Is There a General Principle of Increasing Complexity?

BEYOND: Center for Fundamental Concepts in Science
Arizona State University • 10, 11, and 12 December 2010

ABOVE:
M.C. Escher's "Butterflies"

Contact: Mary Ann Meyers, Ph.D., *Senior Fellow*

Purpose

Scientists and philosophers have long argued that many natural systems, and perhaps even the universe as a whole, possess an inbuilt tendency for complexity to increase with time. This claim, however, rests uncomfortably with the second law of thermodynamics, with its emphasis on the rise of entropy. Attempts to reconcile the tension have led to interesting theoretical advances in the study of gravitational physics, self-organizing systems, computational models of complexity, and mathematical models of biological evolution. The purpose of this symposium is to explore these reconciliation attempts, both scientific and philosophical, and to address the questions of under what circumstances complexity will increase with time and whether it is possible to identify a general principle of increasing complexity. How best, moreover, should we quantify complexity to capture both systematic characteristics and to exhibit dynamic behavior generically? Those gathered to explore issues at the heart of complexity science, a field of inquiry the John Templeton Foundation has designated as a priority category for research funding, meet in a venue dedicated to pushing the boundaries of research.

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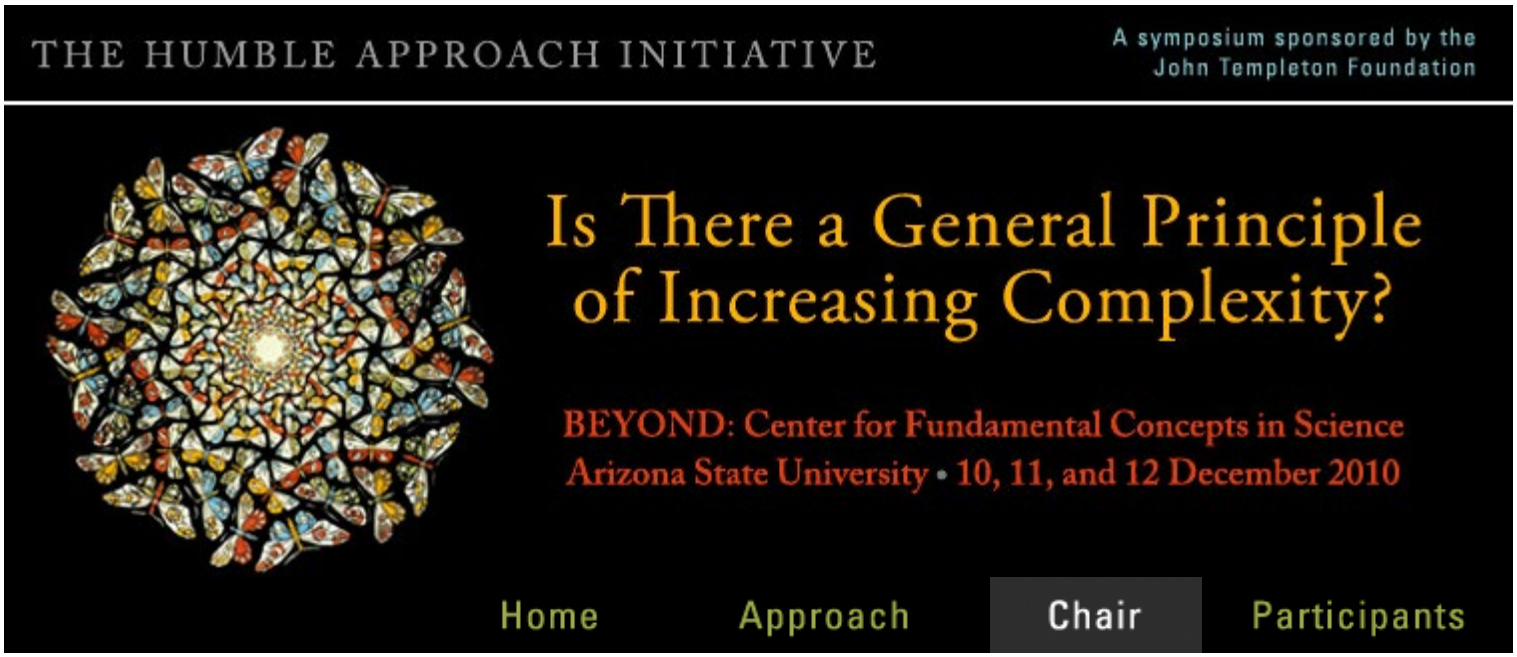
"Biospheres and the universe create novelty and diversity as fast as they can manage to do so without destroying the accumulated propagating organization that is the basis and nexus from which further novelty is discovered and incorporated into the propagating organization."

Stuart Kauffman
Investigations (2002)

Approach

The symposium is part of the Templeton Foundation's Humble Approach Initiative. The goal of the initiative is to bring about the discovery of new spiritual information by furthering high-quality scientific research. The "humble approach" is inherently interdisciplinary, sensitive to nuance, and biased in favor of building linkages and connections. It assumes an openness to new ideas and a willingness to experiment. Placing high value upon patience and perseverance, it retains a sense of wondering expectation because it recognizes, in Loren Eisley's haunting phrase, "a constant emergent novelty in nature that does not lie totally behind us, or we would not be where we are." A fundamental principle of the Foundation, in the words of its founder, is that "humility is a gateway to greater understanding and open[s] the doors to progress" in all endeavors. Sir John Templeton believed that in their quest to comprehend foundational realities, scientists, philosophers, and theologians have much to learn about and from one another. The humble approach is intended as a corrective to parochialism. It encourages discovery and seeks to accelerate its pace.



“The principle of maximum diversity says that the laws of nature, and the initial conditions at the beginning of time, are such as to make the universe as interesting as possible.”

Freeman Dyson
"Progress in Religion" (2002)
A talk given at the National Catherdral in Washington, D.C. upon receiving the Templeton Prize

Chair

Paul Davies, a theoretical physicist, cosmologist, and astrobiologist, is a professor and the founding director of BEYOND: Center for Fundamental Concepts in Science at Arizona State University (ASU). He is also principal investigator in the Center for the Convergence of Physical Science and Cancer Biology and co-director of ASU’s Cosmology Initiative. For three decades, he has been a leading communicator on science through books and broadcasts for general audiences. Educated at University College London, where he achieved first class honors in physics and went on to earn a Ph.D. in theoretical physics in 1970, Dr. Davies held academic appointments in astronomy, physics, and mathematics at the universities of Cambridge, London (King’s College), Newcastle upon Tyne, and Adelaide. He was then professor of natural philosophy in the Australian Centre for Astrobiology at Macquarie University before joining the ASU faculty in 2006. His research has spanned the fields of cosmology, gravitation, quantum field theory, and astrobiology, with particular emphasis on black holes, the origin of the universe, and the origin of life on which he has published several hundred papers in scientific journals. For the past five years, he has chaired the Search for Extraterrestrial Intelligence Post-Detection Science and Technology Taskgroup of the International Academy of Astronautics, which is dedicated to reflecting on the societal consequences of the discovery of evidence for extraterrestrial intelligence. Awarded honorary degrees by Macquarie and by Chapman University, he received the 1995 Templeton Prize. He also is the recipient of the 2001 Kelvin Medal presented by the UK Institute of Physics and the 2002 Michael Faraday Prize of the Royal Society, both of which recognized his contributions to promoting science to the public, as well as the Order of Australia. The asteroid 1992 OG was officially named (6870) “Pauldavies” in his honor. He is a fellow of the Institute of Physics, the Australian Institute of Physics, the Royal Literary Society, and the World Economic Forum. Dr. Davies has edited a number of volumes, including (with Philip Clayton) *The Re-Emergence of Emergence* (2006) and (with Niels Gregersen) *Information and the Nature of Reality: From Physics to Metaphysics*, which was published this autumn by Cambridge University Press. The author of more than twenty-five books, his specialist works include *The Physics of Time Asymmetry* (1974) and *Quantum Fields in Curved Space* (1982). His better known popular works are *The Mind of God* (1992), *About Time: Einstein’s Unfinished Revolution* (1995), *How to Build a Time Machine* (2002), *The Goldilocks Enigma: Why the*

Universe is Just Right for Life (2006) and, most recently, *The Eerie Silence: Renewing Our Search for Alien Intelligence*, which was published by Houghton Mifflin Harcourt (USA) and Penguin Books (UK) in 2010 to critical acclaim for its deep questioning of the assumptions that aliens would be like us and that life must always evolve on planets that can support it. Dr. Davies also has extensive experience in television and radio, including the presentation of two Australian television series entitled *The Big Questions*. His work in astrobiology was the subject of a BBC television documentary, "The Cradle of Life."

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An astrophysicist and science educator, Eric J. Chaisson is director of the Wright Center for Science Education at Tufts University where he is research professor of physics and astronomy and research professor of education. He is also an associate of the Harvard College Observatory and teaches an undergraduate course at Harvard on cosmic evolution. His scientific research involves an interdisciplinary, thermodynamic study of physical and biological phenomena that seeks to understand the origin, evolution, and unification of galaxies, stars, planets, and life forms in the universe. His educational research engages experienced teachers and computer animators in creating better methods, technological aids, and novel curricula to stimulate teachers and instruct students in all aspects of the natural sciences. A graduate of the University of Massachusetts, he earned a Ph.D. in astrophysics at Harvard in 1972. He held a National Academy of Sciences post-doctoral fellowship at the Smithsonian Astrophysical Observatory then joined the Harvard faculty in 1974 as an assistant professor of astrophysics and a staff member of the Harvard-Smithsonian Center for Astrophysics. He was promoted to associate professor in 1979. In the mid-1980s, he joined the Space Telescope Science Institute as a scientist on the senior staff and director of educational programs, posts he held along with an adjunct professorship of physics at Johns Hopkins University and the associate directorship of Maryland Space Grant Consortium until accepting his present position in 1992. Dr. Chaisson has been the recipient of an Alfred P. Sloan Foundation research fellowship and two Harvard awards, the Bart J. Bok Prize and the Smith-Weld Prize, as well as a NASA certificate of merit for his work on the Hubble Space Telescope and five book awards. He has delivered numerous named lectures, including the Phi Beta Kappa National Lectures in 1995-96 and, most recently, the Collins Lectures at Harvard Medical School. A former member of the Board of Overseers of the Boston Museum of Science, he is currently a member of the board of directors of the Foundation for the Future. In addition to some 150 papers published in scientific journals, he is the author of a dozen books. They include: *Cosmic Dawn* (1981), a finalist for the National Book Award for distinguished science writing in 1982 and winner of a Phi

Beta Kappa Prize and an American Institute of Physics Award; two works on relativity, *La Relativita* (1983) and *Relatively Speaking* (1988); (with George Field) a volume outlining the scientific rationale for the United States' national space policy, *The Invisible Universe: Probing the Frontiers of Astrophysics* (1985); *The Life Era: Cosmic Selection and Consciousness Evolution* (1987); (with Steve McMillan) a widely used college astronomy textbook, *Astronomy Today* (1993 first edition through 2011 seventh edition); *The Hubble Wars: Astrophysics Meets Astropolitics in the Two-Billion Struggle over the Hubble Space Telescope* (1994), winner of an American Institute of Physics Science Writing Award and cited by the New York Times in its "best book of year" category; *Cosmic Evolution: The Rise of Complexity in Nature* (2001); and, most recently, *Epic of Evolution: Seven Ages of the Cosmos*, which was published by Columbia University Press in 2006 and won the Kistler Book Award.

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Widely acknowledged as one of the foremost paleontologists of his time, Simon Conway Morris is professor of evolutionary paleobiology at Cambridge University. He has devoted his research career to the study of the 510-million-year-old Burgess Shale, found near the village of Field in the Canadian Rockies, and related fossil-rich formations. In his acclaimed 1998 study, *The Crucible of Creation*, he reinterpreted the soft-body fauna found in this remarkable shale as evincing the preeminent role of convergence in evolution. His demonstration that many of the Burgess Shale animals are related, albeit remotely, to modern forms supports the theory that similar solutions are found to the same kind of environmental challenges in independent lines and places and impugns, as seriously incomplete, the reductionist viewpoint that the present-day world arises as the result of chance past events. In his most recent book, *Life's Solution: Inevitable Humans in a Lonely Universe* (Cambridge University Press, 2003), he extends his argument and builds his case for the inevitability of numerous evolutionary outcomes on a foundation laid by Charles Darwin himself in *Origin of the Species*, the epochal work to which critics have compared *Life's Solution*. Dr. Conway Morris concludes that large-scale features of the history of evolution "are congruent with a Creation"—and he helps restore humanity's place at its center by his insistence that intelligence is not a fluke, though a life-friendly planet like Earth may be unique. A graduate of the University of Bristol, where he took first-class honors in geology, Dr. Conway Morris went on to Cambridge and studied at Churchill College with Harry Whittington, the first reinterpreter of the Burgess Shale, on a Natural Environment Research Council (NERC) Studentship. He was elected a research fellow of St. John's College in 1975 and received his Ph.D. in evolutionary paleobiology the next year. Appointed a lecturer in earth sciences at The Open University in 1979, he returned to Cambridge as a lecturer four years later and was promoted to his current chair in 1995. Dr. Conway Morris is a fellow of the Royal Society and an honorary fellow of the European Union of Geosciences and serves on the board of advisors of the John Templeton Foundation. His work has been supported by research grants from the society as well as

from the Nuffield Foundation, the Carlsberg Foundation, the NERC, the National Geographic Society, and the Leverhulme Foundation. He has delivered numerous invited lectures throughout the United Kingdom, Europe, Asia, Canada, and the United States, including the Gifford Lectures at the University of Edinburgh in 2007 and the keynote address at the International Conference on the Cambrian Explosion in Banff, which marked the one hundredth anniversary of the discovery of the Burgess Shale last year. Among many honors, he has been awarded the Walcott Medal of the National Academy of Sciences, the Charles Schuchert Award of the Paleontological Society of the United States, Yale University's George Gaylord Simpson Prize, the Lyell Medal of the Geological Society of London, the Kelvin Medal of the Philosophical Society of Glasgow, and the Ide and Luella Trotter Prize given by Texas A&M University. Dr. Conway Morris holds honorary doctorates from the University of Uppsala and the University of Hull. He contributes frequently to general magazines and encyclopedias and to radio and television programs on science and is a member of the editorial board of *Geology*. The author of more than one hundred research papers, he has served as editor of five books, including *The Deep Structure of Biology: Is Convergence Sufficiently Ubiquitous to Give a Directional Signal?* which was published in 2008 by the Templeton Press. *The Crucible of Creation* was translated into Japanese and has been reprinted seven times.

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Marcelo Gleiser is Appleton Professor of Natural Philosophy and professor of physics and astronomy at Dartmouth College. His research interests include the physics of the early universe, the properties of solitons in classical and quantum field theories, and questions related to the origins of life and self-organizing complexity. Born in Brazil, he earned his baccalaureate degree at the Catholic University of Rio de Janeiro, a master's degree in physics from the Federal University of Rio de Janeiro, and a Ph.D. in theoretical physics from King's College London in 1986. He did postdoctoral work at Fermilab as a research associate with the Theoretical Astrophysics Group and was a postdoctoral fellow at the Institute for Theoretical Physics at the University of California, Santa Barbara. Dr. Gleiser joined the Dartmouth faculty as an assistant professor of physics and astronomy in 1991 and was promoted to full professor in 1997. He was named to his present chair the next year. His research is supported by the National Science Foundation (NSF) and, in the past, by both the National Aeronautics and Space Administration and NATO. A fellow of the American Physical Society and an elected member of the Brazilian Academy of Philosophy, he held a Presidential Faculty Fellow Award given by NSF and the White House from 1994 to 1999 and is the recipient of two Dartmouth awards, a Wilson Faculty Research Fellowship and a Karen E. Wetterhahn Memorial Award for Distinguished Creative Scholarly Achievement, along with the 2001 José Reis Prize for the Public Understanding of Science given by the National Research Council of Brazil. He serves on the editorial board of *National Geographic* magazine. In addition to some ninety papers published in scientific journals, he is the author of ten books in Portuguese and English, including *The Dancing Universe: From Creation Myths to the Big Bang* (1997 and 2005), winner the Jabuti Award, the highest literary award given by Brazil for a non-fiction book, and *The Prophet and the Astronomer: A Scientific Journey to the End of Time* (2002), winner of a second Jabuti Award. His most recent book, *A Tear at the Edge of Creation: A Radical New Vision for Life in an Imperfect Universe*, published this year by Simon & Shuster to high critical praise and translated into nine languages, argues that the millennial-old quest for an overarching

Theory of Everything, in which he once shared, is fundamentally misguided, as there is no grand plan or cosmic blueprint for our existence and, furthermore, according to the author's reading of the latest scientific evidence, imperfections in the fabric of the universe are the driving forces behind its very existence. Dr. Gleiser has written two science books for young readers, an award-wining screenplay, and a work of fiction, *Skybound: A Biographical Novel of Johannes Kepler*, which was published in Portuguese as *A Harmonia do Mundo* (2006). His two science series for Brazil's TV Globo were watched by more than 30 million viewers. He writes a weekly science column for a Brazilian newspaper and is the co–founder of a science and culture blog hosted by National Public Radio.

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A pioneer in the field of complexity theory, Stuart A. Kauffman is a biologist, trained as a medical doctor, who studies the origins of life and the origins of molecular organization. While still a graduate student, he began testing his ideas by simulating the interaction of various abstract agents—representative of chemical and biological substances—on computers. He concluded that upon reaching a certain level of diversity, a system of simple chemicals undergoes a dramatic transformation, similar to a phase change in physics, whereby molecules spontaneously combine to create larger, more complex molecules with catalytic capability leading to the formation of collectively autocatalytic sets of molecules. If so, life may be an expected property of complex chemical systems. His theory led him to the further hypothesis that complex arrays of interacting genes, which turn one another on and off, do not behave randomly but tend to converge toward a relatively small number of recurring patterns that exhibit stunning degrees of order. In *The Origins of Order: Self Organization and Selection in Evolution* (1993), Dr. Kauffman proposed that the principle of self-organization may have played a larger role than natural selection in shaping the development of life on Earth. On a practical level, his ideas about what is sometimes called "molecular diversity" helped spawn a field known as combinatorial chemistry. The new field continues to revolutionize drug development by making it possible to create and sift through vast quantities of potential drug ingredients with lightening speed. Holder of a dozen broad biotechnology patents, Dr. Kauffman was the founding general partner (with Ernst & Young) of Bios Group LP, a company that sought to apply biological theories to business and was acquired by NuTech Solution in 2003. He is currently affiliated with several educational and research institutions, including: the University of Calgary, where he served for five years as founding director of the Institute of Biocomplexity and Informatics and is now iCore Visiting Professor; Tampere University of Technology, where he is Finland Distinguished Professor; and the University of Vermont, where he is Macmillian Scholar-in-Residence at the Complex Systems Center and holds joint appointments as a visiting distinguished research professor in the College of Medicine and

the College of Mathematical and Engineering Sciences. He also is an adjunct professor of pathology at M.D. Anderson Cancer Center, an internal visiting professor at George Mason University's Krasnow Institute, and an affiliate in neurobiology at Montana State University. A Phi Beta Kappa graduate of Dartmouth College, Dr. Kauffman studied philosophy at Oxford University on a Marshall Scholarship and took his M.D. in 1968 from the University of California-San Francisco School of Medicine. He began his career as an assistant professor of biophysics and theoretical biology at the University of Chicago then taught for twenty years at the University of Pennsylvania School of Medicine, where he is now emeritus professor of biochemistry and biophysics, before moving on to the Santa Fe Institute. He was a professor there for more than a decade, served on the Institute's board of trustees and its scientific advisory board, and continues his association as a member of the external faculty. From 2003 to 2005, he was a research professor in cell biology and physiology at the University of New Mexico. Last year he was a visiting professor in the Harvard Divinity School.
Dr. Kauffman has served as president of the Society for Mathematical Biology and presently serves as a member of the science advisory boards of Icosystems, Gene Network Science, Applied Molecular Evolution, KatFat Inc., McMaster University's Origins Institute, and the Natural Research Council of Canada's Steacie Institute for Molecular Sciences. The recipient of many awards, he held a John D. and Catherine T. MacArthur Fellowship, the so-called "genius prize," from 1987 to 1992 and won the American Cybernetic Society's Weiner Gold Medal in 1971 and the Gold Medal of the Italian Accademia Nazionale dei Lincei in 1997. He is a fellow of the Royal Society of Canada and was awarded an honorary degree last year by the Catholic University of Louvain. The former co-editor-in-chief of the *Journal of Theoretical Biology*, he has served on the editorial boards of many other journals. Dr. Kauffman has published more than 180 scientific papers and is the co-editor of one book and the author of four others. Following his groundbreaking *Origins of Order*, his widely acclaimed *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* (1996) spelled out the implications of his theories on biological evolution as he showed how order emerges naturally—and possibly even necessarily—out of chaos. *Investigations* (2002) defines and explains autonomous agents and work in the contexts of thermodynamics and of information theory leading the author to explore the requirements for the emergence of a new biology that will transcend terrestrial biology in search of laws governing biospheres anywhere in the cosmos. His most recent volume, the provocative *Revisiting the Sacred: A New View of Science, Reason, and Religion*, which was published by Basic Books in 2008, refutes the kind of physicalism that rules out ontological emergence and, in redefining God as the natural creativity in the universe itself, proposes a novel metaphysics.

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David C. Krakauer is chair of the faculty and a research professor at the Santa Fe Institute. His research focuses on the evolutionary history of information processing mechanisms in adaptive systems. It spans levels of organization that includes genetics, cell biology, microbiology, and society. The current emphasis of his work is on robust information transmission and signaling dynamics, particularly their role in constructing novel, higher level structures, such as social systems and language. A graduate of the University of London, where he went on to earn a master's degree in computer science and mathematics, Dr. Krakauer received his D.Phil. in evolutionary theory from Oxford University in 1995. He remained at Oxford as a postdoctoral research fellow, and two years later was named a Wellcome Research Fellow in mathematical biology and lecturer at Pembroke College. In 1999, he accepted an appointment to the Institute for Advanced Study in Princeton and served as visiting professor of evolution at Princeton University. He moved on to the Santa Fe Institute as a professor three years later and was made faculty chair in 2009. Dr. Krakauer has been a visiting fellow at the Genomics Frontiers Institute at the University of Pennsylvania and a Sage Fellow at the Sage Center for the Study of the Mind at the University of Santa Barbara. His research has been supported by the National Science Foundation and the National Institutes of Health as well as by Lockheed Martin and several private foundations. A member of the editorial boards of the *Journal of Theoretical Biology*, *Theory in Biosciences*, *Biology Digest*, *Interdisciplinary Science Review*, Springer's Monographs in Mathematical Biology, and Primers in Complex Systems, a series published by the SFI and Princeton University Press, he is the author of more than eighty papers published in scientific journals and the co-editor of *Protocells: Transitions from Non-living to Living Matter*, an account of current approaches to making new forms of life in the laboratory, which was published in 2008 by MIT Press. He is completing two new books, *Adaptive Information Theory* (for the SFI PUP Primer series), and (with Dan Rockmore) *TranScience: The New Ideas and Education Revolution*.

JOHN TEMPLETON FOUNDATION

SUPPORTING SCIENCE-INVESTING IN THE BIG QUESTIONS

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Eric J. Chaisson
Philip Clayton
Simon Conway Morris
Marcelo Gleiser
Stuart A. Kauffman
David C. Krakauer
Charles H. Lineweaver
Michael Ruse
D. Eric Smith
William C. Wimsatt
Stephen Wolfram
David Wolpert

Participants

An astrophysicist, Charles H. Lineweaver is an associate professor at the Australian National University's Planetary Science Institute (PSI), a joint venture of the ANU Research School of Astronomy and Astrophysics and Research School of Earth Science. His research involves analysis of the statistical distribution of exoplanets, the cosmic microwave background radiation, and cosmological prerequisites for the formation of terrestrial planets and life. Educated at Ludwig-Maximillians-Universität in Munich where he was awarded highest honors in physics, Dr. Lineweaver earned a Ph.D. in physics at the University of California, Berkeley in 1994. He was a postdoctoral fellow at the Observatoire Astronomique in Strasbourg and, successively, a vice chancellor's postdoctoral research fellow and Australian Research Council (ARC) fellow at the University of New South Wales (UNSW). He joined the UNSW faculty as a senior lecturer in 2002 and was appointed to his present position two years later. A member of the editorial board of *Astrobiology Magazine*, he is the author of more than fifty papers published in scientific journals or in volumes of collected works.

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The Lucyle T. Werkmeister Professor of Philosophy at Florida State University, Michael Ruse is a philosopher of science who has found in evolution a kind of *Weltanschauung*, a world picture that gives meaning to life. He is one of the foremost contemporary Darwin scholars. He believes that we know what we know because of biology and remains a skeptic on the existence of an ultimate reality as attractive as he finds the possibility. Born in England, he attended a Quaker school before entering the University of Bristol, where he studied philosophy and mathematics. Immigrating to North America, he took a master's degree in philosophy at McMaster University in Ontario, Canada, and then returned to Bristol where he earned a Ph.D. in philosophy in 1970. Already on the faculty of Ontario's University of Guelph, he became a full professor of philosophy of science and of zoology there in 1974, a position he held until accepting his present chair at Florida State in 2000. Dr. Ruse has been a visiting professor at Indiana University, a visiting scholar at Harvard University's Museum of Comparative Zoology, and, at Cambridge University, an associate at Clare Hall, a visiting scholar at Pembroke College, and a fellow of Wolfson College. He also has served as invited director of the École Pratique des Hautes Études in Montpellier, France. A former Erskine Fellow at the University of Canterbury in Christchurch, New Zealand, he has held Guggenheim and Killam fellowships and a John Templeton Foundation research grant for exploring the constructive interaction of science and religion. He has honorary degrees from the University of Bergen in Norway and McMaster University, and is a fellow of both the Royal Society of Canada and the American Association for the Advancement of Science (AAAS). In 2001, he delivered the Gifford Lectures at the University of Glasgow. The founding editor of *Biology and Philosophy*, he serves on the editorial boards of eight other journals as well as serving as general editor of the Cambridge Studies in Philosophy and Biology. He is a former president of the History and Philosophy of Science Section of the AAAS and presently an associate of the Zygon Center for Religion and Science at the Lutheran School of Theology in Chicago. A prolific author, Dr. Ruse has written twenty-two books, edited twenty, contributed to some sixty others, and

published more than a hundred papers in academic journals. His comprehensive study of the history of the relationship between scientific ideas about evolution and cultural notions of progress, *Monad to Man: The Concept of Progress in Evolutionary Biology* (1996), was widely hailed as demonstrating how a pervasive Enlightenment optimism regarding the possibility of ongoing social and moral improvement influenced the speculative theorizing of early biologists. In *Mystery of Mysteries: Is Evolution a Social Construction?* (1999), Dr. Ruse considered the careers and theories of past and contemporary scientists as he probed the extent to which science is both an objective reality with special standards of truth finding and a sequence of paradigms that subjectively mirror our ever-shifting views of the world; *Darwin and Design: Does Evolution Have a Purpose?* (2003) explores the relation between evolutionary theory and the classical argument from design for the existence of God; *The Evolution-Creation Struggle* (2005) links the ongoing debate between evolutionists and creationists to pre-millennial and post-millennial thinking in Christian eschatology; *Darwinism and its Discontents* (2006) is an ardent defense of the theory of evolution against its contemporary critics; *Charles Darwin* (2007) provides an assessable overview of the author's understanding of Darwinism; and *Defining Darwin: Essays on the History and Philosophy of Evolutionary Biology* (2009) reevaluates Darwin's legacy and considers, in particular, the impact of the great naturalist's work on religion. Dr. Ruse's latest book, *Science and Spirituality: Making Room for Faith in the Age of Science*, which was published by Cambridge University Press in 2010, presents a new analysis of the science and religion relationship.

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D. Eric Smith is a research professor at the Santa Fe Institute. He works on problems of self-organization in thermal, chemical, and biological systems. His particular focus at present is the statistical mechanics of the transition from the geochemistry of the early earth to the first levels of biological organization with an emphasis on the emergence of the metabolic network. A graduate of the California Institute of Technology, Dr. Smith earned a Ph.D. in physics at the University of Texas at Austin in 1993. He worked in physical, nonlinear, and statistical acoustics for seven year at the university's Applied Research Laboratories and at the Los Alamos National Laboratory before joining the Santa Fe faculty in 2000. He has published more than twenty papers in scientific journals.

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Professor of philosophy emeritus at the University of Chicago, William C. Wimsatt is known for his groundbreaking work in the philosophy of biology. His research and writing center on a cluster of problems arising in the analysis of the structure, behavior, and evolution of complex, functionally organized systems. He currently spends each fall term at the Minnesota Center for the Philosophy of Science at the University of Minnesota, where he is Winton Chair of Liberal Arts, and continues to teach at Chicago during the spring. A graduate of Cornell University, Dr. Wimsatt first studied engineering physics then, after a year working as a designer in industry, turned to philosophy and received his baccalaureate degree *magna cum laude*. He went on to the University of Pittsburgh, where he held Woodrow Wilson and Mellon fellowships, and, after research in population biology at the University of Chicago as a Hinds Fellow, was awarded a Ph.D. in the philosophy of science by Pittsburgh in 1971. He then joined the Chicago faculty as an assistant professor of philosophy and was promoted to full professor in 1981. In 2007, he was named the Peter H. Ritzma Professor in Philosophy and Evolutionary Biology, a post he help until his retirement last year. Dr. Wimsatt has been a University Visiting Distinguished Professor at The Ohio State University, a Visiting Hurst Professor and a Clark-Way Harrison Distinguished Visitor at Washington University in St. Louis, a fellow at the Rockefeller Foundation's Bellagio Study and Conference Center in Italy, a senior fellow at the Konrad Lorenz Institute for Evolution and Cognition Research in Austria, and a fellow at the Franke Humanities Institute in Chicago. He has held a National Humanities Center Fellowship and grants from the National Science Foundation, the System Development Foundation, the American Council of Learned Societies, Hewlett Packard, the Annenberg Foundation, and the Arthur Vining Davis Foundation. A fellow of the American Association for the Advancement of Science, he is the recipient of awards for curriculum innovation and outstanding graduate teaching. He serves on the scientific advisory board of the Land Institute, the board of advisors of the Philosophical Gourmet (Leiter) Report, as advisory editor *Biological Theory*, and on the editorial boards of *Foundations of*

Science, *Journal of Cognition and Culture*, the electronic *Evolutionary Psychology*, and of the BioQUEST Educational Consortium. In addition to more than fifty papers published in academic journals, Dr. Wimsatt is the co-author (with J.C. Schank) of *Modelling—A Primer* (1993), a laboratory manual to accompany BioQUEST software, and *Re-Engineering Philosophy for Limited Beings: Piecewise Approximations to Reality*, a collection of the author's essays addressing biological complexity, which was published by Harvard University Press in 2007.

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Scientist and entrepreneur, Stephen Wolfram is the creator of Mathematica and Wolfram/Alpha and the founder and CEO of Wolfram Research, Inc. He was educated at Eton and St. John's College, Oxford, and earned his Ph.D. in theoretical physics at the California Institute of Technology in 1979. He joined the Caltech faculty as a research associate in physics at nineteen, the year before receiving his doctorate, and led the development of the computer algebra system SMP (Symbolic Manipulation Program). He was awarded a John D. and Catherine T. MacArthur Fellowship in 1981, the youngest recipient in the first class of prize winners, and accepted appointment to the faculty of the School of Natural Sciences at the Institute for Advanced Study in Princeton in 1983 where he began the research for which he would become best known—and effort to understand naturally-occurring complexity. His first key idea was to use computer experiments to study the behavior of simple computer programs known as cellular automata, and the series of papers he quickly published laid much of the groundwork for the emerging field of complexity science. Dr Wolfram was named a professor of physics, mathematics, and computer science at the University of Illinois at Urbana-Champaign in 1986 where he founded the Center for Complex Systems Research and started the first journal in the field, *Complex Systems*. He left academia two years later to launch Wolfram Research and developed the first version of Mathematica, the powerful computational system now generally acknowledged to be the most complete technical and graphical software for mathematicians, scientists, and engineers. He has led the continuing development of Mathematica for twenty years, with the latest version, Mathematica 8, released just last month. While his company grew, Dr. Wolfram devoted part of his time to basic complexity research, which culminated in the publication of *A New Kind of Science* (2002). The revolutionary and still controversial 1,200-page book presents an empirical study of very simple computational systems and argues that they, rather than traditional mathematics, are needed to model and understand complexity in nature. The year of its publication, he was selected as *R&D Magazine*'s Scientist of the Year in recognition of his achievement. In 2009, he launched

Wolfram/Alpha, a computational data engine built with Mathematica that offers a new approaching to presenting knowledge based on systematic data collection, computation, a large library of algorithms, and an understanding of natural language inputs. In addition to more than sixty papers published in scientific journals, a selection of which were collected in *Cellular Automata and Complexity* (1994), Dr. Wolfram is also the author of *The Mathematica Book* (1988), which appeared in four subsequent editions and was translated into Japanese, German, French, and Chinese, as well as two derivative works. He contributes regularly to the Wolfram Research and the Wolfram/Alpha blogs and gives frequent guest lectures about his continuing ambition to remake science.

Is There a General Principle of Increasing Complexity?

BEYOND: Center for Fundamental Concepts in Science
Arizona State University • 10, 11, and 12 December 2010

Participants

David Wolpert is a senior computer scientist at the NASA Ames Research Center and a consulting professor in aeronautics and astronautics at Stanford University. He also holds an appointment as the Ulam Scholar at the Center for Nonlinear Studies (CNS) at Los Alamos National Laboratory. His research focuses on probability collectives, combinatorial organization, machine learning and statistics, complexity measures, and the physics of information. A *cum laude* graduate of Princeton University, he earned a Ph.D. in physics at the University of California, Santa Barbara, in 1989. He did postdoctoral research in the theoretical division and at CNS as a director's fellow and at the Santa Fe Institute. He then served as director of research at TXN, Inc. and as a research manager in data mining solutions at IBM's Almaden Research Center before joining NASA in 1997. Dr. Wolpert is a senior member of the Institute of Electrical and Electronics Engineers (IEEE). An associate editor of *Advances in Complex Systems*, *IEEE Transactions on Evolutionary Computation*, and *ACM Transactions on Autonomous and Adaptive Systems*, he serves on the editorial boards of the *Journal of Artificial Intelligence Research*, *Theory in Biosciences*, and the *Journal of Economic Interaction and Coordination* and is on the advisory board for Springer's *Handbook in Natural Computing*. He is the author of some one hundred papers published in scientific journals and the editor of *The Mathematics of Generalizations* (1994) and (with Kagan Tumer) of *Collectives and the Design of Complex Systems*, a survey of research on self-motivated agents published by Springer in 2004, which lays the foundation for the study of collective intelligence and how these entities can be developed to achieve optimal system performance.

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