Saturday, November 22, 2014
Institute for Advanced Study
Wolfensohn Hall
9:00 a.m. - 6:00 p.m.

On the Sciences
Lens of Computation
Lens of Computation on the Sciences

The Theory of Computation (ToC) is the study of the mathematical foundations of computer science and technology. In the first few decades of its existence, it has dealt mainly with developing the models of a variety of computational devices, and studying their power and limits to solve natural computational problems. It developed algorithms and analysis tools for them, as well as ways of arguing hardness. ToC played a crucial role in developing such fields as cryptography (enabling the Internet and E-commerce) and machine learning (enabling “Big Data” applications). As computers became essential to all sciences, many algorithms were developed to serve the needs of scientists and mathematicians, with von Neumann’s early work on weather prediction and the Human Genome Project as examples of numerous such works.

In the past few decades, the connections and interactions of ToC with the sciences deepened considerably. It was recognized that many natural processes may be viewed as information processes. These include the activities inside a living cell and immune system, the evolution of quantum systems, flocking of birds, formation of communities and influence on the Internet, and numerous others. As information processes, their computational modeling and the study of how efficiently resources are utilized can be naturally captured by the vocabulary and methods of ToC. Interactions with biologists, physicists, economists, and social scientists have found that this computational lens on processes and algorithms occurring in nature sheds new light on old scientific problems in understanding, e.g., evolution and markets. At the same time, what nature does suggests new computational models that may become part of computer technology.

This workshop on the computational lens, organized by Avi Wigderson, Herbert H. Maass Professor in the School of Mathematics, will highlight the state-of-art and future challenges of some of these exciting interactions.

Saturday, November 22, 2014

9:00 am Continental Breakfast and Registration, Fuld Hall
10:00 am Welcome
Robbert Dijkgraaf, Director and Leon Levy Professor Institute for Advanced Study
Opening Remarks and Introduction of Biology Session
Avi Wigderson, Herbert H. Maass Professor Institute for Advanced Study
Leslie Valiant
Harvard University
The Computational Universe

11:15 am Coffee Break, Fuld Hall and Wolfensohn Hall
11:45 am Introduction of Economics Session
Tim Roughgarden
Stanford University
Theoretical Computer Science and Economics

1:00 pm Lunch, Simons Hall

2:30 pm Introduction of Social Science Session
Jon Kleinberg
Cornell University
Computational Phenomena in Social Interaction

3:30 pm Coffee Break, Fuld Hall and Wolfensohn Hall

4:00 pm Introduction of Physics Session
Scott Aaronson
Massachusetts Institute of Technology
Computational Phenomena in Physics

5:00 pm Reception, Simons Hall
The idea that computation has its own laws and limitations emerged in the 1930s. Some of the early computing pioneers, most notably Turing and von Neumann, already understood that this idea had far reaching implications beyond technology. It offered a new way of looking at the world, in terms of computational processes. Turing and von Neumann themselves pursued this perspective in such areas as genetics, biological development, cognition, and the brain. There has been much progress in the intervening years in understanding computation. The question that arises for our generation is how to exploit this increasing knowledge to obtain insights into the natural world that cannot be obtained otherwise. Valiant will focus on biological evolution approached from this standpoint. The scientific question is to determine the molecular mechanism of biological evolution, to a level of specificity that it can be simulated by computer, and to understand why this mechanism can do the remarkable things that it has done within the time that has been available. The talk will explore the tools needed to approach this come from machine learning, the field that studies how mechanisms that achieve complex functionality can arise by a process of adaptation rather than design.

Leslie Valiant is the T. Jefferson Coolidge Professor of Computer Science and Applied Mathematics in the School of Engineering and Applied Sciences at Harvard University. Valiant received his Ph.D. from Warwick University in 1974. Valiant’s work has ranged over several areas of theoretical computer science, particularly complexity theory, learning, and parallel computation. He also has interests in computational neuroscience, evolution, and artificial intelligence and is the author of two books, Circuits of the Mind (Oxford University Press, 1994) and Probably Approximately Correct (Basic Books, 2013). Valiant received the Nevanlinna Prize, the Knuth Award, the European Association for Theoretical Computer Science EATCS Award, and the A. M. Turing Award. He is a Fellow of the Royal Society and a member of the National Academy of Sciences. http://people.seas.harvard.edu/~valiant/

Jon Kleinberg. Cornell University

Computational Phenomena in Social Interaction

With an increasing amount of social interaction taking place in the digital domain, and often in public online settings, we are that were once essentially invisible to us: the collective behavior

Tim Roughgarden, Stanford University

Theoretical Computer Science and Economics

Theoretical computer science offers a number of tools to reason about economic problems in novel ways. For example, complexity theory sheds new light on the “bounded rationality” of decision-makers. Approximation guarantees, originally developed to analyze heuristics, can be usefully applied to Nash equilibria. Computationally efficient algorithms are an essential ingredient to modern, large-scale auction designs. Roughgarden will survey the key ideas behind these connections and their implications.

Tim Roughgarden is an Associate Professor of Computer Science and (by courtesy) Management Science and Engineering at Stanford University, where he holds the Chambers Faculty Scholar development chair. Roughgarden received his Ph.D. from Cornell University in 2002. His research interests lie on the interface of computer science and game theory, and he is currently investigating a wide range of game-theoretic issues in networks and auctions. For his research, he has been awarded the ACM Grace Murray Hopper Award, the Presidential Early Career Award for Scientists and Engineers (PECASE), the Shapley Lecturership of the Game Theory Society, a Sloan Fellowship, INFORM’s Optimization Prize for Young Researchers, the Mathematical Programming Society’s Tucker Prize, and the Gödel Prize. http://theory.stanford.edu/~tim/
and social interactions of hundreds of millions of people, recorded at unprecedented levels of scale and resolution. Modeling and analyzing these phenomena computationally offers new insights into the design of online applications, as well as new perspectives on fundamental questions in the social sciences. Kleinberg will review some of the basic issues around these developments; these include the problem of designing information systems in the presence of complex social feedback effects, the opportunity to develop and refine rich computational models of complex social phenomena, and the emergence of a growing research interface between computing and the social sciences, facilitated by these new forms of data and new computational models.

Jon Kleinberg is the Tisch University Professor in the Departments of Computer Science and Information Science at Cornell University. Kleinberg received his Ph.D. from the Massachusetts Institute of Technology in 1996. His research focuses on algorithmic issues at the interface of networks and information, with an emphasis on the social and information networks that underpin the Web and other online media. Kleinberg is also the recipient of research fellowships from the MacArthur, Packard, Simons, and Sloan Foundations, as well as awards including the Nevanlinna Prize, Harvey Prize, and ACM-Infosys Foundation Award in the Computing Sciences. He is a member of the National Academy of Sciences, the National Academy of Engineering, and the American Academy of Arts and Sciences. http://www.cs.cornell.edu/home/kleinber/

Scott Aaronson, Massachusetts Institute of Technology

Computational Phenomena in Physics

Scott Aaronson will discuss the quest to understand the limits of efficient computation in the physical universe, and how that quest has been giving us new insights into physics over the last two decades. He will explore the following questions: Can scalable quantum computers be built? Can they teach us anything new about physics? Is there some new physical principle that explains why they cannot be built? What would quantum computers be good for? Can quantum computing help us resolve which interpretation of quantum mechanics is the right one? Which systems in nature can be universal computers, and which cannot? Aaronson will end by describing a striking recent application of computational complexity theory to the black hole information loss problem.

Scott Aaronson is an Associate Professor of Electrical Engineering and Computer Science at the Massachusetts Institute of Technology. Aaronson earned his Ph.D. at the University of California, Berkeley, in 2004. His research focuses on the capabilities and limits of quantum computers, and more generally on computational complexity and its relationship to physics. Cambridge University Press published his first book, Quantum Computing Since Democritus, in 2013. Aaronson has written about quantum computing for Scientific American and the New York Times, and writes a popular blog www.scottaaronson.com/blog. He's received the National Science Foundation's Alan T. Waterman Award, the United States PECASE Award, and MIT's Junior Bose Award for Excellence in Teaching. http://www.csail.mit.edu/user/1324

Avi Wigderson, Institute for Advanced Study

Avi Wigderson is the Herbert H. Maass Professor in the School of Mathematics at the Institute for Advanced Study. Wigderson earned his Ph.D. from Princeton University in 1983. His research covers many aspects of computational complexity theory and its interactions with mathematics, including randomness and pseudorandomness; algorithms and optimization; circuit and proof complexity; quantum computation and communication; and cryptography. Wigderson has received many awards for his work in the field including the Gödel Prize, Conant Prize, and Nevanlinna Prize. He is also a member of the American Academy of Arts and Sciences and the National Academy of Science. http://www.math.ias.edu/avi/home