**NASA Astrobiology Institute Virtual Workshop, 27 February 2012**

# Intelligence in Astrobiology

# Workshop 1: What Don't We Know About Intelligence?

## Participant Bios and Abstracts

***In progress, version evening 26 Feb 2012, to be superseded  n.b. not all participants have yet submitted bios***

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**Ariel D. Anbar** is a professor in the School of Earth and Space Exploration at Arizona State University. He is a biogeochemist and isotope geochemist who applies novel analytical methods to astrobiology research questions. Most of his work revolves around the analysis of natural materials, using high-precision, high-sensitivity mass spectrometry, to study environmental conditions on the ancient Earth. His research also involves extensive laboratory experiments. The goal of this research is to understand the conditions that make planets habitable, the rules that govern the environmental and biological evolution of inhabited worlds, and the means by which such worlds can be detected from Earth. Anbar is the PI of the NASA Astrobiology Institute Team at Arizona State University. He has been the PI, Co-PI or Co-I of many collaborative projects for NASA and NSF since 1996.

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**Sarah Bengston** is a graduate student at the University of Arizona in the department of Ecology and Evolutionary Biology where I work with Dr. Anna Dornhaus My Alma mater is the University of Tennessee at Knoxville where I earned a B.S. in Biology with a concentration in Honors Ecology and Evolutionary Biology. Most broadly, I am interested in behavioral ecology, behavioral syndromes and the stability of behavioral type through time. Specifically, I am focused on intercolony behavioral variation in ants of the genus *Temnothorax*, how this correlates to environmental conditions and what role learning and genetics play.

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**Aaron Blaisdell**. After receiving his BA and MA in Biological Anthropology (at SUNY Stony Brook and Kent State University, respectively), Dr. Blaisdell realized that animal cognition was even more interesting than studying dead humans. So he trekked on over to SUNY Binghamton for his Ph.D. in Experimental Psychology with Dr. Ralph Miller, where he studied learning, memory, and temporal cognition in the rat. This was followed by a brief stint as an NRSA Postdoctoral Fellow with Dr. Robert Cook, an expert on Avian Visual Cognition at Tufts University, where he learned how pigeons perceive and think about the world. Since 2001, Dr. Blaisdell has emigrated to the climatological and cultural paradise of sunny LA as Associate Professor in Learning & Behavior and Behavioral Neuroscience in the UCLA Psychology Department. He presides over a comparative cognition lab, studying cognitive processes in rats, pigeons, hermit crabs, and humans. Aaron is currently president of the International Society for Comparative Psychology and the Ancestral Health Society. His interest in Ancestral Health reunites his fascination with anthropology with his interest in comparative approaches to evolution and health. His lab website is http://pigeonrat.psych.ucla.edu.

**Blaisdell Abstract:** Intelligence is a characteristic of organisms with a nervous system (animals) that adapts the individual to its surroundings. The building blocks of intelligence reside in any physiological function that adapts behavior to an unpredictable, changing environment. Thus, the simplest intelligences may be found among single-celled organisms, such as paramecium, even though they lack a nervous system. To understand how intelligence may evolve among alien creatures, it is useful to look at the origins and phylogenetic distribution of intelligence among Earth's creatures to identify similarities (especially homoplasies) and differences in the behavioral processes and mechanisms. Similarities and differences in how honey bees and mammals perform in behavioral experiments on learning and memory provide a useful example of the comparative approach. Similarities are particularly intriguing when they are the result of shared homologies at one level of analysis, such as neurochemical, and convergent evolution at another, such as neural circuits.

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**Daniel T. Blumstein** is a Professor and Chair of the Department of Ecology & Evolutionary Biology, at UCLA, and a Professor in UCLA's Institute of the Environment & Sustainability. He received his undergraduate degrees in Environmental, Population, and Organismic Biology (*Magna Cum Laude*), and in Environmental Conservation (*Cum Laude*) at The University of Colorado, Boulder. He received his M.S. and Ph.D. in Animal Behavior at the University of California Davis, and was a DAAD post-doctoral fellow at the University of Marburg (Germany), an NIH-NRSA at the University of Kansas, and an Australian Postdoctoral Fellow at Macquarie University (Australia). He has studied animal behavior and conservation biology in Australia, Canada, the Caribbean, Germany, Kenya, New Zealand, Pakistan, Russia, and the United States. He was a Fulbright Fellow (to Pakistan) and is an elected Fellow of the Society of Biology and the Animal Behavior Society. His work has been supported by the NSF, the NIH, the National Geographic Society, the Australian Research Council, as well as by other private organizations. He is the author of five books and over 200 scholarly publications. He was an Editor of the journal *Animal Behaviour*, and is currently an Associate Editor of the *Quarterly Review of Biology*, and is (or was) on the Editorial Boards of *Behavioral Ecology*, *Biology Letters*, and *Ethology*. A new thrust of his research works to integrate different fields and apply ecological, evolutionary, and behavioral principles to public policy. He spends his summers studying marmot behavior and ecology at the Rocky Mountain Biological Laboratory, Gothic, Colorado.

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**Robert Boyd** is Distinguished Professor of Anthropology at UCLA and external faculty member at the Santa Fe Institute. Much of his research focuses on population and dynamic models of culture, and he has published seminal work on the evolution of social behavior, especially reciprocity and collective action. He brings a mathematical approach to the study of cultural evolution. His work with economists Samuel Bowles and Herbert Gintis has resulted in numerous publications in such journals as *PNAS* and *Science*. Along with P.J. Richerson, Robert is the author of *Not by Genes Alone: How culture transformed human evolution*, University of Chicago Press, Chicago, IL. 2005.

**Abstract: How culture transformed human evolution.** Humans are a paradoxical species. On the one hand we are exceptionally good at adapting. Humans occupy a wider ecological and geographic range than any other species using a much greater range of subsistence strategies and social organizations. On the other hand, much of our behavior seems frankly maladaptive. For example, humans engage in cooperation in large groups of unrelated individuals. In this talk I will try to persuade you that both our exceptional adaptability and our propensity for folly stem from the fact that humans, unlike any other animal, acquire important components of their behavior by observing the behavior of others. This ability allows us to rapidly evolve superb culturally transmitted adaptations to local conditions, but it also necessarily leads to the cultural evolution of maladaptive behavior.

**Daniel Charbonneau** is a Ph.D. student at the University of Arizona in the Entomology and Insect Science Graduate Interdisciplinary Program where he works with Dr. Anna Dornhaus studying emergent behavior in social insects with a special focus on complex systems, interactive networks and the evolution of intelligence.

His past research includes work on modeling population dynamics at the landscape scale. Having explored population dynamics at a very large scale, he is now looking at the opposite end of the spectrum, focusing on dynamics happening at the individual level.

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**Paul Davies** is a theoretical physicist, cosmologist and astrobiologist. He holds the title of Regent's Professor at Arizona State University, where he is Director of The Beyond Center for Fundamental Concepts in Science, and co-Director of the ASU Cosmology Initiative. He is also Principal Investigator of the Center for the Convergence of Physical Science and Cancer Biology, funded by the National Cancer Institute. He previously held academic appointments at the universities of London, Cambridge, Newcastle-upon-Tyne, Adelaide and Macquarie, and helped create the NAI-affiliated Australian Center for Astrobiology. He joined Arizona State University in 2006.

Davies has published 143 journal papers and about 30 books, of which *Quantum Fields in Curved Space* (co-authored with his student Nicholas Birrell) is the most cited textbook in the field. He writes regularly for newspapers, journals and magazines in several countries, and has devised or contributed to many radio and television documentaries in the UK, Australia and the US. He is the recipient of many awards, including honorary degrees from Macquarie University and Chapman University and Fellowship of University College London. The asteroid 1992 OG was renamed (6870) Pauldavies in recognition of his work on cosmic impacts. He has received the Michael Faraday Prize from The Royal Society, The Kelvin Medal and Prize from the UK Institute of Physics, the Robinson Cosmology Prize, the Chilean Bicentenary Medal and the 1995 Templeton Prize, the world's largest prize for intellectual endeavor. In June 2007 Davies was named as a Member of the Order of Australia in the Queen's birthday honors list.

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**Terrence Deacon** is Professor of Biological Anthropology and Neuroscience, and Chair of the Department of Anthropology, at University of California, Berkeley. Terry Deacon is an anthropologist whose research has combined human evolutionary biology and neuroscience, with the aim of investigating the evolution of human cognition. His work extends from laboratory-based cellular-molecular neurobiology to the study of semiotic processes underlying animal and human communication, especially language. Many of these interests are explored in his 1997 book, *The Symbolic Species: The Coevolution of Language and the Brain*. His neurobiological research is focused on determining the nature of the human divergence from typical primate brain anatomy, the cellular-molecular mechanisms producing this difference, and the correlations between these anatomical differences and special human cognitive abilities, particularly language. In pursuit of these questions he has used a variety of laboratory approaches including the tracing of axonal connections, quantitative analysis of regions of different species brains, and cross-species fetal neural transplantation.

His theoretical interests include the study of evolution-like processes at many levels, including their role in embryonic development, neural signal processing, language change, and social processes, and how these different processes interact and depend on each other. Currently, his theoretical interests have focused on the problem of explaining emergent phenomena, such as characterize such apparently unprecedented transitions as the origin of life, the evolution of language, and the generation of conscious experience by brains. His latest book, *Incomplete Nature: How Mind Emerged from Matter*, offers a radical new approach to the riddle of consciousness.

**Deacon Abstract: Extra-terrestrial mentality is not just intelligence.** I worry that the term "extraterrestrial intelligence" somewhat misrepresents (or under-specifies) what we are actually looking for in a possible extra-terrestrial counterpart. Or rather it is only part of what is relevant; and the less relevant part at that. I believe that we are implicitly seeking what might better be described as sentient (or conscious) intelligence. I.e. we are not seeking to interact with some highly adaptive automatic computing device, except to the extent that it might store knowledge derived from the experience of sentient programmers. It is the sharing of experience with another sentient agent that is most of interest, not just interacting with some sophisticated clockwork automaton. The term 'intelligence' in many ways plays into the current tendency to confuse cognition with computation or behavioral adaptation. As a result it has significantly limited our capacity to represent the potential range of forms that minds might possibly take. What is critically lacking, both on and off the earth, is an adequate account of the dynamical nature of what constitutes a sentient/conscious process. Without this we inevitably limit our theorizing to merely extrapolating analogically from human experience or falling back on inadequate computational metaphors. For this reason, there is a significant overlap between the enterprise that we might call exo-psychology and the challenge of understanding the physical basis of human and animal conscious experience. So developing a general theory of mentality that is sufficient to include extra-terrestrial mentality requires us to pay special attention to this most enigmatic product of complex animal brains, and not only to the evolution of brains, behavioral adaptations, and problem-solving algorithms. Indeed, the challenge of trying to imagine the range of forms that extra-terrestrial mentality might take could provide important new insights into the mystery of conscious experience itself.

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**Kathryn Denning** is an Associate Professor of Anthropology at York University (Canada), where she is also a member of the Science & Technology Studies program. Denning's BA and MA are in anthropology from McMaster University, Canada, where she specialized in physical anthropology, North American archaeology, and archaeological method and theory, particularly pertaining to prehistoric health. She obtained her PhD in 1999 in Archaeology & Prehistory from the University of Sheffield (UK), focusing upon epistemic questions in archaeology, the social construction of the archaeological past in Britain, and the use of 'the ancient' in popular eschatology and theories of history. Some of her subsequent research concerns ethical issues in the display of living animals and dead humans in zoos and museums. Denning teaches in the broad areas of human biological, cultural, and technological evolution as understood through archaeology and anthropology, as well as STS approaches to astrobiology and other human interests in outer space.

Denning's work on life in the universe primarily focuses upon the use of Earth historical and cultural analogs within the SETI and astrobiology communities, particularly representations of evolutionary trajectories, and notions of contact. Denning has also presented and published on Active SETI debates, the societal aspects of SETI and astrobiology, and epistemologies of Earth analogs. Some recent work includes: "Social Evolution: State of the Field" in *Cosmos and Culture* (Dick and Lupisella, eds.); "Is Life What We Make of It?" in the Royal Society Symposium on *The Detection of Extraterrestrial Life and the Consequences for Science and Society* (Dominik and Zarnecki, eds.); and "Rethinking Life: Astrobiology and the Future of the Social, Behavioral, and Economic Sciences" (a white paper for National Science Foundation, with Margaret Race).

Denning is a member of the International Academy of Astronautics SETI Permanent Study Committee, including the Post-Detection Task Group, and related IAA groups. Being a member of Crew 78 at the Mars Desert Research Station sparked her ongoing work on the anthropology of Mars, particularly with respect to stewardship issues and the many roles of analogs. After the 100 Year Starship conference, she joined Icarus Interstellar as a contributor of anthropological perspectives. She is co-lead, with Margaret Race, of the Astrobiology & Society Focus Group of the NASA Astrobiology Institute. Her involvement, with Lori Marino, in the present project on Intelligence in Astrobiology is grounded in her belief that rigorous, empirically-grounded consideration of Earth's entire evolutionary history – from the first replicating chemistry to the present biological, cultural, and technological moment of your eyes reading these words on a screen – is essential to informed thought about life on Earth, life in the universe, and human expansion into space.

**Edna DeVore**. Science and astronomy educator Edna DeVore is the Deputy CEO and the Director of Education and Public Outreach (EPO) at the SETI Institute. She's been a researcher, planetarium director, teacher, and curriculum writer, and currently is busy with projects related to education and SETI. Notable among these are the "Life in the Universe" curriculum materials for students in grades 3-9 and a new high school course, "Voyages Through Time". Edna also co-directs the education and public outreach programs for two NASA missions: SOFIA and Kepler. SOFIA (Stratospheric Observatory for Infrared Astronomy) is a modified 747 commercial jet that will carry a large (2.5 m) telescope up to 45,000 feet to observe the universe in infrared wavelengths – a part of the spectrum which cannot be seen from the ground. The Kepler Mission is a space-based telescope that will hunt for Earth-sized planets in orbit about Sun-like stars.

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**Anna Dornhaus:** Complex societies in miniature - social insects like ants and bees, and their surprisingly sophisticated group and individual behaviors are my main research topics. I am a Behavioral Ecologist and an Associate Professor in the Ecology & Evolutionary Biology Department at the University of Arizona. Before the UA, I worked and studied at the University of Bristol with Nigel Franks, University of Wuerzburg with Lars Chittka, and the University of Freiburg. My group uses social insect colonies (bumble bees, honey bees and ants) as model systems for group organization, which are studied in the laboratory and in the field, as well as using mathematical and individual-based modeling approaches. For example, we investigate mechanisms of coordination in foraging, collective decision-making, task allocation and division of labor.

**Abstract: How does intelligence arise - from neuronal networks or any other system (unicellular organisms, aliens, computer programs)? And why is it there?** Neither of these fundamental questions about intelligence - which I take to mean some kind of flexible problem solving - has been answered. Although we understand a great deal about how individual neurons work, and also quite a bit about how animals perceive stimuli and and process this information, the link between these insights is uncharted territory: how do neurons have to be wired to allow an animal to recognize a food item and bring it back to its nest? How many neurons are necessary to achieve this? Insects seem to perform many complex behaviors (learning, tool use, communication) with tiny brains (perhaps only 10^5-10^6 as opposed to 10^11 in humans). Studying how behavior and decisions emerge from a network of information processing units in a completely different system, such a social insect colony, may help to uncover the general principles here. Why are some organisms more intelligent than others? Several types of environments have been identified that promote the evolution of particular cognitive skills, but what promotes the evolution of all-purpose problem-solving skills? In humans, sexual selection may be the only answer, but comparisons of more different organisms, especially invertebrates, and their environments should give us a more general answer.

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**Laurance R. Doyle** was raised along the California coast in the small town of Cambria. He attended San Diego State University and after receiving his Bachelor and Master of Science degrees in astronomy, he worked as an engineer with the Voyager spacecrafts in the Space Image Processing Group at the NASA Jet Propulsion Laboratory. He thereafter received his PhD from the University of Heidelberg in Germany in 1987 on radiative transfer modeling of Saturn's rings using Voyager imaging data. Since 1987 he has been a Principal Investigator with the SETI Institute in Mountain View, California where his main projects have been the photometric detection of extrasolar planets, the application of information theory to animal communications, and the application of quantum physics to solve certain astronomical problems. He has been a visiting Lecturer at the University of California, Santa Cruz teaching classes on Life in the Universe, and Light & Optics, and has about one hundred refereed papers in the scientific literature. He has taught quantum physics, thermodynamics, introductory astronomy, history of science and Native American history at Principia College in Illinois. During the 2010-2011 academic year he was the visiting Annenberg Scholar to Principia College in Elsah, Illinois. He is a Participating Scientist with the NASA Kepler Mission Science Team with responsibility for detection of extrasolar planets around double star systems (circumbinary planets) and in 2011 led the team that found the first transiting circumbinary planetary system, Kepler-16, nicknamed "Tatooine."

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**David Gold** is a Ph.D. candidate at the University of California, Los Angeles (UCLA). He studies developmental genetics in the moon jellyfish *Aurelia*, and animal fossils across the Precambrian-Cambrian boundary. You can find out more about his research at www.DavidGoldLab.com.

**Abstract:** The advent of phylogenomics has revolutionized our understanding of the animal tree of life. However, several important clades have proven difficult to constrain, and their ultimate placement will prove critical to our hypotheses of the trajectory of nervous system and brain evolution. I will discuss the importance of two of these ambiguous clades—the ctenophores and the acoel worms—and briefly discuss how future advances in solidifying the animal tree should give us new insights into the trajectory (or, more likely, trajectories) of nervous system complexity.

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**Lev Horodyskyj** completed his PhD in Geosciences and Astrobiology at Pennsylvania State University in 2009. He currently works in curricula development for ASU Online, focusing on developing innovative astrobiology online courses and virtual simulators for a variety of scientific concepts. His interests are in early terrestrial ecosystems and their biosignatures and more recently in online science education.

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**Chris Impey** is a University Distinguished Professor and Deputy Head of the Astronomy Department at the University of Arizona, in charge of academic programs. His research is on observational cosmology, gravitational lensing, and the evolution and structure of galaxies. He has over 170 refereed publications and 60 conference proceedings, and his work has been supported by $20 million in grants from NASA and the NSF. As a professor, he has won eleven teaching awards, and has been heavily involved in curriculum and instructional technology development. Impey is a past Vice President of the American Astronomical Society. He has also been an NSF Distinguished Teaching Scholar, a Phi Beta Kappa Visiting Scholar, and the Carnegie Council on Teaching's Arizona Professor of the Year. Impey has written over thirty popular articles on cosmology and astrobiology and authored two introductory textbooks. His has published three popular science books: *The Living Cosmos* (2007, Random House), *How It Ends* (2010, Norton) and *How It Began* (2012, Norton), and has three more in preparation. He was a co-chair of the Education and Public Outreach Study Group for the Astronomy Decadal Survey of the National Academy of Sciences. In 2009, he was elected a Fellow of the American Association for the Advancement of Science.

**Abstract**: Astrobiology is poised to come of age with the first detection of exobiology. There are probably a billion habitable worlds in the Milky Way and 100 billion times more in the observable universe. Unless the inception of biology on Earth and its subsequent evolution is a fluke or atypical, there will be many instances of extraterrestrial intelligent life forms. The difficulty of coming up with robust and generalized definitions of life and intelligence mean that broad thinking is warranted.

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**Lucia Jacobs** is an Associate Professor of Psychology and Neuroscience at the University of California at Berkeley. Since her Ph.D. research (Biology, Princeton), demonstrating spatial memory for cache locations in wild tree squirrels, she has established a comparative research program on the evolution of spatial navigation. Her work established for the first time a link between hippocampal size and mating system in wild rodents, as well as hippocampal size and food-storing strategy. This empirical work led to the development, with Françoise Schenk, of the parallel map theory (PMT) of navigation and hippocampal function, the first theory of hippocampal function derived from an evolutionary framework. PMT is being used now to explain patterns of results ranging from patterns of synaptic plasticity in rodent hippocampus to sex differences in navigation in humans navigating virtual environments. The research in the Jacobs Cog-Evo-Devo lab also focuses on social selection and its role in the evolution of decision making in foraging and social conflict situations, examining these processes in food-storing squirrels, domestic dogs and humans.

**Abstract: The evolution of spatial navigation.** The basic tenet of behavioral evolution is that behavior evolves in response to the distribution, in time and space, of critical resources, whether those be food, shelter or mating opportunities. This primacy of spatial navigation and memory may explain the extraordinary plasticity and rapid evolution of neural systems underlying this ability in mobile animals. Despite the multiple independent evolution of the brain and spatial learning across metazoans (vertebrates, insects, crustaceans, cephalopods), the cognitive tools with which animals encode spatiotemporal variations in resources across space are remarkably convergent. Patterns of spatial encoding that differ among species and sexes across diverse taxa suggest the existence of functional similarities in cognitive mechanism (e.g., parallel mapping) despite the divergence in neural structure.

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**Stephanie Langhoff** holds a B.S. in chemistry (1968) from Colorado College, a Ph.D. in physical chemistry (1973) from the University of Washington and a M.B.A (1998) from the Sloan School of Management at Massachusetts Institute of Technology. Her research interests are in the field of computational chemistry, especially electronic structure and molecular spectroscopy. Applications include re-entry physics, high-energy density materials, Earth science and astrophysics. She has authored or co-authored over 240 peer-reviewed journal and review articles. A publication list is available on the Institute for Scientific Information's highly cited researchers web site: http://isihighlycited.com/

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**Christopher Lowe** is an assistant professor at the Hopkins Marine Station, Department of Biology at Stanford University. His lab works in the general area of evolution of development or EvoDevo. We have a long-standing interest in the evolution of nervous systems and the link between morphological and molecular genetic innovations over large evolutionary distances. The animal systems that we work on are within the deuterostomes and include hemichordates and echinoderms.

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**Curtis W. Marean** received his Ph.D. in anthropology from the University of California at Berkeley 1990. From 1990 to 2001 he was on the faculty of the anthropology department at SUNY at Stony Brook, and in 2001 moved to Arizona State University. He is currently a professor in the School of Human Evolution and Social Change, and associate director of the Institute of Human Origins. His research interests focus on the record for the origins of modern humans in Africa. He is particularly interested in when, where, and how the suite of human uniqueness traits first appeared in the human lineage.

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**Lori Marino** is a Senior Lecturer in Psychology and a Faculty Affiliate of the Center for Ethics at Emory University in Atlanta. Dr. Marino received her Ph.D. in 1995 from the State University of New York at Albany where she began her current research program on cetacean and primate intelligence and brain evolution. Her specific interests are in brain-behavior relationships, the evolution of intelligence, self-awareness in other species, and, more recently, relationships between humans and other animals, animal protection and conservation.

Dr. Marino has worked collaboratively with The SETI Institute and in the broader domain of astrobiology for many years on projects related to the evolution of intelligence on this and other planets. From 2000-2004 she served on the Strategic Planning Committee for the SETI Institute Carl Sagan Center for the Study of Life in the Universe.

Dr. Marino has authored over 80 peer-reviewed papers, articles, book chapters and policy papers and has given numerous invited international talks. She teaches several courses at Emory in neuroscience, animal behavior, animal welfare, and brain imaging.

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**Jennifer Mather** teaches in the Department of Psychology at the University of Lethbridge, Canada, and has been studying the behaviour of cephalopods, mostly octopuses but also squid and cuttlefish, for over 30 years. My real love is to go out and see what the animals are doing in their natural environment, involving field work in Bermuda, Hawaii and Bonaire (in the Caribbean). But I have also collaborated extensively with Roland Anderson at the Seattle Aquarium, and we have looked at octopus personalities, play and problem solving, to name a few areas. I believe they may have a simple form of consciousness, and feel understanding how their foraging is behind their development of intelligence is important, so have been looking into that area lately.

**Abstract:** Cephalopods (we know more about octopuses) take a different evolutionary route to intelligence from vertebrates. They offer us five things to think about for development of intelligence. They are: you don't have to be social, you don't have to have a highly centralized nervous system, it helps to have manipulative capability, a complex environment and no protection can push you to intelligence, and evolution can result in some really strange adaptations (such as the fabulous skin display system). We don't know how these aspects of their natural history work—we're just starting to understand.

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**Stephen C. Pratt** is an Assistant Professor in the School of Life Sciences at Arizona State University. His research focuses on the emergence of complex social behavior in leaderless and decentralized animal groups, particularly social insects. He employs both theoretical and empirical approaches, and is also active in the development of bio-inspired algorithms for swarm robotics applications. He received a Ph.D. in neurobiology and behavior from Cornell University in 1997, and since then has worked at Harvard University, the Massachusetts Institute of Technology, Princeton University, and the University of Bath, United Kingdom.

**Abstract**: **The collective intelligence of insect societies.** The social insects vividly illustrate how intelligence can be a property of an entire group. A colony gathers information about itself and its environment, weighs options, and makes decisions in a manner analogous to a single organism. The colony's decisions are not mere summations of individual choices, but instead emerge in complex ways from the actions and interactions of colony members. This emergence of functional design at the level of an entire society is one of the great transitions in the evolution of biological complexity, on a par with the evolution of multicellular organisms from single-celled life forms. Indeed, comparison of the organismic and collective levels may reveal essential features of intelligence. Despite the obvious differences, common themes can be detected, including distributed processing across a large array of nodes (whether neurons or workers), highly decentralized control, a key role for positive feedback, and the importance of nonlinear interactions. In one way, however, social insects have a unique value to the study of intelligence: they exhibit it both as individuals and as whole colonies. This allows direct comparison of the abilities of the colony and its constituent members, shedding light on the advantages of sharing cognitive tasks across a group, and on possible tradeoffs between group and individual intelligence. In this way, studying the collective intelligence of insect societies can be of value beyond understanding the insects themselves.

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**Margaret S. Race** is an ecologist and Sr. Research Scientist at SETI Institute (Mountain View, California), who works with NASA and international space agencies on research and risk communication about astrobiology and planetary protection. Her current work focuses on legal and policy issues in space exploration, biosafety, and societal concerns related to astrobiology and the search for extraterrestrial life in the solar system. Race's long-term research has been on the public decision making process, environmental impact assessments, and policy issues associated with new technologies and science advances. Her interest in microbial intelligence is linked to basic astrobiology advances as well as to potential policy, management and ethical issues associated with life, biodiversity and environments on Earth and in outer space. Race received her BA (Biology) and MS (Energy Management & Policy) degrees from the University of Pennsylvania and her Ph.D. in Zoology (Ecology) from the University of California at Berkeley.

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**Nipam Patel** is Professor of Molecular Cell Biology and Integrative Biology at the University of California, Berkeley. He studies the evolutionary changes responsible for generating the diversity of life we see on Earth today, with a specific focus on the evolution of body patterning and segmentation at the molecular and genetic level. Dr. Patel received an A.B. from Princeton University and a Ph.D. from Stanford University. Before moving to Berkeley, he was a staff associate in the Department of Embryology at the Carnegie Institution, visiting fellow at the Australian National University, and a professor at the University of Chicago. Dr. Patel is a former co-director of the Woods Hole Embryology Course and a member of the scientific advisory board of the Whitney Marine Station of the University of Florida. His honors include an NSF Predoctoral Fellowship, McKnight Scholars Neuroscience Fellowship Award, the Butler Chair at the UC Berkeley, and he is an elected fellow of the American Association for the Advancement of Science (AAAS). He currently holds editorial positions with the journals *Evolution and Development*, *Development Genes and Evolution*, *Developmental Biology, Evo-Devo,* and is an editor for the journal *Development*.

**Patel Abstract**: Our work focuses on the evolution of development, with an emphasis on the mechanisms that have contributed to the diversity of arthropod bodyplans. Our recent work has revealed the potential role that Hox (homeotic genes) play in the evolution of bodyplans through the "tinkering" of segmental specification along the anterior-posterior axis. Using the model crustacean, *Parhyale*, we have been able to decipher the mechanisms that specify particular functional units used for feeding, walking, and swimming. These genes appear to have been used in evolution to generate morphological diversity, but we believe that at the same time these genes are used to maintain segments as functional units. An important aspect of this is to maintain integration between the nervous system and the appendages of each segment. This design allows for remarkable flexibility in the design and function of arthropod nervous systems and lays the groundwork for thinking about how complex nervous systems may evolve in independent lineages of organisms.

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**Carl B. Pilcher** is Director of the NASA Astrobiology Institute (NAI), a distributed research, training, and educational organization headquartered at the NASA Ames Research Center in Mountain View, California. http://astrobiology.nasa.gov/nai He received bachelors and doctorate degrees in chemistry from the Polytechnic Institute of Brooklyn and the Massachusetts Institute of Technology, respectively. Upon receiving his Ph.D., he joined the Institute for Astronomy (and later the Department of Physics and Astronomy) at the University of Hawaii, where he taught and conducted planetary science research for 12 years. His scientific research included discoveries of water ice in Saturn's rings and on three of Jupiter's Galilean satellites including Europa, now a high priority astrobiology exploration target because of its subsurface liquid water ocean. He also discovered and analyzed "weather" on Neptune and participated in the discovery of methane ice on Pluto.

He transitioned from academia to government through a master's degree from the Woodrow Wilson School of Public and International Affairs at Princeton University. His NASA management career began as Science Director in the Office of Exploration, established at NASA Headquarters by astronaut Sally Ride following the loss of the space shuttle Challenger. Dr. Pilcher subsequently held a series of NASA Headquarters management positions with responsibility, sequentially, for continued planning for human and robotic solar system exploration; strategic planning and developing international partnerships for the space science program; and scientific direction of the solar system exploration program. His transition to astrobiology was inspired by announcements, in 1995-96, of the first discoveries of planets around other stars and possible evidence of biological activity in the Martian meteorite ALH 84001. He initially assumed responsibility for astronomy-related astrobiology programs, then moved to overall management responsibility for the Astrobiology Program, and to his current position as NAI Director in September 2006.

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**Lynn Rothschild** is an evolutionary biologist/ astrobiologist at NASA Ames, and Professor at Stanford and Brown University, where she teaches Astrobiology and Space Exploration. She has broad training in biology, with degrees from Yale, Indiana University, and a Ph.D. from Brown University in Molecular and Cell Biology. Since arriving at Ames in 1987, her research has focused on how life, particularly microbes, has evolved in the context of the physical environment, both here and potentially elsewhere, and how we might tap into "Nature's toolbox" to advance the field of synthetic biology. Field sites range from Australia to Africa to the Andes, from the ocean to 100,000 feet on a balloon. In the last few years Rothschild has brought her expertise in extremophiles and evolutionary biology to the field of synthetic biology, addressing how synthetic biology can enhance NASA's missions. Rothschild is a Fellow of the Linnaean Society of London, the California Academy of Sciences and the Explorers Club.

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**Takao Sasaki** is a fourth year graduate student in Stephen Pratt's lab at Arizona State University. My research mainly focuses on how colony-level intelligence emerges from large numbers of relatively ignorant ants through simple behavioral rules and communication pathways. I adopt theories developed in psychology and economics for humans to explore the emergence of collective decision-making in ants.

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**Svetlana Shkolyar** has a background in physics, space studies, and science communication. I have experience working at the NASA Goddard Space Flight Center studying biosignatures in Mars analog samples as well as in astronomy public outreach. I am currently a first year PhD student in ASU's School of Earth and Space Exploration (SESE) with a research interest in astrobiology. I study various life detection techniques, including thermal life detection and spectroscopic detection and characterization of organics within sulfate minerals.

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**Seth Shostak** is the Senior Astronomer at the SETI Institute, in Mountain View, California. He has an undergraduate degree in physics from Princeton University, and a doctorate in astronomy from the California Institute of Technology. For much of his career, Seth conducted radio astronomy research on galaxies, and has published approximately sixty papers in professional journals. He has written over four hundred popular magazine, newspaper and Web articles on various topics in astronomy, technology, film and television. He lectures on astronomy and other subjects at Stanford and other venues in the Bay Area, and for six years was a Distinguished Speaker for the American Institute of Aeronautics and Astronautics. He is also Chair of the International Academy of Astronautics' SETI Permanent Study Group. Every week he hosts the SETI Institute's science radio show, "Are We Alone?" Seth has written, edited and contributed to a half dozen books. His most recent tome is *Confessions of an Alien Hunter: A Scientist's Search for Extraterrestrial Intelligence* (National Geographic).

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**Con Slobodchikoff** is Professor Emeritus, Biology Department, Northern Arizona University. Communicating with extraterrestrial intelligences is similar to the problem that we have in communicating with the intelligences that we have on Earth, namely the many animal species whose communication systems we are unable to decode. I have spent a number of years decoding the language of prairie dogs. My studies have shown that, at present, prairie dogs have the most sophisticated and complex animal language that has been decoded. Their alarm calls contain labels for different species of predators, such as coyote, domestic dog, human, and red-tailed hawk, and also contain labels that describe the physical features of individual predators, such as their color, size, and shape. The alarm calls are made up of phonemes, much like human words are made up of phonemes, that can be used in different combinations to generate the labels. The animals can also generate labels for objects that they have never seen previously. Prairie dogs have all of the criteria that Hockett listed as design criteria for language. I currently have a book in press exploring how many other animal species have language-like capabilities (*Chasing Doctor Dolittle*, St. Martin's Press).

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**Brian H. Smith** is a Professor in the School of Life Sciences at Arizona State University. Smith's laboratory specializes in linking behavioral analyses of olfactory and visual learning in honey bees to electrophysiology and optical imaging from the honey bee brain. His laboratory has extensive experience in using Proboscis Extension Conditioning of odors in honey bees to analyze nonassociative, associative and operant conditioning. In particular he has used these techniques to evaluate how odors are represented in neural activity patterns in the Antennal Lobes of the honey bee brain, and how these patterns change as a result of association of odors with different types of rewards. His laboratory has also published on genetic selection for differential learning abilities in honey bees, and he and coworkers have used quantitative trait locus mapping to identify regions of the genome correlated with phenotypic expression of a trait.

**Nicholas James Strausfeld** is a Fellow of the Royal Society of London and a recipient of a Guggenheim and a MacArthur Fellowship. He is a Regents' Professor in the Department of Neuroscience at the University of Arizona, Professor of Ecology and Evolutionary Biology, and an Adjunct Professor of Art. He currently directs the university's Center for Insect Science. His research incorporates three areas of interest. 1. Arthropod evolution, as indicated by brain organization and neural cladistics. 2. The evolution of neural organization in annelid and arthropod learning and memory centers. 3. Functional organization of the insect visual system. A synthesis of these research directions has been recently published by Harvard University Press under the title "Arthropod Brains. Evolution, Functional Elegance, and Historical Significance."

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**Douglas Vakoch** is the Director of Interstellar Message Composition at the SETI Institute, as well as the only social scientist employed by a SETI (Search for Extraterrestrial Intelligence) organization. Dr. Vakoch researches ways that different civilizations might create messages that could be transmitted across interstellar space, allowing communication between humans and extraterrestrials even without face-to-face contact. He is particularly interested in how we might compose messages that would begin to express what it's like to be human. Dr. Vakoch leads the SETI Institute's project to compose interstellar messages of the kind that may some day be sent in reply to a signal from extraterrestrials. As a member of the International Institute of Space Law, he examines international policy issues related to sending such responses. He serves as Chair of both the International Academy of Astronautics (IAA) Study Group on Interstellar Message Construction and the IAA Study Group on Active SETI: Scientific, Technical, Societal, and Legal Dimensions. Dr. Vakoch has published widely in scholarly books and journals in psychology, anthropology, astronautics, and the relationship between the arts and sciences. He is the editor of several books, including *Communication with Extraterrestrial Intelligence*, *Civilizations Beyond Earth: Extraterrestrial Life and Society*, *Psychology of Space Exploration: Contemporary Research in Historical Perspective*, and *Ecofeminism and Rhetoric: Critical Perspectives on Sex, Technology, and Discourse*. His work has been featured in newspapers and magazines such as the *New York Times, Nature, Science,* and *Der Spiegel.* As a spokesman on the cultural aspects of SETI, he has been interviewed on radio and television shows on the BBC, NPR, ABC, The Learning Channel, The Discovery Channel, and many others.

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**Sara I Walker** is a NASA Astrobiology Postdoctoral Fellow working in the Beyond Center for Fundamental Concepts in Science at Arizona State University. She completed her Ph.D. in Physics and Astronomy at Dartmouth College. She then worked as postdoctoral fellow in the NSF/NASA Center for Chemical Evolution and the NASA Astrobiology Institute Center for Ribosomal Origins and Evolution, based at the Georgia Institute of Technology. She is interested in how physical concepts central to the origins of life might inform our understanding of intelligence as well as how research in intelligence might inform novel modes of inquiry into the origins of life. Her research focuses on the origin of life, particularly on uncovering deeper physical principles that may play a role in the transition from nonliving to living systems. Sara is also member of the leadership council for the space science research and education non profit organization Blue Marble Space, where she is currently involved in an initiative to develop a grassroots educational and social networking website aimed at promoting unity with international awareness, education, and collaboration in space exploration, particularly within the astrobiology discipline.

**Walker Abstract: Is there a physics of intelligence?** The emergence of life and the evolution of intelligence are two seemingly disparate subjects, separated by a vast gulf in the scale of complexity from the self-organizing molecular assemblies that might initiate life, to the rudimentary 'intelligent' behavior displayed by even the simplest microbes. Yet, despite this disparity, they do share common ground: an understanding of both subjects relies on a fundamental knowledge of information and how it is processed in nature – a physical theory that is currently only in its infancy. A key-missing piece in the development of such a framework is a lack of theoretical work focused on the unique dynamics of systems where information plays an active role. We suggest some avenues of research that might illuminate a path forward toward achieving the goal of understanding the unique dynamics of `intelligent' systems, which builds on crossover between the origins and intelligence communities.

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**Tim White** is a Professor of Integrative Biology at U.C. Berkeley and Director of Human Evolution Research Center and Curator of Biological Anthropology at the P. A. Hearst Museum of Anthropology. My primary interests involve human evolution in all its dimensions. My research emphasizes fieldwork designed to acquire new data on early hominid skeletal biology, environmental context, and behavior. I have worked on hominids spanning the Pliocene and Pleistocene, from phylogenetic and functional perspectives. In parallel with this research, but in a more behavioral realm, I have investigated bone modification in the Pleistocene of the Old World and in the Holocene Southwest United States. Research underway includes fieldwork in Ethiopia and Turkey, and laboratory studies in both countries and in Berkeley.

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