A Santa Fe Institute workshop funded by the Miller Omega Program

LIMITS: THE ROLE OF COLLECTIVE EFFECTS IN INDIVIDUAL &TEAM PERFORMANCE

JUNE 25–27, 2018 • SANTA FE, NEW MEXICO • SANTA FE INSTITUTE

Organized by Jessica Flack & John Krakauer

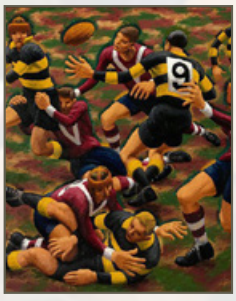
PARTICIPANTS

BRYAN DANIELS
Arizona State University

Bryan Daniels investigates collective behavior in living systems by integrating empirical data with concepts and methods from statistical physics, dynamical systems, and model selection. Across a diverse set of disciplines—neuroscience, animal behavior, cell biology—he works to extract the computational logic of adaptive collective systems. Bryan is currently an Assistant Research Professor in the ASU–SFI Center for Biosocial Complex Systems, a joint venture between Arizona State University and the Santa Fe Institute.

CATERINA DE BACCO
Max Planck Institute for Intelligent Systems

Caterina De Bacco obtained a degree in physics at University of Padova and a PhD in statistical physics at Universitè Paris Sud 11 in 2015, advised by Silvio Franz and Satya Majumdar. She spent two years as a postdoctoral fellow at the Santa Fe Institute, working with Cris Moore, and then at Columbia Data Science Institute working with David Blei. Beginning July 2018, Caterina will be an Independent Research Group Leader at Cyber Valley, Max Planck Institute for Intelligent Systems in Tubingen, Germany. She has played and studied soccer since she was little and is currently collaborating with a professional soccer team to develop machine learning models to analyze soccer data.



PAUL DITURO
US Military

Paul Dituro has a BS in astrophysics from Villanova, looking for extrasolar planets, and an MS in high -energy particle physics, looking for trileptonic Higgs breaking in the supersymmetric model at Fermilab. He has also spent 15 years in Special Operations.

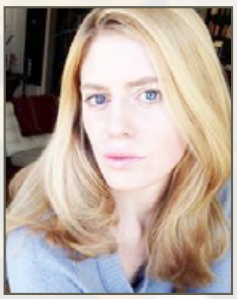
JENNIFER DUNNE
Santa Fe Institute

Vice President for Science at the Santa Fe Institute, Jennifer Dunne has been on the faculty since 2007. She received an A.B. from Harvard where she studied philosophy, an M.A. in ecology and systematic biology from San Francisco State University, a Ph.D. in energy and resources from UC Berkeley, and an NSF Postdoctoral Fellowship in biological informatics. Jennifer's research interests are in analysis, modeling, and theory related to the organization, dynamics, and function of ecosystems. Much of this work focuses on ecological networks, in particular, food webs which specify the complex feeding interactions among species in a given habitat. Food webs provide a way to track and quantify the flows of energy and resources in ecosystems and thus play a central role in ecological and evolutionary dynamics. Drawing on cross-system analysis and computational modeling, Jennifer and her collaborators seek to identify fundamental patterns and principles of ecological network structure and dynamics at multiple spatial and temporal scales. Such research provides a powerful framework for understanding the coexistence of species and the robustness, persistence, and stability of ecosystems, including how humans fit into and impact ancient, historic, and current ecosystems around the world.

BRIAN FERGUSON
Arena Labs

Brian Ferguson has spent a career exploring the edges of human performance. Much of his early work was in national security, both as a civilian and in uniform. Aside from contributions at the tactical level, he built several entities to advance cognitive and physical performance for military operators. He is now the CEO of Arena Labs, a collaboration of professionals who have worked in high-stress environments ranging from the military and aviation to the creative arts and elite athletics. Arena Labs works primarily with surgical teams in "High Performance Medicine" to focus on how principles of high-per-

forming cultures can be combined with emerging technology for improving health care outcomes. By applying models of performance from sports, the creative arts, and unique military organizations, Arena Labs explores opportunities around human-machine interface, monitoring stress in the operating room, or using 360-degree cameras for immersive learning. Brian received an MSc from The London School of Economics and is an alumnus of the Santa Fe Institute's summer program.



JESSICA FLACK
Santa Fe Institute

Jessica Flack is a professor at the Santa Fe Institute and director of SFI's Collective Computation Group (C4). The focus of Flack's research program is a theory for how adaptive systems collectively compute. Research in C4 draws on evolutionary theory, cognitive neuroscience and behavior, statistical mechanics, information theory, dynamical systems, and theoretical computer science to study the roles of information processing and collective computation in the emergence of robust structure and function in biological and social systems. Goals include identifying the computational principles that allow nature to overcome subjectivity due to information processing to produce ordered states and understanding why adaptive systems typically have many space and time scales. A central idea is that noisy information processors construct their macroscopic worlds through collective coarse-graining in evolutionary and/or learning time. In other words, how the appropriate aggregation of information from individuals making decisions under uncertainty can produce good collective forecasts. Flack was previously founding director of University of Wisconsin-Madison's Center for Complexity and Collective Computation in the Wisconsin Institutes for Discovery. Flack's work has been covered by scientists and science journalists in many publications and media outlets, including the BBC, NPR, *Nature*, *Science*, *The Economist*, *New Scientist*, *Current Biology*, *The Atlantic*, and *Quanta Magazine*. Flack loves sports.

SIMON GARNIER
The Swarm Lab, New Jersey Institute of Technology

Simon Garnier is an assistant professor in the Federated Department of Biological Sciences at the New Jersey Institute of Technology. He is the head of the Swarm Lab, an interdisciplinary research lab that studies the mechanisms underlying collective behaviors and swarm intelligence in natural and artificial systems. His lab works toward 'reverse engineering' these mechanisms in systems as diverse as slime mold, ant colonies, goat and sheep herds, baboon troops, and human groups. Simon Garnier's goal is to understand the origin and development of these collective behaviors, to measure their efficiency and adaptability, and to determine the conditions of their success and failure. He also translates these findings into the language of applied sciences, where they might serve to design new solutions to human-related and societal issues.

ALEX HUTCHINSON
Author and journalist

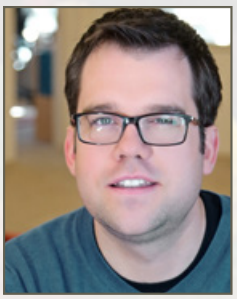
Alex Hutchinson's primary focus these days is the science of endurance and fitness, which he covers for *Outside* (where he's a contributing editor and author of the "Sweat Science" column), *The Globe and Mail* (where he writes the "Jockology" column), and *Canadian Running* magazine. He has also covered technology for *Popular Mechanics*, where he earned a National Magazine Award for his energy reporting, and adventure travel for *The New York Times*, and was a *Runner's World* columnist from 2012 to 2017. His books include *Endure: Mind, Body, and the Curiously Elastic Limits of Human Performance*, *Which Comes First, Cardio or Weights? Fitness Myths, Training Truths, and Other Surprising Discoveries from the Science of Exercise*, and *Big Ideas: 100 Modern Inventions That Have Transformed Our World*.

Alex has a Ph.D. in physics from the University of Cambridge and was a postdoctoral researcher with the U.S. National Security Agency, working on quantum computing and nanomechanics. During that time, he competed as a middle- and long-distance runner for the Canadian national team. He still runs most days, enjoys the rigors of hard training, and occasionally races—but hates to think how he'd do on an undergraduate physics exam. He is based in Toronto.

MICHAEL JOYNER
Mayo Clinic

Michael J. Joyner is a physician-researcher and one of the world's leading experts on human performance and exercise physiology. Using humans as his model system, he has made major contributions to understanding muscle and skin blood flow, blood pressure regulation, and human athletic performance. His ideas about human performance are widely quoted in both the popular media and scientific publications.

Mike has been a consultant to the National Institutes of Health (NIH) and NASA. His research lab at Mayo Clinic has been continuously funded by the NIH since 1993. Mayo Clinic named him a Distinguished Investigator in 2010. He is an entertaining lecturer and has a keen interest in how new ideas emerge, fade and then re-emerge in physiology. In addition, he is a forceful advocate for the increased relevance of physiology in a scientific landscape currently dominated by reductionism.

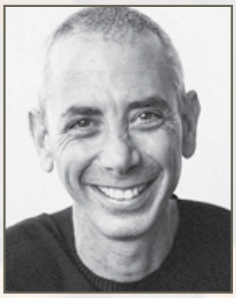


CHRIS KEMPES
Santa Fe Institute

Chris Kempes is a professor at SFI. His goal, in the broadest terms, is to find theories and principles that apply to a wide range of biological scales and hierarchies. Chris generally focuses his work on biological architecture—which may include phenomena ranging from explicit biological morphology to metabolic and genetic network structure—as an intermediate between organism physiology and environmental conditions. Mathematical and physical theories lie at the heart of his methodologies to predict how evolution has shaped architecture and how this, in turn, forms a foundation for reliable predictions of environmental response and interaction. Chris's work spans the scales of genetic information architecture to the morphology of microbial individuals and communities to the regional variation of plant traits and their feedback with climate and available resources. He aims to connect these first-order trends to the limitations imposed by environments in order to predict specific evolutionary events and consequences. Several collaborations with experimentalists and theorists have led to models that inform experiments and assimilate empirical data in fields including single-cell experimental biology and forest dynamics. For example, Chris's work on trees has applied a theory of plant architecture to derive individual physiology, interactions with the environment, and the unique whole forest structure of specific regions. This is theory that goes from individual branches to planetary-scale energy balance, but does so in a way that uses a small set of common principles and assumptions.

MATT KOEHLER
The MITRE Corporation

Matt Koehler is the Applied Complexity Sciences Area Lead in the Information Discovery and Understanding Department at The MITRE Corporation. Before joining MITRE, Matt was a Presidential Management Fellow at the Center for Army Analysis. Matt holds an AB in Anthropology from Kenyon College, a MPA from Indiana University, and a JD from George Washington University, and a PhD in Computational Social Science from the Krasnow Institute for Advanced Study's Department of Computational Social Science at George Mason University. Matt is an alum of SFI's Complex Systems Summer School.



STEVEN KOTLER
Author

New York Times bestselling author Steven Kotler is a an award-winning journalist, and the cofounder and director of research for the Flow Genome Project. He is the author of several books, including *Stealing Fire, The Rise of Superman, Tomorrowland, Bold, Abundance, West of Jesus, A Small Furry Prayer* and *The Angle Quickest for Flight*. His writing has been translated into over 40 languages, and has been nominated for two Pulitzer Prizes and appeared in over 100 publications, including *The New York Times, Atlantic Monthly, Wall Street Journal, Forbes, Wired* and *TIME*. Alongside his wife, author Joy Nicholson, Kotler is also the co-founder of the Rancho de Chihuahua dog sanctuary.

DAVID KRAKAUER
Santa Fe Institute

President and William H. Miller Professor of Complex Systems at the Santa Fe Institute, David Krakauer's research explores the evolution of intelligence on Earth. This includes studying the evolution of genetic, neural, linguistic, social, and cultural mechanisms supporting memory and information processing, and exploring their generalities. At each level Krakauer asks how information is acquired, stored, transmitted, robustly encoded, and processed. This work is undertaken through the use of empirically supported computational and mathematical models.

Krakauer served as the founding director of the Wisconsin Institute for Discovery, the co-director of the Collective Computation Group (C4), and was professor of mathematical genetics at the University of Wisconsin, Madison. He has previously served as chair of faculty, resident professor, and external professor at SFI. In 2012 he was included in the *Wired* Magazine Smart List as one of 50 people "who will change the world." In 2016 he was included in *Entrepreneur* Magazine's Visionary Leaders Advancing Global Research and Business.

JOHN KRAKAUER
Johns Hopkins University School of Medicine

Dr. Krakauer is currently John C. Malone Professor of Neurology, Neuroscience, and Physical Medicine and Rehabilitation, and Director of the Brain, Learning, Animation, and Movement Lab at The Johns Hopkins University School of Medicine. Dr. Krakauer is also co-founder of the of the creative engineering Hopkins-based project named KATA, which is predicated on the idea that animal movement based on real physics is highly pleasurable and that this pleasure is hugely heightened when the animal movement is under the control of our own movements. Dr. Krakauer's book, *Broken Movement: The Neurobiology of Motor Recovery after Stroke* has recently been published by the MIT Press.

EDDIE LEE
Cornell University and Santa Fe Institute

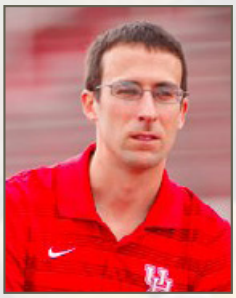
Eddie Lee works at the intersection of physics and society—using physics models, ideas, and intuitions to look for general principles in human behavior. In particular, he is interested in harnessing the tools of statistical physics to investigate universal behavior in conflict and decision-making across humans and animals. He has worked on voting in the US Supreme Court, conflict in a society of pigtailed macaques, and models for how avalanches spread. His current projects include sychronization of human motion, Supreme Court voting across time, parallels between human and primate conflict, and making maximum entropy methods more widely accessible.

Eddie is a PhD candidate in physics and information science at Cornell University, working with Paul Ginsparg. He graduated from Princeton University with an AB in physics and a certificate in biophysics, and received an MA in physics from Cornell University. Previously, he was at the Center for Complexity & Collective Computation (C4) at the Wisconsin Institute for Discovery and in the Lewis-Sigler Institute for Integrative Genomics in the Biophysics Theory Group.

Eddie also breakdances with Absolute Zero, the breakdancing crew at Cornell.

CRISTINE LEGARE
The University of Texas at Austin

Cristine Legare is an associate professor of psychology and the director of the Evolution, Variation, and Ontogeny of Learning Laboratory at The University of Texas at Austin. Her research examines how the human mind enables us to learn, create, and transmit culture. She conducts comparisons across age, culture, and species to address fundamental questions about cognitive and cultural evolution.



STEVE MAGNESS
Performance coach, author, and lecturer

Steve Magness currently serves as a coach to almost 20 professional runners and is the head cross country coach at the University of Houston and a lecturer on strength and conditioning at St. Mary's University, UK. In addition, he has served a consultant or executive coach to high performers in a variety of business fields. He just published his second book, *Peak Performance*, with co-author Brad Stulberg, about performance across domains. His first book, *The Science of Running*, was an Amazon Top 100 bestseller. He got his start in writing as a columnist for *Running Times Magazine*. Additionally, his work has appeared in *Wired, New York Magazine, Sports Illustrated, Runner's World, Outside Magazine, Meter Magazine, New Studies in Athletics*, and *the International Journal of Athletic Training & Therapy*. As an expert, Magness has been featured in articles in *The New Yorker, Wired, Runner's World, Outside, The Wall Street Journal, The New York Times, National Geographic* and *ESPN the Magazine* and on TV for the BBC, CNN, BeIN Sport. As a consultant, Magness has worked with a variety of businesses, executives, entrepeneurs, and athletes and has served as advisor to tech startups. Finally, as a runner, Magness ran a mile in 4:01 in high school, which ranked him #1 in the US and #3 in the world as a high school athlete. He went on to compete at both Rice University and the University of Houston, reaching Academic All-American status and qualifying for the NCAA National Championships.

JEAN-PHILIPPE MAGUÉ
ENS de Lyon

Jean-Philippe Magué is an assistant professor in linguistics at the ENS de Lyon and a member of the Interactions-Corpus-Apprentissages-Representations lab. The ICAR laboratory is characterized by its multidisciplinary scientific activities focused on the multidimensional analysis of the use of language for interaction, captured and understood in a large body of interactive oral and textual data.

CADE MASSEY
The Wharton School

Cade Massey is a practice professor in the Wharton School's Operations, Information and Decisions Department. He received his PhD from the University of Chicago and taught at Duke University and Yale University before moving to Penn in 2012. Massey's research focuses on judgment under uncertainty—how, and how well, people predict what will happen in the future. His work draws on experimental and "real world" data such as employee stock options, 401k savings, the National Football League draft, and graduate school admissions. His research has led to long-time collaborations with Google, Merck, and multiple professional sports franchises. Massey is faculty co-director of Wharton People Analytics, co-host of "Wharton Moneyball" on SiriusXM Business Radio, and co-creator of the Massey-Peabody NFL Power Rankings for the *Wall Street Journal* and *Washington Post.* He is originally from San Angelo, Texas, and now lives in Bucks County, Pennsylvania.

BRICE MÉNARD
Johns Hopkins University

Brice Ménard joined the faculty at Johns Hopkins in 2010. He received doctorates from both the Institut d'Astrophysique de Paris and the Max Planck Institute for Astrophysics in Germany. He was a postdoctoral member of the Institute for Advanced Study in Princeton and a senior research associate at the Canadian Institute for Theoretical Astrophysics in Toronto. His research, which combines astrophysics and Big Data, focuses on galaxy formation and cosmology. His work has led to the detection of gravitational magnification by dark matter around galaxies and the discovery of tiny grains of dust in the intergalactic space which make the Universe less transparent. He is currently developing a new technique to estimate the redshift (or distance) of extragalactic objects. Ménard is a joint member of the Kavli Institute for Physics and Mathematics at Tokyo University. He received the Packard fellowship for Science and Engineering in 2014, the Sloan Research fellowship in 2012, was named the 2012 Outstanding Young Scientist of Maryland, and was awarded the 2011 Henri Chrétien grant award by the American Astronomical Society.

BILL MILLER
Miller Value Partners

Bill Miller is the Chairman and Chief Investment Officer of Miller Value Partners, LLC and is the Portfolio Manager for MVP1, LP. During his tenure as sole manager of the Legg Mason Value Trust, its performance exceeded its S&P 500 benchmark index for a record 15 consecutive years[1]. He was named Fund Manager of the Year in 1998 by Morningstar[2], The Greatest Money Manager of the 1990s by *Money Magazine*, selected as Fund Manager of the Decade by Morningstar.com, was named by Barron's to its All-Century Investment Team (1999), and received the Sauren Golden Award in 2015.

Bill was the director of research for Legg Mason from October 1981 through June 1985, and assumed overall responsibility for Legg Mason's equity funds management division in 1990. Prior to joining Legg Mason in 1981, he served as treasurer of the JE Baker Company, a major manufacturer of products for the steel and cement industries.

Bill earned his economics degree from Washington and Lee University where he graduated with honors in 1972. Subsequent to graduation, he served as a military intelligence officer overseas and then pursued graduate studies in philosophy in the PhD program at The Johns Hopkins University. He received his CFA designation in 1986. Mr. Miller is Chairman Emeritus of the Board of Trustees of the Santa Fe Institute where he served as chairman from 2005 to 2009. The Santa Fe Institute is one of the world's leading scientific research laboratories, conducting multidisciplinary research in complex systems theory.

[1]Legg Mason Value Trust-Class C beat the S&P 500 on an annual basis from 1990-2005. Bill Miller no longer manages the fund.

[2]Moringstar's Award for "Domestic Equity Fund Manager of the Year 1988" recognizes portfolio managers who demonstrate excellent investment skill, the courage to differ from consensus, and the commitment to shareholders necessary to deliver outstanding long-term performance.

JOSHUA MILLER
University of Alicante

Joshua Miller is a visiting scholar at the Department of Economics, UC Santa Cruz, Stanford Institute for Economic Policy Research, whose research interests include behavioral economics, statistical and experimental methods, judgment and decision-making, game theory, and decision theory.

KEVIN O'KEEFFE
MIT

Kev is an applied mathematician. He did his doctoral work on complex systems under Steve Strogatz at Cornell, mainly in synchronization, swarming and their intersection. Now he's a postdoctoral fellow at the MIT Senseable City Lab trying to understand how cities work, from a complex systems / data science / machine learning perspective.

DEAN OLIVER
TruMedia

Dean Oliver is a pioneer in sports analytics, working in both basketball and football. Dean wrote *Basketball on Paper*, the handbook for basketball analytics. He has worked in NBA front offices, with ESPN, and now as VP of Data Science with TruMedia, a firm that provides video-integrated sports analytics databases to professional and college teams, as well as media properties.

SCOTT PAGE
University of Michigan and Santa Fe Institute

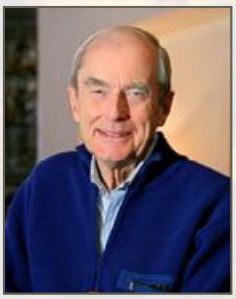
Scott E. Page's research focuses on the function of diversity in complex social systems. His book,*The Diversity Bonus*, was published in 2017 as a joint project from Princeton University Press and the Mellon Foundation. His forthcoming book,*The Model Thinker*, describes the value of multiple, diverse models in understanding complexity and will published by Basic Books in the fall. He is the author of more than 90 research papers in fields ranging from economics, political science, sociology, psychology, philosophy, physics, public health, geography, computer science, to management. Scott is married to SFI external faculty member Jenna Bednar. They have two sons, Orrie (18) and Cooper (16), and three large dogs

SID REDNER
Santa Fe Institute

Sid Redner received an A.B. in physics from the University of California, Berkeley in 1972 and a Ph.D. in Physics from MIT in 1977. After a postdoctoral year at the University of Toronto, Sid joined the physics faculty at Boston University in 1978. He is currently a resident faculty member at SFI.

Sid's research interests lie broadly in non-equilibrium statistical physics and its applications to a variety of phenomena. In recent years, he has worked extensively on the structure of complex networks, where he has developed new models and new methods to elucidate network structures. He has also devoted considerable effort to formulate and solve physics-based models of social dynamics. He continues to investigate problems of phase-ordering kinetics and has advanced our understanding of zero-temperature coarsening in Ising and Potts models. Sid has an enduring interest in diffusion processes and their applications in the natural world and in stochastic transport processes in disordered porous media. As part of this latter line of research, he investigates fundamental aspects of first-passage processes.

His books include the monograph *A Guide to First-Passage Processes* (Cambridge Univ. Press, 2001) and the graduate text, jointly with P. L. Krapivsky and E. Ben-Naim, *A Kinetic View of Statistical Physics* (Cambridge Univ. Press, 2010).



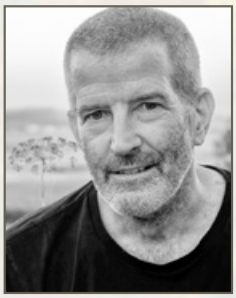
TED ROGERS
Santa Fe Institute

SFI Trustee Ted Rogers is co-founder of American Industrial Partners, an investment firm focused on companies in the manufacturing and industrial service sectors. He has held leadership positions with a wide variety of corporations. Rogers is widely involved in arts and education organizations. He led the United Way's annual fund drive to a record setting increase in Houston. He served as Chairman of the New York City Ballet and remains Chairman Emeritus; he is currently Chairman of the Theatre for a New Audience and Vice Chairman of the Board of Governors of St. John's College. He is also a board member of The New York Society Library. He was elected a Fellow of the American Academy of Arts and Science. He holds a BS from Miami University, an MBA from Marquette University, and an MA from St. John's College.

ADAM RUSSELL

Defense Sciences Office (DSO) Program Manager

Adam Russell joined DARPA as a program manager in July 2015. He is interested in new experimental platforms and tools to facilitate discovery, quantification, and "big validation" of fundamental measures in social science, behavioral science, and human performance. Russell has broad technical and management experience across a number of disciplines, ranging from cognitive neuroscience and physiology to cultural psychology and social anthropology. Before joining DARPA, he was a program manager at the Intelligence Advanced Research Projects Activity, where he developed and managed a number of high-risk, high-payoff research projects for the Office of the Director of National Intelligence. Prior to IARPA, he was in industry, where he was a senior scientist and principal investigator on a wide range of human performance and social science research projects and strategic assessments for a number of different government organizations. He holds a BA in cultural anthropology from Duke University, and an M.Phil. and a D.Phil. in social anthropology from Oxford University, where he was a Rhodes Scholar.



MARK TWIGHT

Author and coach

In the mountains Mark Twight pioneered alpine style and single-push ascents like the 60-hour, nonstop climb of the Slovak Direct on Denali. He worked with the DoD to design and develop the PCU and MARS cold weather clothing systems, and trained SMUs from all branches of service and USIC personnel. He is the founder of Gym Jones and has trained actors for a variety of Hollywood blockbusters. Twight's books on climbing have been translated into five languages. He currently hosts the *Dissect* podcast and produces *RAZE*, a 'zine he describes as A Fistfight With Human Nature