of fetuses using MRI technology.

- Two Hariri Junior Fellows, Assistant Professor of Computer Science Sharon Goldberg and Assistant Professor of Physics Pankaj Mehta were selected as Alfred P. Sloan scholars for 2014, in recognition of distinguished performance and unique potential for advancing their fields.

- Hariri Junior Fellow, Assistant Professor of Physics Pankaj Mehta was named as a Simons Investigator, a prestigious award given only to four researchers throughout the country. He was also named a Scialog Fellow for his "Molecules Come to Life" paper.

- Hariri Junior Fellow and computer science faculty Sharon Goldberg was selected as a member of the US Federal Communications Commission (FCC) working group on Internet security. She is the first and only junior faculty member ever to serve on that influential body.

- Hariri Junior Fellow and Electrical and Computer Engineering faculty Douglas Densmore is one of 81 engineers selected for the National Academy of Engineering's "Frontiers of Engineering" symposium. His work on synthetic biology CAD tools was featured in Discover Magazine "Life as We Grow It" program.

- Hariri Junior Fellow, Assistant Professor of Economics Francesco Decarolis won the NET Institute Award and is one of two junior faculty invited to present their work at the 2014 Annual Meeting of the Toulouse Network for Information Technology at Microsoft Research.

- Hariri Junior Fellow and Questrom Marketing faculty Giorgos Zervas' work on data-driven approaches in marketing was cited by the Wall Street Journal as evidence that Harvard Business School "is Behind in Tech" and that it needs to "hit refresh" and rethink its curriculum.


(Left)The Hariri Institute for Computing participated in RSI, a residential summer program for aspiring high-school juniors worldwide. In summer of 2014, Institute Founding Director, Azer Bestavros, worked with Sally Akkawi, a Lebanese high-school junior from Beirut. Sally, a self-proclaimed "warrior" with a passion for biology, who was funded by the Hariri Foundation, strives to attain a Ph.D. in Cancer Biology.

Incubating transformative projects that leverage major research thrusts at BU

Imagine a world where physicians are able to diagnose a problem with a fetus instantly and on-demand by exploiting 10K CPU cores for one second to process high-throughput MRI imaging. Imagine a world where the next Facebook could grow to massive scale in one day by using a ubiquitous, high-performance computing utility. Imagine a world where our digital communication is secure, our privacy is guaranteed, and our information systems are beyond the reach of hackers, government intrusion, and rogue agents. Imagine a world where sensors all over a smart city stream information into a cloud, enabling a huge marketplace of applications that are available to citizens and businesses alike. Imagine a world where an art historian can instantly identify all the direct and indirect influences of an artist by mining digital humanities artifacts. Imagine a world where personalized educational content and fully-automated, personalized one- on-one assistance is provided to students studying algebra online all over the world. Imagine no more!

While seemingly unrelated, these challenges, all of which are associated with on-going projects by Institute Fellows, are at the nexus of three of today's most important areas of IT research: Cyber

Security, Cloud Computing, and Big Data. These areas are synergistic: Tackling big-data problems require on-demand, high-performance computing at a scale offered only by cloud systems; operating on massive data in the cloud requires sophisticated approaches for cybersecurity and information assurance; and real progress in cybersecurity has become, in part, a big data problem. Below are examples of Institute projects at this nexus, all of which were awarded in 2014.
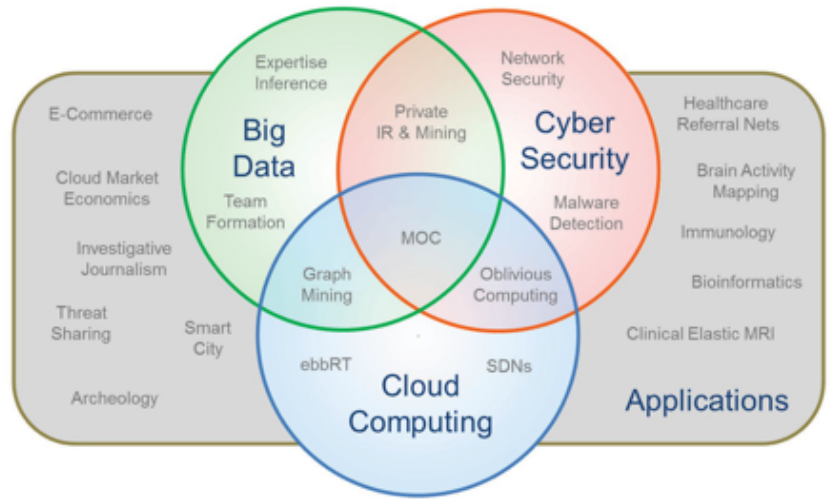
Institute Research Thrusts and Projects

The Massachusetts Open Cloud

Cloud computing has emerged as an important and cost-effective technique for providing computational resources, most often for commercial projects. The speed of this development, coupled with business needs and off-the-shelf technology, has developed a vigorous market, but one that has imposed many limits on applications based on a simplified view of the underlying potential of computing systems. Since its inception and recognizing BU's potential to be a major player in the development of cloud technology, the Hariri Institute for Computing has been investing in projects that both deepen understanding of optimal architectures for cloud systems as well as enable novel uses of cloud computing in research. These investments culminated in the creation of BU's Cloud Computing Initiative (CCI), led by Orran Krieger, a veteran cloud engineer with an accomplished career at IBM and EMC VMware, who came to the Hariri Institute for Computing as a visitor in 2013, and is now leading major CCI projects. One of the first projects of the CCI is the Massachusetts Open Cloud (MOC), which aims to build an open, production-quality cloud computing system that enables research on the computer systems while providing leading-edge services for scientific computing as well. The project has already generated significant interest with a $3M commitment from the state of Massachusetts; and well over $20M of commitments of hardware, software, and direct funding from several industry leaders including Intel, CISCO, Red Hat, Dell, Lenovo, Two-Sigma, Hanscom Air Force Base, among others. Led by BU, the MOC is a collaborative effort that also includes Harvard, MIT, and Northeastern, as well as the Massachusetts Green High-Performance Computing Center. With significant payoff to the public and private sectors, the MOC will be a catalyst for the economic development of business clusters that engage both industrial and academic institutions.
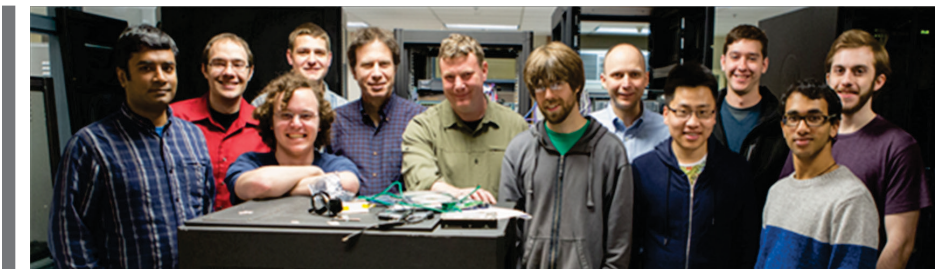
(Left) Members of the MOC team under the leadership of Institute Fellow, ECE Professor of the Practice Orran Krieger who also directs the Institute's Cloud Computing Initiative. The MOC project is supported by $20M from industry by $3M from the Commonwealth.

The SCOPE Big-Data for Smart Cities Project

21st century cities are challenged to respond to increasingly diverse constituent needs, prepare for major environmental changes, improve urban quality of life, and foster economic development in times of resource reductions. At the same time, technology innovations present tremendous opportunities for connecting people with resources, and guiding changes in collective behavior. To that end, SCOPE envisions the development of a Smart-city Cloud-based Open Platform within an Ecosystem that enables stakeholders to collectively harness, learn and innovate from big data by monetizing

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A New Smart–City Cloud Platform in Boston

The project is a collaborative effort to develop cloud-based smart–city services that will improve quality of life for Boston residents.

(Above) Media Coverage of the SCOPE project at the Institute, September 2014.

unused assets, creating new spaces for public policy debate, enhancing quality/equity of services, and developing new ones. SCOPE is led by Institute Director Azer Bestavros, in collaboration with Faculty Fellow Evimaria Terzi (Computer Science), Christos Cassandras (Systems Engineering), and Lucy Hutyra (Earth and Environment). The project entails the design of capabilities that are currently not available in public cloud offerings, enabling the investigators and their collaborators to develop novel smart- city services, including transportation and mobility services to reduce traffic congestion; energy and environmental services that monitor and estimate greenhouse gas emissions for coordination of smart-grid energy demand- response solutions; public safety and security services for big-data-driven coordinated scheduling of public works and municipal repairs; and tools for management of city assets through mining of large data sets. Once developed, SCOPE services will be offered through the MOC. SCOPE is funded by a $1M award from the NSF's Partnership for Innovation program and by funding from industrial partners, including two large businesses (Schneider Electric and International Data Corporation) and three startups. SCOPE has generated significant interest from other prospective partners, e.g., INRIX, Microsoft, and CISCO.

The MACS Cybersecurity Project

The security of computers and networks has grown to be a considerable challenge, not only for computer scientists and engineers, but for anyone who relies on them—that is to say, everyone. Solving these problems is not merely a technical one, but one that involves business leaders, policy-makers, economists, diplomats, and others in a multi-disciplinary approach to ensuring the safety of the information society. These efforts cut across nearly every computational research project today, and security thinking is critical everywhere, but it is unfortunately scarce. Working with faculty at BU and elsewhere, the Institute is actively engaged in shaping new research programs that bring together these diverse areas to create a better understanding of how to protect the information systems that have become so essential to society, as well as how to protect the privacy of individuals as data collection and sharing have become easier and more routine. A good indication of the extent to which the Institute has been successful in cementing BU's presence and leadership in cybersecurity is the recent launch of the Modular Approach to Cloud Security (MACS) project. Announced in June 2014, the National Science Foundation's Secure and Trustworthy Cyberspace (SaTC) program awarded a $10M Frontier grant to BU in support of MACS, which is one of two new national-scale "Frontier" awards by the NSF to support large, multi-institution projects that address grand challenges in cybersecurity science and engineering with the potential for broad economic and scientific impact. Led by Institute Fellow and Director of RISCS (one of the Institute's federated centers), Ran Canetti, MACS aims to develop methods for building information systems with meaningful multi-layered security guarantees. MACS' modular approach aims at systems that are built from smaller and separable functional components, where the security of each component is asserted individually, and where security of the system as a whole can be derived from the security of its components. MACS is a BU-led multi- institutional project that involves leading academics at MIT, Northeastern, and University of Connecticut, and comprises experts in information security, cryptography, and cloud computing.

Seeding New Collaborations

In addition to the major projects described above, the Institute also invests in its fellows and affiliates by selectively seed-funding new collaborations that cross typical disciplinary boundaries and that support ambitious, high-risk, high-reward work.

The process for exploring and developing such projects encourages investigators to involve the Institute in refining their research ideas, suggesting potential collaborations, identifying additional or alternative sources of funding, and finding other creative ways to help support the project. The Institute supports the following sponsored activities from 2014:

- Funded by $50K from the Institute, Hariri Junior Fellows Evimaria Terzi (CS) and Nachiketa Sahoo (Questrom) used data sets of observed teamwork outcomes to identify individual expertise and to study various algorithms for effective team formation.

- Funded by $60K from the Institute (matched with $80K from RISCS), Junior Fellow Sharon Goldberg (CS) and Leonid Reyzin (CS) organized the Privacy Year at BU by bringing leading data privacy scholars Kobbi Nissim, Sofya Raskhodnikova, and Adam Smith to BU, making it a hub of activities, leading to new collaborations, major research outcomes, and media coverage.

- Funded by $30K from the Institute (matched by $30K from Questrom), Junior Fellow Ben Lubin (Questrom, IS) and Keith Ericson (Questrom, Marketing) are combining algorithm design, data analytics, and economic models to study the network structure of physician referral patterns, especially in relation to patient outcomes, using unique healthcare insurance claim data.

- Funded by $71K from the Institute, Faculty Fellow James Galagan (Biomedical Engineering and Microbiology) is developing predictive computational models of the complete regulatory and metabolic networks of the Tuberculosis Mycobacterium to accelerate the discovery of potential drug targets, effectors of host-pathogen interactions, and key regulators of pathogenesis.

> Working at the Institute has resulted in some of the best experiences I have had since coming to BU. In hindsight our project feels very organic, though it is unlikely that it would have come about without the Institute's support.
> Dino Christenson, Hariri Junior Fellow
> Assistant Professor of Political Science

Developing Unique Resources

Recognizing that the quality of research and the potential impact of research outcomes are both highly dependent (and increasingly so) on the development of quality software artifacts, the Institute launched its Software and Application Innovation Lab (SAIL) to provide essential software development capacity in support of the computational and data-driven projects at BU. Funded initially by the Paul Maritz initial gift of $300K, SAIL consists of a core team (currently two) of professional software architects and developers who are assigned to work directly with faculty members (and their research teams) on specific projects. Depending on the nature and scale of these projects, the extent of SAIL assignments varies from weeks to months. When appropriate, SAIL will act as the clearing house for software developed by students, thus leveraging the untapped software development capacity of undergraduate and graduate students at BU and providing much-needed professional training to students. The SAIL team is envisioned to grow significantly using funding from sponsored research projects with minimal institutional support.

Looking Forward

Computational and data-driven approaches are sweeping over every area of research at BU. While traditionally computational fields (such as physics, chemistry, and biology) have been applying these approaches for decades, others (such as precision medicine, marketing, and political science) have barely scratched the surface. In all cases, the sheer amount and type of data available is increasing at a ferocious rate. The critical resource for continued progress, then, is a growing cadre of scientists who think computationally, and who can apply a growing body of analytical techniques in solving hard research problems. For the next few years, through the Data Science Initiative (DSI), the Institute will purposefully target its resources for developing the environment that supports DSI scientists – both currently at BU and to be recruited through DSI, giving the Institute an unparalleled opportunity to affect the productivity of all manner of scientific research at BU.

For more information, please contact

Azer Bestavros, *Professor of Computer Science and Founding Director*
best@bu.edu
617-353-9726

Linda Grosser, *Director of Program and Project Development*
lgrosser@bu.edu
617-358-6695

BU Rafik B. Hariri Institute for
Computing and Computational Science & Engineering
111 Cummington Mall, Boston, MA 02215