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Bibliography and Annotations by: Arthur Fabel

Altmann, Gabriel, and Walter A. Koch, eds. *Systems: New Paradigms for the Human Sciences.* Berlin: Walter de Gruyter Inc., 1998.
Altmann and Koch present a European compendium that situates the human phase of existence in a self-developing universe.

Anderson, Philip, et al., eds. *Downward Causation: Mind, Bodies, and Matter.* Aarhus, Denmark: Aarhus University Press, 2000.
Essays in this volume explore how self-organizing, agent-based systems produce an increasing influence over lower or prior levels through higher order. This produces more consciously informed domains.

Anderson, Philip. "More Is Different: One More Time." In *More Is Different: Fifty Years of Condensed Matter Physics,* eds. Phuan Ong and Ravin Bhatt, 1–8. Princeton, N.J.: Princeton University Press, 2001.
Anderson, a Nobel prize-winning physicist, revisits his 1967 paper that helped to facilitate a change in scientific thinking from a rather narrow focus on subatomic domains toward a deeper understanding of the emergent complexity of the universe.

Bak, Per. *How Nature Works: The Science of Self-Organized Criticality.* New York: Springer-Verlag, 1996.
A succinct account of the theory of self-organization criticality poised between order and chaos.

Bar-Yam, Yaneer. *Dynamics of Complex Systems*. Reading, Mass.: Addison-Wesley, 1997.
Bar-Yam's accessible 800-page introduction to the dynamics of complex systems investigates a range of topics. He includes everything from first principles to protein folding, to neural networks, to the origin and evolution of life, and onwards toward an emerging global civilization.

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Barabasi, Albert-Laszlo. *Linked: The New Science of Networks.* Cambridge, Mass.: Westview Press, 1997.
In recent years, scientists have discovered that complex systems exhibit a common, universal behavior regarding the interconnection of nodes (agents) and links (local relations). One of the prime investigators of this theory reveals the story of this encounter with the nested, dynamic nature of great consistency.

Brown, James H., and Geoffery B. West, eds. *Scaling in Biology*. New York: Oxford University Press, 2000.
This collection of papers from a Santa Fe Institute conference explores the fractal and allometric scaling and self-similarity present in ecosystems, evolution, and the Metazoan anatomy and physiology.

Brown, James H., et al. “The Fractal Nature of Nature: Power Laws, Ecological Complexity and Biodiversity.” *Philosophical Transactions of the Royal Society of London B* 357 (2002): 619–32.
This article reveals insights on an intricate and tangled natural kingdom that is knowable by virtue of its universally recurring principles. The physical and biological diversity of the Earth’s surface and its inhabitants is complemented by emergent patterns that serve to unite them.

Buchanan, Mark. *Ubiquity: The Science of History, or Why the World is Simpler Than We Think.* London: Weidenfeld and Nicolson, 2000.
Buchanan’s accessible work describes how the nonlinear sciences reveal a type of “universality” (e.g., the same patterns and processes in evidence from cosmic origins to world history and economic society) through the independent dynamics of power laws and critical self-organization.

Chandler, Jerry, and Gertrudis Van de Vijver, eds. *Closure: Emergent Organizations and Their Dynamics.* Annals of the New York Academy of Sciences, vol. 901. New York: New York Academy of Sciences, 2000.
This collection of essays describes a “biosemiotic” autopoiesis—a sign-based organic viability—that pervades the natural realm as living systems that refer to and enhance their own internal definition and individuality.

Corning, Peter. *Nature’s Magic: Synergy in Evolution and the Fate of Humankind.* Cambridge: Cambridge University Press, 2003.
Corning argues that cooperative effects between components, such as genes or individuals, are as important as the components themselves. The theory posits that when cooperation produces beneficial functional effects or synergies, these effects may be favored or selected (synergistic selection). This synergy then plays a causal role in the evolution of emergent complexity from the origin of life to human societies.

Cowan, George, et al., eds. *Complexity.* Reading, Mass.: Addison Wesley, 1994.
This compendium of papers explores unifying themes of complex adaptive systems and includes articles by Philip Anderson, Brian Arthur, Per Bak, Walter Fontana, Murray Gell-Mann, Brian Goodwin, John Holland, Erica Jen, Stuart Kauffman, Melanie Mitchel, Peter Schuster, and many others.

Deacon, Terrence. “Three Levels of Emergent Phenomena.” *Science and the Spiritual Quest.* Berkeley, Calif.: Center for Theology and the Natural Sciences, 2001.
Deacon, a biological anthropologist, utilizes complexity theory to explain a self-organizing evolution that brings forth life and mind.

de Rosnay, Joel. *The Symbiotic Man: A New Understanding of the Organization of Life and a Vision of the Future.* New York: McGraw-Hill, 2000.

Flake, Gary. *The Computational Beauty of Nature: Computer Explorations of Fractals, Chaos, Complex Systems, and Adaptation.* Cambridge, Mass.: MIT Press, 1998.
Flake provides a technical appreciation, through nonlinear science, of the recurrent harmony of the natural kingdoms.

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Fontana, Walter, and Leo Buss. "The Arrival of the Fittest." *Bulletin of Mathematical Biology* 56, no. 1 (1994): 37–56.

Natural selection is unable to explain how organisms occur. This oft-cited paper, however, proposes that an independent dynamic, autopoietic networks, serve to organize a hierarchical scale of life.

Freeman, Walter J. "Foreword." In *The Complex Matters of the Mind,* ed. Franco Orsucci, xi–xvii. River Edge, N.J.: World Scientific, 1998.

Freeman discusses the transition in physics and biology from Newtonian dynamics to nonlinear dynamics. He argues that that Newtonian dynamics is "rigid, deterministic, and predictable" whereas nonlinear dynamics "opens a vast field of complexity to exploration and modeling" (xiii). One key concept present in nonlinear dynamics, self-organization, enables us to create new structures from within.

Gisiger, Thomas. "Scale Invariance in Biology: Coincidence or Footprint of a Universal Mechanism?" *Biological Reviews* 76, no. 2 (2001): 161–209.

After an introduction to dynamical systems in their physical embodiment, from which a power law self-similarity is established, Gisiger postulates that properties are shown to pervade biological and neurological realms so as to affirm "universality" throughout nature.

Goldberg, Elkhonon. *The Executive Brain: Frontal Lobes and the Civilized Mind.* New York: Oxford University Press, 2001.

A Russian-American neuroscientist recounts a lifetime of clinical experience and presents a novel synthesis of brain evolution. A universal complex system is seen to drive this process of encephalization from isolated thalamic modules to the mammalian neocortex with its gradiental, neural net integration. The same sequence, Goldberg argues, can be observed on a global scale as nation-states break up into autonomous microregions.

Grand, Steve. *Creation: Life and How to Make It.* Cambridge, Mass.: Harvard University Press, 2001.

Grand, a computer scientist, writes about a quickening universe that intrinsically organizes itself. He argues that "[w]e now have quite a towering hierarchy of more and more sophisticated forms of persistence: photons, particles, atoms, molecules, autocatalytic networks, self-reproducing systems, adaptive systems, intelligence, and mind. . . . [W]e can perhaps add society as another level of being. A society is a self-sustaining emergent phenomenon that comes into existence among populations of communicating and interdependent organisms, just as an organism is an emergent phenomenon that comes into being among populations of interdependent cells" (p 60).

Hazen, Robert. "Emergence and the Origin of Life." *Astrobiology* 1, no. 3 (2001): 234–52.

In this abstract from the April 2001 NASA Astrobiology Institute General Meeting, Hazen argues that the study of life and intelligence on the scale of the universe gives credence to its self-organizing dynamics and their resultant scale of sentient complexity.

Helbing, Dirk. "Traffic and Related Self-Driven Many-Particle Systems." *Reviews of Modern Physics* 73, no. 4 (October, 2001): 1067–1142.

Helbing presents an extensive survey of how human behavioral patterns such as vehicular and pedestrian traffic have a mathematical basis in terms of nonlinear dynamical theories. He finds a power-law criticality that, by its universality, can be seen to apply to biological economic, and cognitive systems.

Heylighen, Francis, et al., eds. *The Evolution of Complexity: The Violet Book of "Einstein Meets Magritte."* Dordrecht: Kluwer Academic Publishers, 1999.

This book is one of eight volumes from the interdisciplinary conference, "Einstein Meets Magritte," held in Brussels in 1996. The series' premise is that evolution leads to systems of increasing complexity. In this particular volume, the editors aim to incorporate complex adaptive systems into general systems theory.

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Holland, John. *Hidden Order: How Adaptation Builds Complexity.* Reading, Mass.: Addison-Wesley, 1995.

Holland's work, an introduction to complex adaptive systems, discusses how many autonomous agents engaged in networks of interaction, immersed in an environment, and guided by tacit rules, will give rise to emergent organization and behavior.

_______. *Emergence: From Chaos to Order.* Reading, Mass.: Addison-Wesley, 1998.

Holland provides additional explorations of complex adaptive systems and argues that they contain a propensity toward ascendant scales of complexity. Questions concerning the human condition, he argues, "will depend on understanding the emergent properties of [these] systems" (p 2).

Ilachinski, Andrew. *Cellular Automata: A Discrete Universe.* Singapore: World Scientific, 2001.

Illachinski provides an understanding of the computer-based physics and mathematics of nonlinear systems and argues that these phenomena reveal a discrete, information-rich universe in the process of organizing and discovering itself. He also provides theoretical support for a radically creative, increasingly personified reality.

Johnson, Steven. *Emergence: The Connected Lives of Ants, Brains, Cities, and Software.* New York: Scribner, 2001.

Johnson, a computer scientist, explains how a spontaneously creative nature employs the same pattern and dynamics of multiple interacting agents at every stage—from social insects to neural nets, cities, and computer software.

Kauffman, Stuart A. *The Origins of Order: Self Organization and Selection in Evolution.* New York: Oxford University Press, 1993.

Kauffman describes an innate self-organization of complex living systems prior to the winnowing action of natural selection.

_______. *Investigations.* New York: Oxford University Press, 2000.

This volume reveals Kauffman's latest insights regarding a view of Earth-life that creates itself by means of intentional, autonomous agents that continually expand the niche of animate complexity. He offers glimpses of a "fourth law of thermodynamics," a "general biology" for emergent life, autocatalytic biospheres, and a "coconstructing cosmos."

Kiel, L. Douglas. "Knowledge Management, Organizational Intelligence and Learning, and Complexity." *UNESCO-EOLSS Joint Committee. Knowledge for Sustainable Development.* vol. 1. Paris: UNESCO Publishing, Oxford: EOLSS Publishers, 2002.

Kiel argues that as complexity sciences become familiar, they are causing organizations to become more dynamic, adaptive, ecologically sensitive, and educative (e.g., in continual process of learning). Scholars are also beginning to recognize that the theories of complexity and self-organization that shape the natural universe are applicable to the development of human culture and activities.

Kitano, Hiroaki. "Computational Systems Biology." *Nature* 420, no. 6912 (14 November 2002): 206–10.

Kitano introduces a special journal section on the application of sophisticated mathematical concepts and computer software that are capable of discerning universal principles across biomolecular, genetic, cellular, and organismic levels.

Laughlin, Robert, and David Pines. "The Theory of Everything." *Proceedings of the National Academy of Sciences* 97, no. 1 (4 January 2000): 28–31.

Laughlin and Pines argue that the continual search for an elemental level in physics should be abandoned for a new century of synthesis based on the emergent hierarchy of nature.

Lehn, Jean-Marie. "Toward Self-Organization and Complex Matter." *Science* 295, no. 5564 (29 March 2002): 2400–2403.

Lehn contends that a cross-fertilization between complex systems, biological evolution, and

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chemistry leads to a synthesis of self-organization and selection as a science of dynamically adaptive “informed matter.”

Mikhailov, Alexander S. *From Cells to Societies: Models of Complex Coherent Action.* Berlin: Springer, 2002.
Using an approach to self-organizing systems known as synergetics, Mikhailov finds that general principles characterize the collective behavior of populations of interactive agents.

Miller, James G. *Living Systems.* New York: McGraw-Hill, 1978.
A classic treatise on the nested, hierarchical organization of biological and social life wherein twenty critical subsystems that process either matter-energy or information, repeat at each subsequent level. These similar, isomorphic features “thread out” at each stage from the genetic to the global. The resultant field of living systems theory has been further elaborated in the journals *Behavioral Science* and its successor *Systems Research and Behavioral Science*.

Minkel, J. R. “Hollow Universe.” *New Scientist* 27, no. 2340 (April 27, 2002): 22–26.
At the frontier of physics is the theory of an information-based, fine-grained, holographic cosmos where the same “image,” “message,” or “system” plays out everywhere in its emergent development. Minkel speculates that nature stores data about basic elements in a similar manner to how holograms are produced. “In a conventional hologram, a laser beam bouncing off an object is mixed with another laser beam and the resulting interference pattern is recorded on a flat surface. Shine new light onto the recording, and a three dimensional image leaps out. If nature works like this, then information somehow lives on the boundary of any region of spacetime. The material stuff within that boundary, the objects that we perceive and touch, is just the unpacked, higher-dimensional manifestation of that hologram. That is the holographic principle” (p 24).

Morowitz, Harold, and Jerome Singer, eds. *The Mind, the Brain, and Complex Adaptive Systems.* Reading, Mass.: Addison-Wesley, 1995.
Morowitz and Singer describe a paradigmatic shift in science over the past two decades. Drawing on examples in fields ranging from astrophysics to economics to psychology, the editors document a growing theoretical focus on complex adaptive systems and present a departure from traditional linear, cause-effect, scientific models.

Mumford, David, et al. *Indra’s Pearls: The Vision of Felix Klein.* Cambridge: Cambridge University Press, 2002.
With computers consistently increasing in speed, software programs are now able to graphically depict, in color, Felix Klein’s mathematical theories from the last century. Klein’s concepts disclose a fractal self-similarity that seems to pervade nature on every scale. This similarity seems to correspond to an ancient Buddhist vision of reality as a net or web of pearls. Just as each pearl in the web of the Buddhist reality reflects the entire universe, Klein’s equations and images convey a universally repeated interrelationship, a mutual identity, among every domain and member of the cosmos.

Nadeau, Robert, and Menas Kafatos. *The Non-Local Universe: The New Physics and Matters of the Mind.* New York: Oxford University Press, 1999.
Nadeau and Kafatos offer a synthesis of physics and biology that describes the cosmos as a unified, organic whole. The results of sophisticated experiments demonstrating that widely separated objects have been found to be in instant contact with each other seem to imply a seamless, holistic reality. At each subsequent stage, such a universe develops levels of increasing complexity and sentience due to a complementary interplay of particle and wave, entity and relation, analysis and system. This information could provide scientists with “. . . a basis for better understanding how increasing levels of complexity in both physical and biological reality result from the progressive emergence of collections of parts that constitute new wholes that display properties and behavior that cannot be explained in terms of the sum of the parts” (p 103).

New England Complex Systems Institute. updated n.d. http://www.necsi.org (cited 3 August 2003).
This multifaceted site contains general and specific information about nonlinear system properties. This group also runs the biannual International Conference on Complex Systems in Nashua, New Hampshire.

Oltvai, Zoltan N., and Albert-Laszlo Barabasi. "Life's Complexity Pyramid." *Science* 298, no. 5594 (25 October 2002): 763–64.
In their synoptic report, the authors propose that nature is arrayed in an emergent scale with the same form and dynamics in effect everywhere. "At the lowest level, these components form genetic-regulatory motifs or metabolic pathways (level 2), which in turn are the building blocks of function modules (level 3). These modules are nested, generating a scale-free hierarchical architecture (level 4). Although the individual components are unique to a given organism, the topologic properties of cellular networks share surprising similarities with those of natural and social networks. This suggests that universal organizing principles apply to all networks, from the cell to the World Wide Web" (763).

Perez-Mercader, Juan. "Scaling Phenomena and the Emergence of Complexity in Astrobiology." In *Astrobiology: The Quest for the Conditions of Life,* eds. Gerda Horneck and Christa Baumstark-Khan, 337–60. New York: Springer, 2002.
In recently published literature, scientists describe a new concept of the universe whose emergent, nested stages express not only a sequence of whole stages from atom to human to cosmos, but also a universality where the same, invariant form and process recurs over and over.

Pietronero, Luciano. "The Simple and the Complex: Scale Invariance and Self-Organization from Physics to Biology." In *Frontiers of Life,* vol. 1., eds., David Baltimore, Renato Dulbecco, Francois Jacobs, Rita Levi-Montalcini, 69–86. San Diego, Calif.: Academic Press, 2002.
This article, from the four-volume compendium of research on the *Frontiers of Life,* presents challenges from physics to intelligent and ecological systems that illustrate how the complexity of the sciences and the principle of self-organization have helped researchers understand the universe as being more conducive to the development of life and mind.

Prigogine, Ilya, and Isabelle Stengers. *Order Out of Chaos: Man's New Dialogue With Nature.* New York: Bantam, 1984.
This early work established significant groundwork for subsequent complexity sciences. A Nobel Prize-winning chemical physicist and a philosopher articulate how a concept of nonequilibrium, the thermodynamics of life, demonstrates that the cosmos is not deterriorating but is rather engaged in the process of becoming.

_______. *The End of Certainty: Time, Chaos, and the New Laws of Nature.* New York: The Free Press, 1997.
The authors maintain that the new sciences reject the old doctrine of a deterministic universe where time is reversible, in favor of an irreversible, creative self-organization.

Rosnay, Joel de. *The Symbiotic Man: A New Understanding of the Organization of Life and a Vision of the Future.* New York: McGraw-Hill, 2000.
A systems scientist employs the "third infinity" of complexity as a "macroscope" to project a directional evolution to its latest stage of a global superorganic brain and being. This emergence is facilitated and structured by a fractally organized symbiosis.

Santa Fe Institute. updated n.d. http://www.santafe.edu (cited 3 August 2003).
The Santa Fe Institute, a major center for the study and application of complex system views of the natural and human world, provides cutting-edge working papers on research in this field.

Schroeder, Manfred. *Fractals, Chaos, Power Laws: Minutes From An Infinite Paradise.* New York: W. H. Freeman and Co., 1991.
Schroeder provides a rich, dense excursion through the "paradise" of mathematical topologies in search of an intrinsic commonality. He argues that "[t]he unifying concept underlying fractals, chaos, and power laws is self-similarity. Self-similarity, or invariance against changes in scale

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or size, is an attribute of many laws of nature and innumerable phenomena in the world around us. Self-similarity is, in fact, one of the decisive symmetries that shape our universe and our efforts to comprehend it" (p xiii).

Schuster, Peter. "How Does Complexity Arise in Evolution: Nature's Recipe for Mastering Scarcity, Abundance, and Unpredictability." *Complexity* 2, no. 1 (September/October 1996): 22–30.
A systems biologist describes the general sequence by which new hierarchical levels are evolved: independent entities first compete for their own benefit. As congregations grow, mutual dependence based on reproductive success becomes more advantageous. A further coupling leads to modular functional units. Finally, such integration creates a new class of individuals to restart the emergent cycle.

Schweitzer, Frank, ed. *Self-Organization of Complex Structures: From Individual to Collective Dynamics.* London: Gordon & Breach, 1996.
This collection of forty-seven papers inspired by synergetic thinking explores the rise of complexity in biological, ecosystem, economic, and urban areas. These studies seek a theoretical continuity between human civilization and the natural patterns and processes from which they have arisen.

Segel, Lee A., and Irun R. Cohen, eds. *Design Principles for the Immune System and Other Distributed Autonomous Systems.* Oxford: Oxford University Press, 2001.
The authors depict how the dynamic interrelationship of many independent agents, as a generic phenomenon, leads to emergent organization and behavior in immune reactions, biochemical systems, social insects, and computer information processing.

Simon, Herbert. A. *The Sciences of the Artificial.* 3rd ed. Cambridge, Mass.: MIT Press, 1996.
Simon's standard source on why the world is arranged in a hierarchical sequence is told through the oft-quoted tale of the watchmakers Hora and Tempus. Hora used ten-piece subassembly modules so that in a 1,000-piece watch any defect or lapse could be easily repaired. Tempus utilized all 1,000 pieces simultaneously. This meant that any error in the piece required the whole watch to be rebuilt.

Smolin, Lee. *The Life of the Cosmos.* New York: Oxford University Press, 1997.
Smolin explains why the universe is theoretically compelled to generate complex structure and sentient life. He argues that physics and biology can be reunited in a cosmos distinguished by nested hierarchies of self-organized systems. Smolin also speculates that twentieth-century physics results in a universe that is hospitable to life because it is characterized by structure and variety.

Stanley, H. Eugene, et al. "Scaling and Universality in Animate and Inanimate Systems." *Physica A* 231, no. 1 (1996): 20–48.
Stanley details mathematical reasons why nature is characterized by the same dynamic, self-organized critical system from crystalline lattices to DNA base pairs, heartbeat intervals, neighborhood geometries, and economic markets. This journal reports on an unexpected convergence between statistical physics and biological phenomena.

Waldrop, Mitchell. *Complexity: The Emerging Science at the Edge of Order and Chaos.* New York: Simon & Schuster, 1993.
A science writer spins a vivid, insightful narrative of the Santa Fe Institute, a place that has been the center for innovative work in nonlinear science since 1984. In vignettes, John Holland explains the complex adaptive systems he sees in everything from cells to ecosystems. In effect he recounts Stuart Kauffman's epiphany as he formed his self-organization vision: "I had a holy sense of a knowing universe, a universe unfolding, a universe of which we are privileged to be a part. I felt that God would reveal how the world works to anyone who cared to listen" (p 133).

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Ward, Mark. *Universality: The Underlying Theory Behind Life, the Universe, and Everything.* London: Macmillan, 2001.
Ward provides an account of the scientific discovery that argued that the same dynamical processes are present from quanta and galaxies to human biology and society.

Wolfram, Stephen. *A New Kind of Science.* Champaign, Ill: Wolfram Media, 2002.
Wolfram, the physicist who conceived the theory of cellular automata and introduced the Mathematica software program, contends that the present universe is a result of the expression or computation of simple rules or algorithms that, as they recursively run, generate a complex, variegated reality from which humans emerge.

3.0 The Creative Development of the Universe

This chapter documents the way in which the cosmos has spawned life and consciousness.

3.1 Cosmogenesis

This section highlights a collection of reports explaining why the universe can be understood as an inherently fertile environment for the flourishing of life, mind, and self-reflective beings.

Quantum Cosmology

Aczel, Amir D. *Entanglement: The Greatest Mystery in Physics.* New York: Four Walls Eight Windows, 2002.
Aczel explains the concept of "entanglement" in quantum physics. Entanglement occurs when two subatomic particles are somehow connected with one another. This connection leads to an interdependent relationship (e.g., if something happens to one particle, the same thing simultaneously happens to the other particle—even if it is a great distance away from its partner) between the two particles.

Astronomical Society of the Pacific Conference Series. Vols. 1–335. San Francisco, Calif.: The Astronomical Society of the Pacific, 1988–2005.
Comprised of more than 200 volumes, this series contains information on the latest research and advances in cosmological science.

Barbour, Julian B. *The End of Time: The Next Revolution in Physics.* Oxford: Oxford University Press, 2000.
Barbour finds that among ruminations about the chimera of duration resides a Leibnizian view, opposed to Cartesian-Newtonian materialism, which perceives a finely variegated reality with each phase formed by a common principle.

Bohm, David. *Wholeness and the Implicate Order.* London: Routledge & Kegan Paul, 1980.
The philosophical physicist describes how an explicit, overt universe, its life-forms, and the concept of consciousness emanates from and reflects an implicit, unmanifested order within the universe itself.

Bousso, Raphael. "The Holographic Principle." *Reviews of Modern Physics* 74, no. 3 (July 2002): 825–74.
This technical paper portrays a discrete, information-rich universe akin to a hologram, in which the informational content or measure of a three-dimensional volume of space is proportional to the area of its two-dimensional outer surface.

Cartlidge, Edwin. "Microwaves Map Cosmic Origins." *Physics World* 14, no. 6 (June 2001): 5–6.
Cartlidge argues that the latest satellite results confirm an inflationary model of the universe and an appreciation of a scale-invariant universe.

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Ferris, Timothy. *The Whole Shebang: A State-of-the-Universe(s) Report.* New York: Simon & Schuster, 1997.
Ferris, a science writer, provides information regarding current notions of cosmic evolution.

Greene, Brian. *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory.* New York: Norton, 1999.
Greene's exposition of frontier physics and multi-dimension string theory strives to unify the quantum and relativity domains.

Guth, Alan H. *The Inflationary Universe: The Quest for a New Theory of Cosmic Origins.* Reading, Mass.: Addison-Wesley, 1997.
Guth proposes that a sudden expansion of the cosmic singularity in its first seconds resolves mathematical and observational disagreements. His model has become generally accepted among contemporary cosmologists.

Hawking, Stephen. "A Brief History of Relativity." *Time.* 31 December 1999, 66–70, 79–81.
Hawking provides a succinct review of modern physics in this piece written for a specific issue (e.g., the Albert Einstein "Person of the Century" issue) of *Time* magazine.

Hogan, Craig J. "Enhanced: The Beginning of Time." *Science* 295, no. 5563 (22 March 2002): 2223–25.
The latest observations from the COBE and MAP satellites connect cosmic and quantum fields through a vast inflation of the universe in its first instants. These findings are in accordance with the multiverse scenario along with its holographic properties.

Linde, Andrei. "The Self-Reproducing Inflationary Universe." *Scientific American* 271, no. 5 (November 1994): 48–55.
Linde describes the universe as a "self-generating fractal" that reproduces in an analogous biological fashion.

Los Alamos National Laboratory Research Library Website. updated 18 April 2005. http://library.lanl.gov/libinfo/ (cited 22 June 2005).
This website showcases a huge source of original e-print papers on technical realms from quantum theory to complex adaptive systems.

Malin, Shimon. *Nature Loves to Hide: Quantum Physics and the Nature of Reality, A Western Perspective.* New York: Oxford University Press, 2001.
Quantum physics, with its roots in the philosophical traditions of Plato and Plotinus, can set aside the machine model to reveal an organic universe that springs from an immaterial source. Alfred North Whitehead's twentieth-century philosophy of a dynamic cosmic organism provides an additional resource for Shimon's thesis. Through this meld of quantum observership and ancient wisdom, human life gains purpose through its creative contemplation of the universe.

Peacock, John A. *Cosmological Physics.* Cambridge: Cambridge University Press, 1999.
Peacock presents information regarding relativity theory, quantum fields, galaxy formation, and an embryonic, developing cosmos.

Pecker, Jean-Claude. *Understanding the Heavens: Thirty Centuries of Astronomical Ideas from Ancient Thinking to Modern Cosmology.* Berlin: Springer-Verlag, 2001.
This comprehensive history of cosmology describes a Renaissance macrocosm-microcosm analogy that is currently represented by the pervasive fractal character of the galactic universe.

Rowan-Robinson, Michael. *The Nine Numbers of the Cosmos.* New York: Oxford University Press, 1999.
Rowan-Robinson argues that scientists can comprehend the universe by considering the totality of the density of baryonic matter, anisotropy, the rate of expansion, the age, the microwave background temperature, the density of both cold and hot dark matter, the cosmological constant, and star formation history.

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Samuel, Eugene. “What Lies Beneath.” *New Scientist* 173, no. 2329 (9 February 2002): 24–27.

Smolin, Lee. “The New Universe Around the Next Corner.” *Physics World* 12, no. 12 (December 1999): 79–84.
Smolin provides a preview of the potential twenty-first century unification of relativity, quantum mechanics, particle physics, and cosmology through a quantum theory of gravity. What appears on the horizon, according to Smolin, is a reality composed of discrete, Planck-size grains contained in pervasive relational networks, all of which share the basic aspect of informational quality: “The fundamental ‘stuff’ of the world,” according to Smolin, “ . . . will be the flow and transformation of information” (p 82).

_______. *Three Roads to Quantum Gravity.* New York: Basic Books, 2001.
Smolin reports on efforts to unify quantum and relativity physics by means of loop quantum gravity, string theory, and black hole thermodynamics. His insight offers glimpses of a fractal or hologram-like cosmos, a duality of particles and relations, self-similar networks, and an inherently self-organizing development.

Turner, Michael S., and J. Anthony Tyson. “Cosmology at the Millennium.” *Reviews of Modern Physics* 71, no. 2. Special Issue. (March 1999): S145–S164.
In the twentieth century, humankind was able to observe and describe, in word, number, symbol, and equation, a vast, developing galactic cosmos.

An Organic Universe

Alper, Joseph. “It Came From Outer Space.” *Astronomy* 30, no. 11 (November 2002): 36–41.
New spectral evidence suggests that the universe generates and is filled with precursor biomolecules for life that constantly bathe the Earth in their flow.

Capra, Fritjof. *The Web of Life: A New Synthesis of Mind and Matter.* New York: Anchor Books, 1995.
The nonlinear sciences of self-organization, chaos theory, thermodynamics, and fractal complexity serve as a basis for an ecological philosophy. Fritjof dedicates a chapter to the “self-making” role of autopoietic systems.

Davies, Paul. “Physics and the Mind of God.” In *Mathematical Undecidability, Quantum Nonlocality and the Question of the Existence of God,* eds. Alfred Driessen and Antoine Suarez, 193–202. Dordrecht: Kluwer Academic, 1997.
An integration of cosmology and complexity reveals an organic cosmos suffused with signs of order and purpose. Davies maintains that the emergence of life and consiousness is intrinsic to the laws of the universe.

de Duve, Christian. *Vital Dust: Life as a Cosmic Imperative.* New York: Basic Books, 1995.
A Nobel Prize-winning biochemist depicts a cosmos that is seemingly made for life and people. De Duve’s universe is not inert but infused with life. The structure of the universe, he argues, is imbued with meaning.

Dick, Steven J., ed. *Many Worlds: The New Universe Extraterrestrial Life and the Theological Implications.* Philadelphia, Pa.: Templeton Foundation Press, 2000.
Dick explores the scientific and theological implications of a “biological universe” ordained to bring forth intelligent life and spiritual consciousness.

Gardner, James. “The Selfish Biocosm.” *Complexity* 5, no. 3 (29 March 2000): 34–45.
Gardner speculates about a biological cosmos whose complex adaptive systems generate scales of sentient life. In its entirety, the universe appears as a self-organizing, organic replicator with selection taking place on every scale. This biocosm is a participatory universe with intelligence and mind progressively involved in its creation.

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Harman, Willis W., and Elisabet Sathouris. *Biology Revisioned.* Berkeley, Calif.: North Atlantic Books, 1998.
Systems scientist Willis Harman and biologist Elisabet Sahtouris collaborate to affirm a holistic, living universe wherein autopoietic and symbiotic processes create and sustain a nested holarchy of whole systems at all levels—from macrocosm to microcosm.

Kauffman, Stuart. *At Home in the Universe: The Search for Laws of Self-Organization and Complexity.* New York: Oxford University Press, 1995.
Kauffman, one of the originiators of the complex systems vision, presents a popular introduction to the field that intends to reunite human beings with a self-organizing cosmos.

Lumsden, Charles, et al., eds. *Physical Theory in Biology: Foundations and Explorations.* Singapore: World Scientific, 1997.
The editors have selected a collection of technical papers set in either the mechanical or organic paradigm, that attempt a unification of life and matter.

McFadden, Johnjoe. *Quantum Evolution: The New Science of Life.* New York: Norton, 2001.
In this piece McFadden hypothesizes that the roots of emergent, sentient life can be traced to quantum principles.

Nozick, Robert. *Invariances: The Structure of the Objective World.* Cambridge, Mass.: Harvard University Press, 2001.
Nozick, a philosophy professor, considers how recent tendencies in cosmological theory accords the universe with organic and Darwinian features.

Salthe, Stan N. "Natural Philosophy and Developmental Systems." *Systems Research and Behavioral Science* 18, no. 5 (September/October 2001): 403–10.
Salthe presents a once and future integral knowledge of a cosmic and earthly gestation.

Shapiro, Robert. *Planetary Dreams: The Quest to Discover Life Beyond Earth.* New York: J. Wiley, 1999.
Shapiro establishes a contrast between the negative materialist and positive organic positions as to whether the self-organizing universe should be filled with intelligent beings. He favors the idea that there are many intrinsic reasons for prolific life.

Smoot, George, and Keay Davidson. *Wrinkles in Time.* New York: W. Morrow, 1993.
Smoot, the astrophysicist who led the COBE satellite team that detected primordial ripples as seeds for galaxy formation, offers a diametricly opposed view of Steven Weinberg's position, by claiming that the universe has both meaning and an underlying unity.

Stevenson, David J. "Planetary Oceans." *Sky & Telescope* 104, no. 5 (November 2002): 38–44.
As the search for extrasolar planets and life proceeds through the implementation of new instrumentation on both Earth and in space, Stevenson argues that liquid water seems to be prevalent throughout the universe as the indispensable medium for life.

Swimme, Brian. *The Hidden Heart of the Cosmos: Humanity and the New Story.* Maryknoll, N.Y.: Orbis Books, 1999.
Swimme's book celebrates the concept of a life-bearing universe as it develops from its fecund fireball to the human presence.

A Conscious, Intelligent Cosmos

Carter, Rita. *Exploring Consciousness.* Berkeley, Calif.: University of California Press, 2002.
Carter's comprehensive book explores the scientific study of sentience and contains many comments on the topic by leading theorists in the field.

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Donald, Merlin. *A Mind So Rare: The Evolution of Human Consciousness.* New York: W. W. Norton, 2001.

Donald, a psychologist, defends consciousness as real, active, informed, and as the central phenomenon of an emergent evolution. The human brain, he argues, is unique due to interactions with an ever-thickening web of culture. First revealed in his book, *The Mind of Humankind,* these insights reveal a social cognizance—an embryonic collective mind and knowledge.

Goswami, Amit. *The Self-Aware Universe: How Consciousness Creates the Material World.* New York: Putnam Publishing Group, 1993.

Goswami, a physicist, interprets quantum theories in a way that indicates that consciousness, not matter, is the ultimate essence of all being. He argues that science can embrace religion to help both fields better understand the human condition.

Green, Herbert S. *Information Theory and Quantum Physics: Physical Foundations for Understanding the Conscious Process.* Berlin: Springer, 2000.

In this book Green hypothetically links consciousness with a quantum universe that is distinguished by its informational qualities. He argues that these elements are now encapsulated in human beings who perform the cosmologically necessary act of observership.

Kafatos, Menas, and Robert Nadeau. T*he Conscious Universe: Parts and Wholes in Physical Reality.* 2nd ed. New York: Springer, 2000.

Kafatos argues that if the implications of a holistic, non-local quantum theory are fully pursued, they would suggest a cosmos where mind and complementarity are both primary and sequentially emergent.

King, Chris. "Quantum Mechanics, Chaos, and the Conscious Brain." *Journal of Mind and Behavior* 18. nos. 2–3 (Spring/Summer 1997): 155–70.

According to King, the human brain manifests a universal evolutionary dynamic that springs from quantum non-locality. Subjective consciousness, King argues, is primal and gives rise to free will and choice.

Kurzweil, Ray. "The Intelligent Universe" Updated n. d. http://www.edge.org/documents/archive/edge107.html (cited 3 August 2003).

Kurzweil, a computer scientist, envisions a cosmos seemingly made to evolve sentient beings that can effect its own future. "Intelligence," according to Kurzweil, "is . . . a powerful force and we can see that its power is going to grow not linearly but exponentially, and [it] will ultimately be powerful enough to change the destiny of the universe" (p 2).

Stapp, Henry P. *Mind, Matter, and Quantum Mechanics.* Berlin: Springer-Verlag, 1993.

Stapp, a philosophical physicist, describes a cosmic nature that is necessarily suffused with consciousness.

Torey, Zoltan. *The Crucible of Consciousness: A Personal Exploration of the Conscious Mind.* Oxford: Oxford University Press, 1999.

Torey argues that the fundamental mind gains self-awareness so that it may intentionally guide further evolution.

van Loocke, Philip R., ed. *The Physical Nature of Consciousness*. Advances in Consciousness. vol. 29. Amsterdam; Philadelphia, Pa.: John Benjamins Publishing, 2001.

Researchers in physics and psychology are finding that conscious perception is built into a developing quantum universe. Karl Pribram, for example, views human sentience as a micro-encapsulation of its essence. Each organism, he argues, re-presents the universe, a universe that simultaneously reflects and observes the very universe that it presents.

Vertosick, Frank T. *The Genius Within: Discovering the Intelligence of Every Living Thing.* New York: Harcourt, 2002.

Vertosick, a neurosurgeon, argues that an intelligence is inherent in every domain of life from enzyme networks, to microbial communities, to the immune system, to brains, to ecosystems,

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to the world wide web, and even, to the living planet itself. This manifested intelligence is said to occur because, in each case, many entities interact for their own purposes, each subsequently self-organizing into a composite cognition. “Evolution and intelligence,” according to Vertosick, “are one and the same process” (p 175).

A Thermodynamics of Life

Chaisson, Eric J. *Cosmic Evolution: The Rise of Complexity in Nature.* Cambridge, Mass.: Harvard University Press, 2001.
Chaisson, an astrophysicist, presents a “millennial synthesis” to explain a developing universe through its particle, galactic, stellar, planetary, chemical, biological, and cultural stages. By means of a nonequilibrium energy flux, this expanding cosmos spawns the emergence of increasingly complex structures and entities. As the universe becomes humanly conscious, a radical new era commences presenting itself as an intentional intelligence. If it can survive, it may encompass and eventually further the larger cosmic evolution. Chaisson also has a website (http://www.tufts.edu/as/wright_center/cosmic_evolution) that explicates these ideas.

Coveney, Peter V., and Roger Highfield. *The Arrow of Time: A Voyage Through Science to Solve Time’s Greatest Mystery.* New York: Fawcett Columbine, 1991.
Coveney provides an accessible explanation of how far-from-equilibrium thermodynamics qualifies as a universal evolution developing in a fractal manner toward intelligent life.

Fussy, Siegried, Gerhard Grossing, Herbert Schwabl. “Irreversibility in Models of Macroevolution” *Cybernetics and Systems* 32, nos. 3–4 (2001): 429–42.
Grossing introduces this special journal issue whose papers affirm a stratified ascent toward conscious complexity.

Jorgensen, Sven, et al. “The Evolution of the Thermodynamic Equilibrium in the Expanding Universe.” *Physica Scripta* 58, no. 5 (1998): 543–44.
The authors propose a “fourth law of thermodynamics” in support of the emergent complication of life. This opposes the idea of an entropy budget.

Layzer, David. *Cosmogenesis: The Growth of Order in the Universe.* New York: Oxford University Press, 1990.
Layzer, an astrophysicist, provides theoretical insights into how an expanding universe can offset the second law of thermodynamics through its generation of hierarchical order and information.

Prigogine, Ilya. *From Being to Becoming: Time and Complexity in the Physical Sciences.* San Francisco, Calif.: W. H. Freeman & Co., 1980.
In Prigogine’s pioneering statement on the thermodynamics of life revolution, the old physics of a closed, static equilibrium is replaced by the open, dynamical emergence of a cosmic genesis. Living systems are therefore viewed as “dissipative structures” that flourish due to their sustenance through a flow of energy and information.

_______.“Nonlinear Science and the Laws of Nature.” *International Journal of Bifurcation and Chaos* 7, no. 9 (September 1997): 1917–26.
Prigogine theorizes that in an irreversible universe, the arrow of an “evolutionary thermodynamics,” can justify the directional rise of life.

Root-Bernstein, Robert, and Patrick Dillon. “Molecular Complementarity I: The Complementarity Theory of the Origin and Evolution of Life.” *Journal of Theoretical Biology* 188, no. 4 (21 October 1997): 447–79.
The authors argue that complementarity is ubiquitous within living systems. More specifically, they argue that “the mechanism of molecular complementarity serves to unify a currently disparate array of conceptual approaches to understanding living processes, ranging from non-equilibrium thermodynamics, systems theory, and hierarchy theory, to homeostasis, self-organization and emergent properties. It also suggests [that there are] basic similarities between the processes governing prebiotic evolution and embryological development” (p 447).

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Stewart, Ian. *What Shape Is a Snowflake?* New York: W. H. Freeman, Co., 2001.
The question posed in the book's title leads to the consideration of deeply patterned features present in a mathematical cosmos. This self-similarity is in evidence in everything from the ice on windowpanes to galactic clusters. As a result, the universe seems to exist as a fractal in kind because the second law of thermodynamics does not apply to large-scale gravitating systems. This supposition, however, also suggests that a self-organizing drive is in opposition to the entropic principle.

Swenson, Rod. "Thermodynamics, Evolution, and Behavior." In *Comparative Psychology: A Handbook,* eds. Gary Greenberg, and Maury M. Haraway, 207–18. New York: Garland Publishing, 1998.
Swenson argues that the universe is developmental and that it therefore does not decay into disorder. "Rather than being infinitely improbable 'debt payers' struggling against the laws of physics in a 'dead' world collapsing toward equilibrium and disorder, living things and their active, end-directed striving or intentional dynamics," argues Swenson, "can now be seen as productions of an active order-producing world following directly from natural law" (p 216).

Ulanowicz, Robert E. *Ecology: The Ascendent Perspective.* New York: Columbia University Press, 1997.
After noting the deficiencies of the determinist Newtonian model of the universe, a theoretical ecologist elucidates the inherent propensity of the universe, through the development of nested stages, to evolve toward increasingly aware and purposeful organisms. As a process of "entitification," this vectorial ascendancy of life can offset the "overhead" of entropic dissipation and can be seen as a revival to Aristotle's formal and final causes.

Fractal Spacetime

Argyris, J., et al. "Fractal Space Signatures in Quantum Physics and Cosmology I. Space, Time, Matter, Fields, and Gravitation." *Chaos, Solutions, and Fractals* 11, no. 11 (September 2000): 1671–1719.
The authors describe how the topology of nature (space, time, matter, and fields) is "intrinsically fractal" and the manner in which a self-similarity then becomes evident from galactic clusters to the allometric scale of life.

Argyris, J., et al. "Fractal Space, Cosmic Strings, and Spontaneous Symmetry Breaking." *Chaos, Solutions, and Fractals* 12, no. 1 (January 2001): 1–48.
Argyris et al. describes the discovery of a finely grained, iterative genesis. They ". . . show that, starting from the most fundamental of elementary particles and rising up to the largest scale structure of the Universe, the fractal nature of spacetime is imprinted onto matter and fields via the common concept for all scales emanating from the physical spacetime vacuum fluctuations. . . . The key aspect of fractals in physics and of fractal geometry is to understand why nature gives rise to fractal structures. Our present answer is: because a fractal structure is a manifestation of the universality of self-organization processes" (p 1).

Baryshev, Yurij, and Pekka Teerikorpi. *Discovery of Cosmic Fractals.* River Edge, N.J.: World Scientific Publishing Co., 2002.
This book by Baryshev and Teerikorpi presents early research that discusses how the universe is arranged in a hierarchical, self-similar manner.

De Vega, H., et al. "Fractal Structures and Scaling Laws in the Universe: Statistical Mechanics of the Self-Gravitating Gas." *Chaos, Solutions, and Fractals* 10, nos. 2–3 (February/March 1999): 329–43.
De Vega et al present additional features of nature's iterative geometry. They argue that fractal structures are presented in the universe in two ways: "in the gas forming the cold interstellar medium in scales from 10^{-4}pc till 100pc" and through observations of the galaxy's distribution. According to De Vega et al fractal patterns in galactic distribution have been observed in "scales up to hundreds of Mpc (pc = parsecs = 3.26 light years)" (p 329).

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Kroger, Helmut, ed. “Fractal Geometry in Quantum Mechanics Field Theory and Spin Systems.” *Physical Reports* 323, no. 2 (January 2000): 81–181.
This special journal issue explores the pervasive self-similarity in nature from sub-atomic to galactic realms.

Laskin, Nick. “Fractals and Quantum Mechanics.” *Chaos: An Interdisciplinary Journal of Nonlinear Science* 10, no. 4 (December 2000): 780–90.
Laskin presents a novel hypothesis of “fractional quantum physics” as an indication of the universe’s fundamental character.

Ramos, F. M., et al. “Multiscaling and Nonextensivity of Large-Scale Structures in the Universe.” *Physica D* 168 (2002): 404–409.
The authors resolve the problem relating to the transition from multifractal galaxies and clusters to an overall homogeneous universe by presenting a generalized thermostatistics method.

Smolin, Lee. *Three Roads to Quantum Gravity.* New York: Basic Books, 2001.
Smolin, a physicist, describes the grainy, fractal, holographic character of an integral universe.

Tatekawa, Takayuki, and Kei-ichi Maeda. “Primordial Fractal Density Perturbations and Structure Formation in the Universe: One-Dimensional Collisionless Sheet Model.” *The Astrophysical Journal* 547, no. 2, part 1 (1 February 2001): 531–44.
In this article, Tatekawa and Maeda explain how ordered forms came to appear in the evolving cosmos.

Weil, Melinda L., and Ralph E. Pudritz. “Cosmological Evolution of Supergiant Star-Forming Clouds.” *Astrophysical Journal* 556, no. 1, part 1 (20 July 2001): 164–76.
In their article, Weil and Pudritz discuss how galaxies form into hierarchical clusters due to a “robust power-law mass spectrum.”

The Anthropic Principle

Barrow, John D., and Frank J. Tipler. *The Anthropic Cosmological Principle.* New York: Oxford University Press, 1986.
Barrow and Tipler offer a compendium on the anthropic principle and a teleological universe. They also take note of the presence of uniquely appropriate qualities for life—from quantum domains to biochemical intricacies and astrophysical reaches.

Barrow, John D. “Life, the Universe, but Not Quite Everything.” *Physics World* 12, no. 12 (December 1999): 31–35.
Barrow argues that finely tuned physical constants provide innate support for biological complexity.

Hogan, Craig J. “Why the Universe Is Just So.” *Reviews of Modern Physics* 72, no. 4 (October 2000): 1149–61.
Hogan contends that although anthropic arguments are prone to circular “just so” stories, they are still important for cosmological theory.

Rees, Martin. *Before the Beginning: Our Universe and Others.* Reading, Mass.: Addison-Wesley, 1997.
Rees explores a multiverse scenario in which our local cosmos occurs just right for life from a vast number of incipient universes with alternative, unfavorable properties that may expand too fast or recontract early on.

_______. *Just Six Numbers: The Deep Forces that Shape the Universe.* London: Weidenfield & Nicolson, 1999.
Rees argues that if the binding energy of protons and neutrons into helium 4 of .007 of their rest mass varied by plus or minus .001 the universe would not be able to form life. As an astronomer, he also elucidates and updates the precise values required for humans to appear and to develop minds that are capable of producing knowledge and understanding these complex concepts.

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Vilenkin, Alexander. “Open Universes, Eternal Inflation, and the Anthropic Principle.” *International Journal of Theoretical Physics* 38, no. 11 (1 November 1999): 3135–45.
Vilenkin, a cosmologist, argues for an open, inflating universe where the observed value of the density parameter is seen to require an anthropic explanation.

Astrobiology

Chela-Flores, Julian, and Francis Raulin, eds. *Exobiology: Matter, Energy, and Information in the Origin and Evolution of Life in the Universe.* Dordrecht: Kluwer Academic Publishers, 1998.
The congnizant species of this infintesimal but fertile planet surveys the evolution of life and mind, which appears, in this vista, as a cosmic gestation. One paper in this collection reveals ethical tenets (e.g., humility, solidarity, cooperation, hope, universality, etc.) implied by the cosmic sense of life which people might utilize to peacefully change their cultures.

Chela-Flores, Julian, et al., eds. *Astrobiology: Origins from the Big Bang to Civilization.* Dordrecht: Kluwer Academic Publishers, 2000.
This collection of essays is taken from the proceedings of the 1999 Iberoamerican School of Astrobiology conference held in Caracas, Venezuela. Two essays in particular merit special attention: “Information, Life, and Brains,” by Juan Roederer, and the “Evolution of Adaptive Systems,” by Hernan Dopazo.

Cosmovici, Cristiano Batalli, Stuart Bowyer, Dan Werthimer, eds. *Astronomical and Biochemical Origins and the Search for Life in the Universe: Proceedings of the 5th International Conference on Bioastronomy, IAU Colloquium No. 161,* Capri, July 1–5, 1996. Bologna, Italy: Editrice Compositori, 1997.
Papers in this collection present the conviction that the cosmos naturally spawns life that tends toward advanced intelligence.

Darling, David. *Life Everywhere: The Maverick Science of Astrobiology.* New York: Basic Books, 2001.
Darling’s book contributes to the growing concept of a fertile universe that has been created in order to generate complex, life-forms.

Dorminey, Bruce G. *Distant Wanderers: The Search for Planets Beyond the Solar System.* Berlin: Springer-Verlag, 2001.
Dorminey’s book encompasses the formation of planetary bodies and the astronomical observation that occurs within a life-bearing universe.

European Space Administration. Updated 28 March 2002. http://www.lifeinuniverse.org/noflash/liu (cited 3 August 2003).
This site presents an informative, graphic survey from cosmology to the origin of life and considers the various social implications of these presentations.

Horneck, Gerda, and Christa Baumstark-Khan, eds. *Astrobiology: The Quest for the Conditions of Life.* Berlin: Springer-Verlag, 2002.
These extensive conference proceedings consider a range of celestial, planetary, biological, and sociocultural aspects of a universe that naturally complexifies into sentient life-forms.

Lemarchand, Guillermo, and Karen J. Meech, eds. *Bioastronomy ’99: A New Era in Bioastronomy: Proceedings of a Meeting Held at the Hapuna Beach Prince Hotel, Kohala Coast, Hawaii, USA, 2–6 August 1999.* San Francisco, Calif.: Astronomical Society of the Pacific, 2000.
The editors have compiled an array of recent reports on the occasion of life and intelligence in an increasingly biological universe.

Lemonick, Michael D. “Can We Find Another Earth?” *Discover* 23, no. 3 (March 2002): 32–37.
Astronomers are making rapid progress in detecting stars with orbiting planets by measuring perturbations in star movement that are specifically due to the orbiting bodies. In this

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article, Lemonick discusses how new plans for telescopes are able to focus in on planetary presentations covering a wide variety of scales (e.g., from Jupiter to Earth-size globes).

Lissauer, Jack J. “Extrasolar Planets.” *Nature* 419, no. 6905 (26 September 2002): 355–58.
Lissauer argues for a cosmos filled with planetary objects, the diversity of which has exceeded every scientific expectation.

National Aeronautics and Space Administration. Ames Research Center Astrobiology website. updated n. d. http://astrobiology.arc.nasa.gov/ (cited 3 August 2003).
NASA has developed a website that presents a full-range of atmospheric exploration.

Pendleton, Yvonne J., and Jack D. Farmer. “Life: A Cosmic Imperative?” *Sky & Telescope* 94, no. 1 (July 1997): 42–47.
Pendleton and Farmer discuss meteorite biochemistry and the probability of the presence of life in the solar system—especially on the moons of Jupiter.

Reichhardt, Tony. “Planetary Portraits.” *Nature* 415, no. 6872 (7 February 2002): 570–71.

3.2 Evolution as Self-Organization

Over the past decade or more an enriched understanding of the evolutionary development of life, mind, and self has been achieved from a multitude of contributions. If gathered altogether, as listed below, they suggest not a vicarious, branching bush but an oriented emergence of life and intelligence.

- A nonequilibrium thermodynamics connects biological systems with physical theory to give evolution a generative force (Ilya Prigogine, Eric Chaisson).
- New sciences of complexity describe a natural dynamic at work prior to selection that forms self-organized scales of modular wholes (Stuart Kauffman, David Depew, Walter Fontana).
- Hierarchical expansion of evolution into multiple, sequential levels from genes to groups, that exhibit a nested emergence (Stan Salthe, Daniel McShea).
- A punctuated equilibrium where species remain fixed for a long period and change relatively fast, rather than by initiating change through a gradual transition (Niles Eldredge, Stephen Jay Gould).
- A fractal-like self-similarity is witnessed in self-organized speciation and ecosystems (Ricard Sole, Susanna Manrubia, Siegfried Fussy, Yuri Wolf).
- A rational morphology or structural biology revives the sense of an archetypal Bauplan as a basis for a science of homologous organic form (Brian Goodwin, Gerry Webster).
- The perception of an intrinsically convergent evolution of soma and sentience rather than random contingency (Simon Conway Morris, Mark McMenamin, Lori Marino).
- A reunion of evolution and embryology known as evolutionary developmental biology (EDB) integrates individual ontogeny with the paleological radiation of organisms (Brian Hall, Scott Gilbert, Wallace Arthur).
- The recognition of symbiosis as a major contributor to the emergence of cellular, organismic, and social assemblies (Lynn Margulis).
- A developmental systems theory (DST) where epigenetic inputs from organism-environment interactions complement molecular genetic codes (Susan Oyama, Eva Jablonka).
- Altruistic cooperation as the primary agency and competitive conflict as secondary agent in the formation and maintenance of animal and human societies (David Sloan Wilson, Elliott Sober).
- Behavioral influences impact genetic programs from environmentally active rather than passive organisms (Henry Plotkin).
- An increase in modular brain complexity and cognitive capacity defines a linear encephalization and intelligence (Harry Jerison, Barbara Finlay and Richard Darlington, Damon Clark).
- A further axial quality is a cerebrally stored, schematic representation of a species’ expanding environmental niche (Derek Bickerton).
- New appreciations of animal sentience, intelligence, and emotion suggest a continuum of the rise of consciousness (David Griffin, Marc Bekoff, Irene Pepperberg).

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- A semiotic measure of evolution as an ever-better information processing ability and knowledge gain (Werner Loewenstein, Jesper Hoffmeyer, Terence Deacon).
- Major transitions in evolution from gene and cell to human society are facilitated by a novel code from molecules to language (John Maynard Smith, Eors Szathmary).
- An appreciation of evolution as the vectorial emergence of individuality of more distinct, aware selves (Richard Michod, David Buss, Daniel McShea).
- A recovery of the parallel between ontogeny and phylogeny in bodily form, cognitive skills, and language learning (Ernst Mayr, Wallace Arthur, Michael McKinney, Sue Taylor Parker).

Adami, Christoph. "What Is Complexity?" *BioEssays* 24, no. 12 (December 2002): 1085–1094.
Adami's article for this special journal issue on "Modelling Complex Biological Systems," presents evolution as a nested hierarchy that is characterized by growing informational content and aided by the natural selection of this specific quality.

Ananthaswamy, Anil. "Chemistry Guides Evolution, Claims Theory." *New Scientist.* January 18, 2003.
In this article, Ananthaswamy reports on scientists who believe that the Earth's chemistry channeled life to form bounded vesicles that proceed in a predictable way from cells to animals. Ananthaswamy perceives a changing trend in biology from the randomness of Darwinism to a law-regulated emergence of life.

Arthur, Wallace. "The Emerging Conceptual Framework of Evolutionary Developmental Biology." *Nature* 415, no. 6873 (February 14, 2002): 757–64.
Late nineteenth century evolution and embryology existed as a unified subject. Arthur argues that these two fields found divergent paths as quantitative studies as each field progressed. Around 1980, a reconvergence of these fields occurred with the discovery of the homeobox gene complex and the discovery of various epigenetic influences on genes. Arthur provides a review of how developmental and phylogenetic findings currently reinforce each other. He argues that the result presents a reciprocity of discrete gene and field or topological features along with a "broadly recapitulatory" parallel between individual ontogenetic maturation and the course of evolution.

Bekoff, Marc. *Minding Animals: Awareness, Emotions, and Heart.* Oxford: Oxford University Press, 2002.
Bekoff, working in the field of biology, argues that animals qualify as persons and should be treated with due consideration and respect. In so doing, he gives the field of cognitive ethology (the study of animal minds) the foundation to fully appreciate its subject. A century and a half ago Charles Darwin argued for an evolutionary continuity of behavior, emotion, and consciousness. Darwin's argument is now receiving new articulation through research in the field of cognitive ethology.

Camazine, Scott, et al., eds. *Self-Organization in Biological Systems.* Princeton, N.J.: Princeton University Press, 2001.
Camazine provides a primer on generic self-emergent systems and explains how the many interactions between simpler components and local rules give rise to global degrees of order. The book also describes how self-emergent systems are present throughout nature in everything from shell patterns to social insect structures.

Conway Morris, Simon. *The Crucible of Creation: The Burgess Shale and the Rise of Animals.* New York: Oxford University Press, 1998.
Morris, a paleontologist, argues that the Burgess Shale fossils of Cambrian origin do not imply random contingency but rather an oriented channel of animal body plans that eventually lead to the human presence.

Conway Morris, Simon. *Life's Solution: Inevitable Humans in a Lonely Universe.* Cambridge: Cambridge University Press, 2003.
Morris, a paleontologist, affirms the growing quantification and discovery of an evolution that tends to converge on the same pathways and attributes—from sensory systems to intelligence.

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The author’s belief that the Earth is a unique locus of emergent life also suggests that we might be alone in the cosmos.

Cornwell, John, ed. *Nature’s Imagination: The Frontiers of Scientific Vision.* New York: Oxford University Press, 1995.
In this collection Cornwell selects papers from a conference working to expand science beyond reductionism. He finds a view of the natural world that is more dynamic, emergent, and relational.

de Oliveira, P. M. C. “Why Do Evolutionary Systems Stick to the Edge of Chaos.” *Theory in Biosciences* 120, no. 1 (January 2001): 1–20.
The author presents insights into Darwinian selection by noting a critically poised dynamic system that searches for new forms and conditions due to things such as the “scale-free probability distribution power laws.”

Depew, David J., and Bruce H. Weber. *Darwinism Evolving: Systems Dynamics and the Geneaology of Natural Selection.* Cambridge, Mass.: MIT Press, 1994.
This volume presents a more complete evolutionary synthesis through its inclusion of the “dynamical systems theory” of nonequilibrium thermodynamics, developmental paths, and innate self-organization.

Fontana, Walter, and Leo W. Buss. “What Would be Conserved if ‘The Tape Were Played Twice?’” *Proceedings of the National Academy of Sciences of the United States of America* 91, no. 2 (January 18, 1994): 757–61.
Fontana and Buss respond to Stephen Jay Gould’s claim that blind variation and contingent selection would not allow the presence of human life on Earth if the planet were to evolve again by showing that the prior, independent existence of self-organizing dynamics, unknown to Darwin, introduce a novel source of emergent order. What recurs during each phase of the evolutionary process is a nested scale of self-maintaining organizations. Natural selection, therefore, is not the way in which biological order is generated.

Fussy, Siegfried, Gerhard Grössing, Herbert Schwabl, eds. “Irreversibility in Models of Macroevolution.” *Cybernetics and Systems* 32, nos. 3–4 (March/April 2001): 429–42.
In this theoretical exercise, the editors argue that a “hierarchically emergent fractal evolution” founded on invariant power laws can define the radiation of species.

Gilbert, Scott F., et al. “Resynthesizing Evolutionary and Developmental Biology.” *Developmental Biology* 173, no. 2 (February 1996): 357–72.
The authors attempt to create a more complete picture of evolution informed by the concepts of embryology, homology, Bauplan, and morphogenetic fields.

Gilbert, Scott F., and Sahotra Sarkar. “Embracing Complexity: Organicism for the Twenty-First Century.” *Developmental Dynamics* 219, no. 1 (September 2000): 1–9.
Gilbert attempts to recover the unity of evolution and embryology, properly understood, and to go beyond the twentieth-century emphasis on a reduction to physical or genetic parts (e.g., atom or gene) by recognizing structural interrelations that generate emergent wholes. He argues that elements do not exist in isolation, their contextual environment needs to be factored in. A complex adaptive system, one that illustrates the reciprocity of discrete components and dynamic interconnection, is recommended.

Goodwin, Brian. *How the Leopard Changed Its Spots: The Evolution of Complexity.* New York: Scribner’s, 1994.
A structural biologist, Goodwin presents an innovative case for a “science of qualities” that can support a lawful evolution of morphological complexity and altruistic behavior.

Gould, Stephen Jay. “The Paradox of the Visibly Irrelevant.” *Annals of the New York Academy of Sciences* 879 (June 1999): 87–97.
Gould presents a fractal view of evolution as an egalitarian nest of scales rather than as a reduction to one “superior” level.

Hall, Brian Keith. *Evolutionary Developmental Biology.* 2nd ed. Boston, Mass.: Kluwer Publishers, 1999.
Hall describes the revisioning and enrichment of evolution in light of modern embryological science.

Jackson, Jeremy, et al., eds. *Evolutionary Patterns: Growth, Form, and Tempo for the Fossil Record.* Chicago, Ill.: University of Chicago Press, 2001.
This series of papers describes a constant form and dynamics in the nested development of life from modular bacteria colonies to ecological communities.

Jeong, Hawoong, et al. “The Large-Scale Organization of Metabolic Networks.” *Nature* 407, no. 6804 (October 5, 2000): 651–54.
Jeong et al present “a systematic comparative mathematical analysis of the metabolic networks of fourty-three organisms” that represent each of three domains of life. They find that “despite significant variation in their individual constituents and pathways, these metabolic networks have the same topological scaling properties and show striking similarities to the inherent organization of complex non-biological systems. This may indicate that metabolic organization is not only identical for all living organisms, but also complies with the design principles of robust and error-tolerant scale-free networks” (p 651).

Keller, Laurent, ed. *Levels of Selection in Evolution.* Princeton, N.J.: Princeton University Press, 1999.
Keller’s work discusses a conceptual expansion from a gene-centric individual model to multilevel stages from replicators to societies.

Knoll, Andrew, and Richard Bambach. “Directionality in the History of Life.” *Paleobiology* 26, no. 4 (Supplement 2000): 35–51.
The authors present work that elucidates an evolutionary trend from the origin of life through its microbial, eukaryotic, multicellular, and technological stages. They argue that “[e]ach metatrajectory has introduced fundamentally new evolutionary entities that garner resources in new ways, resulting in an unambiguously directional pattern of increasing ecological complexity marked by expanding ecospace utilization” (p 1).

Lipson, Hod, et al. “On the Origin of Modular Variation.” *Evolution* 56, no. 8 (August 2002): 1549–56.
In this article, the authors utilize computer simulations to reveal why functional modules inherently form and evolve due to variation and selection effects.

Margulis, Lynn, and Dorion Sagan. *What Is Life?* New York: Simon & Schuster, 1995.
In their attempt to answer the “What is life?” question originally posed by Erwin Schrodinger, Margulis and Sagan present a wide-ranging, imaginative survey of animate properties and essence. The authors argue that living entities from bacteria to the biosphere are more than mobile protoplasm, they are entities that are best distinguished by their sentience and their recurrent, symbiotic, self-sustained autopoietic organization.

McMenamin, Mark A. *The Garden of Ediacara: Discovering the First Complex Life.* New York: Columbia University Press, 1998.
McMenamin, a paleontologist, describes his discoveries of Precambrian fossil microorganisms in the Ediacaran region of Australia. His findings support a convergent view of evolution characterized by an emergent sentience present even in that ancient era. By endorsing a “neovitalistic” view of evolution, McMenamin concludes that “life evokes mind.”

McShea, Daniel. “The Hierarchical Structure of Organisms.” *Paleobiology* 27, no. 2 (February 2001): 86–94.
McShea presents a summary of how evolution proceeds by a nest of spheres of whole entities from prokaryotes to cells, organisms, and “individuated metazoan colonies.” This theory supports the notion that the passage of life is not a gradual drift or meander but rather constitutes a central trend of stratified complexity. Each subsequent stage of evolution is therefore an autopoietic, symbiotic-like individuation.

Science Bibliography

Michod, Richard. *Darwinian Dynamics: Evolutionary Transitions in Fitness and Individuality.* Princeton, N.J.: Princeton University Press, 1999.
Michod, a biologist, explains his ideas relating to a new multiphase evolution. His theory focuses on a common set of principles that direct the emergence of higher levels of organization.

Minugh-Purvis, Nancy, and Kenneth J. McNamara, eds. *Human Evolution Through Developmental Change.* Baltimore, Md.: Johns Hopkins University Press, 2002.
This book explores the reunion of individual ontogeny and species phylogeny in light of variations in embryo developmental rate and timing known as heterochrony.

Nehaniv, Chrystopher L., ed. *Mathematical and Computational Biology: Computational Morphogenesis, Hierarchical Complexity, and Digital Evolution.* Providence, R.I.: American Mathematical Society, 1997.
These conference reports gather significant insights flowing from novel nonlinear theories in a variety of disciplines. Topics include biology, symbiogenesis, autopoiesis, self-reproducing and self-maintaining systems, constructive biology, and computational morphogenesis.

Oyama, Susan, et al., eds. *Cycles of Contingency: Developmental Systems and Evolution.* Cambridge, Mass.: MIT Press, 2001.
In this broad array of essays, the editors explore how developmental systems theory (DST) can be applied to science in order to move science beyond particulate genetics. DST views the ontogeny of an organism as epigenetic cycles of interaction among a varied set of developmental resources (e.g., DNA, cellular and organismic structural constraints, social, and ecological factors) and finds that elements within the organisms are more likely to be contructed than they are to be predetermined.

Robert, Jason Scott, et al., "Bridging the Gap Between Developmental Systems Theory and Evolutionary Developmental Biology." *BioEssays* 23, no. 10 (October 2001): 954–62.
This article compares the fledgling fields of evolutionary developmental biology (EDB or evo-devo) and developmental systems theory (DST). As embryology rejoins and informs the study of evolution, an inference is formed that everything is "ontogeny." Rather than embracing an either/or scenario, the authors endorse a "particle/wave complementarity" between the two fields, where EDB prefers a genetic program that allows systemic process and DST emphasizes more contingent or epigenetic "constructivist" influences.

Rossi, Claudio, et al., eds. "Tempos in Science and Nature: Structures, Relations, and Complexity." *Annals of the New York Academy of Sciences* 879, no. 1 (1999): 1–447.
This article features reports from a conference on thermodynamic, fractal, and self-organizing systems and presents information on how they manifest themselves in evolution, physiology, ecosystems, cognition, epistemology, and planetary society.

Sendova-Franks, Ann, and Nigel Franks. "Self-assembly, Self-organization, and Division of Labour." *Philosophical Transactions of the Royal Society of London B* 354 (1999): 1395.
Nonlinear theories are being increasingly utilized in the field of biology. This article clearly defines the principles of these theories in order that they may be utilized more consistently in various disciplinary research studies. The authors observe that self-organizing systems tend to divide tasks or functions as they complexify on their way toward a higher ordered whole.

Stadler, Barbel, et al. "The Topology of the Possible: Formal Spaces Underlying Patterns of Evolutionary Change." *Journal of Theoretical Biology* 213, no. 2 (November 21, 2001): 241–74.
The authors present a sophisticated mathematical theory that reveals how preexistent geometries for gene topologies augment selective forces.

Ulanowicz, Robert E. "The Balance Between Adaptability and Adaptation." *BioSystems* 64, nos. 1–3 (January 2002): 13–22.
Ulanowicz's article makes a contribution to the search for a recurrently self-developing universe. This theory of self-organization stands in contrast to the Darwinian model in which selection is exerted from outside the system and presents the idea that "[t]he positive feedback or

autocatalytic like agency inherent in self-organization theory is capable of exerting selection that directly *favors* the growth of participating elements and acts *internal* to the system itself" (p 21).

Van de Vijver, Gertrudis, et al., eds. *Evolutionary Systems: Biological and Epistemological Perspectives on Selection and Self-Organization.* Dordrecht: Kluwer Academic Publishers, 1998.
Van de Vijver et al present an example of where the genesis synthesis is taking place due to a blend of complex dynamics, developmental principles, thermodynamic and informational properties along with a semiotic, textual interpretation. Key theorists include: Vilmos Csanyi, Michael Conrad, Juan Alvarez de Lorenzana, Rod Swenson, Stan Salthe, David Depew, Bruce Weber, Robert Riedl, Susantha Goonatilake, Luis Mateus Rocha.

Wagner, Gunter P. "Homologues, Natural Kinds and the Evolution of Modularity." *American Zoologist* 36, no. 1 (February 1996): 36–43.
Wagner argues that organisms complexify as a whole assembly of semi-autonomous modular organs or characters: "[t]he fact that phenotypic evolution can be studied on a character by character basis suggests that the body is composed of locally integrated units. These units can be considered as modular parts of the body which integrate functionally related characters into units of evolutionary transformation. These units may either emerge spontaneously by self-organization, or may be the product of natural selection" (p 36).

_______. "Complexity Matters." *Science* 279, no. 5354 (February 20, 1998): 1158–59.
Wagner, a biologist, discusses a theory of expanded evolution due to nonlinear theory and organismic biology.

Walleczek, Jan, ed. *Self-Organized Biological Dynamics and Nonlinear Control: Toward Understanding Complexity, Chaos, and Emergent Function in Living Systems.* Cambridge: Cambridge University Press, 2000.
Walleczek et al has an appreciation of organisms as energy-driven, open systems that generate an emergent fractal organization and viability. This understanding implies that there is a physical basis for evolving life. He argues that the nonlinear dynamical systems view (which he also refers to as the paradigm of self-organization) "provides biology with a theoretically sound approach toward a 'holistic biology' for the first time in the history of science" (p 417).

Webster, Gerald, and Brian Goodwin. *Form and Transformation: Generative and Relational Principles in Biology.* New York: Cambridge University Press, 1996.
Webster and Goodwin present the "rational morphology" viewpoint of a primacy of the developmental processes of an organism over purely genetic dictates.

West, Geoffery, et al. "Allometric Scaling of Metabolic Rate from Molecules and Mitochondria to Cells and Mammals." *Proceedings of the National Academy of Sciences of the United States of America* 99, no. 4, Supplement 1 (February 19, 2002): 2473–78.
The authors present a survey of fractal self-similarities present throughout the biological kingdom.

West-Eberhard, Mary Jane. "Development and Selection in Adaptive Evolution." *Trends in Ecology and Evolution* 17, no. 2 (February 2002): 65.
West-Eberhard, a biologist, succinctly critiques the either/or situation of random selection versus topology and dynamics and proposes an integration of the two through an appreciation of the prior effect of self-organizing systems.

Wilke, Claus O., and Christoph Adami. "The Biology of Digital Organisms." *Trends in Ecology and Evolution* 17, no. 11 (November 11, 2002): 528–32.
Wilke and Adami argue that self-replicating computer simulations bring a novel perspective and insight to understanding how organisms mutate and evolve in similar ways.

Wolf, Yuri I., et al. "Scale-Free Networks in Biology: New Insights into the Fundamentals of Evolution?" *BioEssays* 24, no. 2 (February 2002): 105–109.
After all the discrete components (e.g., genes, cells, organisms, etc.) are identified, the presence of dynamic interrelations that join them together can be recognized. The same self-organizing, small world, power law system is then found at each phase from biomolecules to lexicons.

Science Bibliography

3.3 The Nested Holarchy of Life

This section illustrates the point that evolution complexifies into nested levels from life's origin to symbiotic cells and on to global ecosystems.

3.3.1 Emergent Communities of Life

Geophysical Domains

Diego, Perugini, and Poli Giampiero. "Chaotic Dynamics and Fractals in Magmatic Interaction Processes: A Different Approach to the Interpretation of Mafic Microangular Enclaves." *Earth and Planetary Sciences Letters* 175, nos. 1–2 (30 January 2000): 93–103.
Diego and Giampiero argue that "fractal geometry and chaotic dynamics can be considered suitable techniques in studying complex petrological phenomena" (p 93).

Quattrochi, Dale A., and Michael F. Goodchild, eds. *Scale in Remote Sensing and GIS.* Boca Raton, Fla.: Lewis Publishers, 1997.
Many essays in this compendium find Geographic Information Systems (GIS) data in both environmental and social domains to be based on a fractal, scale-invariant nature.

Rodriguez-Iturbe, Ignacio, and Andrea Rinaldo. *Fractal River Basins: Chance and Self-Organization.* Cambridge: Cambridge University Press, 1997.
The authors assert that fractals are a ubiquitous property of branching systems. This book also provides an introduction to self-organization and criticality.

Rowan, Linda, and Jessie Smith. "The Terrestrial Web." *Science* 288, no. 5473 (16 January 2000): 1983.
Rowan and Smith offer a summary of findings about Earth's atmosphere, broadly conceived, from outer space to its crustal mantle and liquid core.

Teisseyre, Roman, and Eugeniusz Majewski, eds. *Earthquake Thermodynamics and Phase Transformations in the Earth's Interior.* San Diego, Calif.: Academic Press, 2001.
Authors in this volume argue that the application of the nonlinear sciences to a dynamic planet still in formation yields the perception of a "fractal universality" of self-organizing systems.

Werner, Brad T. "Complexity in Natural Landform Patterns." *Science* 284, no. 5411 (2 April 1999): 102–104.
The standard reductionist methods of science, according to Werner, are not suitable. He therefore proposes an alternative theory based on self-organization in temporal hierarchies.

Origin of Life

Brack, Andre, ed. *The Molecular Origins of Life: Assembling Pieces of the Puzzle.* New York: Cambridge University Press, 1998.
Brack offers a broad survey of the molecular origins of life including everything from prebiotic compounds, genetic molecules and processes, and autocatalysis to clues given to us from our study of Mars and the moons of Jupiter.

Davies, Paul. *The Fifth Miracle: The Search for the Origin and Meaning of Life.* New York: Simon & Schuster, 1999.
Taking into account the mature stage of research on the advent of life, Davies engages in an overall review to join life on Earth with elemental properties of the universe. The author suggests that the phenomena of self-organization and informed complex systems augur well for life as a natural, intended presence. Davies goes on to argue that we are on the verge of a grand paradigm shift from an older comatose cosmos to an organic universe giving birth to its human phase.

Science Bibliography

de Duve, Christian. *Vital Dust: Life as a Cosmic Imperative.* New York: Basic Books, 1995.
De Duve presents an authoritative exposition of the sequential ages of chemistry, information, protocells, single cell, and multicellular organisms from which, he argues, the mind and humankind arise. According to de Duve, all this occurs because of the ingrained laws and properties that are inherent in cosmic nature.

Dokholyan, Nikolay, et al. “Expanding Protein Universe and Its Origin from the Biological Big Bang.” *Proceedings of the National Academy of Sciences* 99, no. 22 (29 October 2002): 14132–36.
The authors describe how the microcosm of macromolecular proteins exhibits a universal similarity at different levels of complexity.

Ingber, Donald E. “The Origin of Cellular Life.” *BioEssays* 22, no. 12 (December 2000): 1160–70.
Ingber begins with the premise that “evolution is the process by which matter self-organizes in space and, thus, . . . the origin of life is merely one aspect of the natural evolution of the cosmos” (p 1160). He also explains how nature utilizes tensegrity geometry to form a hierarchical cell and skeletal structure that is facilitated by self-renewing functional webs through the emergence of autocatalytic sets.

Lahav, Noam. *Biogenesis: Theories of Life’s Origins.* New York: Oxford University Press, 1999.
Lahav, utilizing information from the latest research findings in the field, provides a technical survey of theories relating to the origin of life.

Morowitz, Harold J. *Beginnings of Cellular Life: Metabolism Recapitulates Biogenesis.* New Haven, Conn.: Yale University Press, 1992.
Morowitz, a biochemist, contends that rudimentary cells were created when vesicles, contained within a membrane, were formed by complexifying biochemicals. This original “biogenesis” was then recapitulated in the metabolism of organisms through the universality of their network reactions.

_______. “A Theory of Biochemical Organization, Metabolic Pathways, and Evolution.” *Complexity* 4, no. 6, (July/August 1999): 39–53.
Morowitz argues that the emergence of life is herein facilitated by hierarchical circuits of biomolecule reactions.

Rizzotti, Martino, ed. *Defining Life: The Central Problem in Theoretical Biology.* Padova, Italy: University of Padova Press, 1996.
In this collection, researchers focusing on the origins of life attempt to convey life’s essence by variously noting its energetic, dynamical, autopoietic, reproductive, self-organizing, and informative qualities.

Schopf, J. William, ed. *Life’s Origin: The Beginnings of Biological Evolution.* Berkeley, Calif.: University of California Press, 2002.
Essays in this book provide a synoptic survey of everything from historical backgrounds to Earth’s formation, biochemical precursors to polymerization, and genetic information to ancient paleontology. The authors surmise that the evolution of cosmic matter naturally results in life.

Wills, Christopher, and Jeffery Bada. *The Spark of Life: Darwin and the Primeval Soup.* Cambridge, Mass.: Perseus Books, 2000.
Willis and Bada argue that the presence of natural seclection, even among biochemical precurses, is often missing in attempts to explain precellular life.

Microbial Colonies

Ben-Jacob, Eshel. “Bacterial Wisdom, Godel’s Theorem, and Creative Genomic Webs.” *Physica A* 248, nos. 1–2 (1 January 1998): 57–76.
Ben-Jacob, a biologist and a pioneer in applying the nonlinear sciences to the microbial realm, explains that complex colonial patterning is an example of adaptive self-organization that is seen to possess self-reference, information, and a modicum of awareness. As the assembly

of microbes interact with mutual dependence through a common language, they give rise to a distinct communal self. In this view, evolutionary progress is "not the result of successful accumulation of mistakes in replication of the genetic code, but is rather the outcome of [a] designed creative processes" (p 58).

Ben-Jacob, Eshel, et al. "Cooperative Self-Organization of Microorganisms." *Advances in Physics* 49, no. 4 (2000): 256–80.
This book-length article explains that microbes live not as individuated, isolated particles but rather survive and flourish in spontaneous communities formed by communication networks. These dynamic, fractal-like assemblies imply common, underlying principles that relate to the organization of all life.

Bown, J. L., et al. "Evidence for Emergent Behaviour in the Community-Scale Dynamics of a Fungal Microcosm." *Proceedings of the Royal Society of London B* 266, no. 1432 (1999): 1947.
The authors argue that cooperative agents at work everywhere give rise to higher-level organizations.

Brown, Sam P., and Rufus A. Johnstone. "Cooperation in the Dark: Signalling and Collective Action in Quorum-Sensing Bacteria." *Proceedings of the Royal Society of London B* 268, no. 1470 (2001): 961–65.

Crespi, Bernard J. "The Evolution of Social Behavior in Microorganisms." *Trends in Ecology and Evolution* 16, no. 4 (1 April 2001): 178–83.
Based on sophisticated studies, Crespi suggests that the systemic processes of modular division of labor, cooperation, chemical talk, and so on occur in microbial societies just as they also occur in animal communities. He cites the example of convergent social phenomena present across widely separated scales.

Maree, Athanasius, and Paulien Hogeweg. "How Amoeboids Self-organize into a Fruiting Body." *Proceedings of the National Academy of Sciences* 98, no. 7 (27 March 2001): 3879–83.
Maree and Hogeweg present an initial achievement of a mathematical, computational analysis, the emergence of a complex organic assembly.

Shapiro, James A. "Thinking about Bacterial Populations as Multicellular Organisms." *Annual Review of Microbiology* 52 (October 1998): 81–104.
James Shapiro has long advocated the cooperative view of bacterial colonies. Here he argues that microbial genetic networks can be seen to contrast with particulate genes.

Wakeford, Tom. *Liaisons of Life: From Hornworts to Hippos, How the Unassuming Microbe Has Driven Evolution.* New York: Wiley, 2001.
Wakeford lauds the new appreciation of symbiotic associations in microbial realms that are leavening the Darwinian emphasis on competition and conflict.

The Symbiotic Cell

Dyson, Freeman. "The Evolution of Science." In *Evolution: Society, Science, and the Universe,* ed. Andrew C. Fabian, 118–35. Cambridge: Cambridge University Press, 1998.
To illustrate how the evolution of the cosmos, science, and life develop in the same, consistent way, physicist Dyson cites the presence of symbiotic unions in both the biological and the celestial realms.

Frank, Steven A. "The Origin of Symbiotic Symbiosis." *Journal of Theoretical Biology* 176, no. 3 (7 October 1995): 403–10.
Frank reviews the general principles that give rise to mutually beneficial assemblies and argues that these principles are an indication of a new integrative model of symbiosis.

Harold, Franklin M. *The Way of the Cell: Molecules, Organisms, and the Order of Life.* Oxford: Oxford University Press, 2001.
Harold reviews the origins, evolution, symbiotic innards, and autopoietic functions of cellularity, basing his insights on a cogent blend of thermodynamics, self-organization, and natural

selection. Even after his review, Harold remains a materialist, holding that life exists because of the "peculiar" complex systems that channel energy and information.

Margulis, Lynn. *Symbiosis in Cell Evolution: Life and Its Environment on the Early Earth.* 2nd ed. San Francisco, Calif.: W. H. Freeman, 1993.
This text is the main source for the scientific exposition of symbiotic assemblies.

Margulis, Lynn, and Rene Fester, eds. *Symbiosis as a Source of Innovation in Evolution: Speciation and Morphogenesis.* Cambridge, Mass.: MIT Press, 1991.
The editors assemble a wide range of papers on "speciation and morphogenesis."

Rizzotti, Martino. *Early Evolution: From the Appearance of the First Cell to the First Modern Organisms.* Basel: Birkhauser, 2000.
Rizzotti provides an account of symbiotic complexification—from prokaryotics to eukarotes to multicellularity.

Ryan, Frank. *Darwin's Blind Spot: Evolution Beyond Natural Selection.* Boston, Mass.: Houghton Mifflin, 2002.
Ryan extols the presence and force of symbiotic assembly in the advancement of life.

Sapp, Jan. *Evolution by Association: A History of Symbiosis.* New York: Oxford University Press, 1994.
Sapp chronicles the history of an alternative view of the rise of life that is due more to symbiotic cooperation than a "survival of the fittest" competition.

Schwemmler, Werner. *Symbiogenesis: A Macro-Mechanism of Evolution: Progress Towards a Unified Theory of Evolution Based on Studies in Cell Bilogy.* Berlin: Walter de Gruyter, Inc., 1989.
Schwemmler offers a holistic reading of an evolutionary scale of symbiotic unions from cosmic beginnings through biological, neural, and human social stages.

Seckbach, Joseph, ed. *Symbiosis: Mechanisms and Model Systems.* Dordrecht: Kluwer Academic Publishers, 2002.
Seckbach has edited an extensive volume of mutually beneficial associations with an emphasis on the formation of the eukaryotic cell.

Woese, Carl. "On the Evolution of Cells." *Proceedings of the National Academy of Sciences* 99, no. 13 (19 June 2002): 8742–47.
Woese argues that the origin of cellular organization is due to an ecosystem-like community of diverse cell designs that share novel features. This design is informed by "'horizontal gene transfers'" that constitute "a universal genetic code." Evolution, according to Woese, began in earnest when these cells gained the capacity for "symbolic representation." Human language can be seen as an illustration of this design's most recent manifestation.

Multicellular Organisms

Bonner, John. *First Signals: The Evolution of Multicellular Development.* Princeton, N.J.: Princeton University Press, 2000.
Bonner reviews decades of inquiry into the appearance of multicellular and communal complexity. In so doing, he uncovers strong parallels between the stages of organic development and animal behavior.

Buchman, Timothy G. "The Community of the Self." *Nature* 420, no. 6912 (14 November 2002): 246–51.
With regard to an organism's anatomy and physiology, in addition to homeostatic effects, Buchman argues that the dynamic properties of interconnected, stratified networks need be factored in. "At all levels — from genes to the web of organ systems that make up an individual — it is the balance of autonomy and connectedness that sustains health. These two fonts of stability have complementary roles in guarding the communities of cells that, in aggregate, is the organism itself" (p 246).

Science Bibliography

Conway Morris, Simon. “Evolution: Bringing Molecules into the Fold.” *Cell* 100, no. 1 (7 January 2000): 1–11.
Conway Morris offers insights into convergent pathways in genetic networks, neural mechanisms, and fish echolocation.

Eldredge, Niles. *The Pattern of Evolution.* New York: W. H. Freeman and Co., 1999.
Eldredge argues for a broader theory of evolution that reaches beyond “internalized competition between genes” to recognize hierarchical scales that contain a law-like continuity within their physical environment.

Furusawa, Chikara, and Kunihiko Kaneko. “Complex Organization in Multicellularity as a Necessity in Evolution.” In *Artificial Life VII: Proceedings of the Seventh International Conference on Artificial Life,* eds. Mark Bedau, et al., 1–12. Cambridge, Mass.: MIT Press, 2000.

Gilbert, Scott F., and Jessica A. Bolker. “Homologies of Process and Modular Elements of Embryonic Construction.” *Journal of Experimental Zoology* 291, no. 1 (April 2001): 1–12.
Gilbert and Bolker argue that in addition to the common dynamical systems, a “bauplan” or archetypal body form, is involked that employs semi-autonomous modules for processes related to organic development.

Ingber, Donald E. “The Architecture of Life.” *Scientific American* 278, no. 1 (January 1998): 48–59.
Ingber outlines a universal set of self-assembly rules that hold and/or give rise to a bodily anatomy that is “organized hierarchically as tiers of systems within systems.” The author also speculates that although achievements such as tensegrity geometry are evident in protein structures, we are finally reading the book of nature foretold to us by Plato and Galileo.

Kaiser, Dale. “Building a Multicellular Organism.” *Annual Review of Genetics* 35 (2001): 103–23.
Kaiser contends that the same process of symbiosis recurs as cells join in beneficial dialogue and assembly. More specifically he notes that “[m]ulticellular organisms appear to have arisen from unicells numerous times. Multicellular cyanobacteria arose early in the history of life on Earth. Multicellular forms have since arisen independently in each of the kingdoms and several times in some phyla. If the step from unicellular to multicellular life was taken early and frequently, the selective advantage of multicellularity may be large. . . . The capacity for signaling between cells accompanies the evolution of multicellularity with cell differentiation” (p 103).

Kingsland, Sharon. “Neo-Darwinism and Natural History.” In *Science in the Twentieth Century,* eds. John Krige and Dominique Pestre, 417–37. Amsterdam: Harwood Academic, 1997.
Kingsland provides a concise review of modern evolutionary synthesis formed in the 1950s.

Klein, Jan, and Naoyuki Takahata, eds. *Where Do We Come From?: The Molecular Evidence for Human Descent.* Berlin: Springer, 2002.
This compendium highlights molecular and phylogenetic reconstructions of the path of human descent.

Michod, Richard, and Denis Roze. “Transitions in Individuality.” *Proceedings of the Royal Society of London B* 264, no. 1383 (1997): 853.
Michod and Roze argue that “[t]he evolution of multicellular organisms is the premier example of the integration of lower levels into a single, higher level individual. . . . We provide an explicit two-locus genetic framework for understanding this transition in terms of the increase of cooperation among cells and the regulation of conflict within the emerging organism” (p 853).

Raff, Rudolf A. *The Shape of Life: Genes, Development, and the Evolution of Animal Form.* Chicago, Ill.: University of Chicago Press, 1996.
Raff’s work expands on ideas relating to the stability and ontogenetic recurrence of bodily plans.

Ridley, Mark. *Evolution.* 2nd ed. Boston, Mass.: Blackwell Scientific, 1993.
Ridley provides information on Darwinian evolutionary biology and natural selection.

Schopf, J. William. *Cradle of Life: The Discovery of Earth's Earlier Fossils.* Princeton, N.J.: Princeton University Press, 1999.
Schopf investigates "the discovery of Earth's earliest fossils" and reviews their Precambrian cellular organisms.

Wilkins, Adam S. *The Evolution of Developmental Pathways.* Sunderland, Mass.: Sinauer Asociates, Inc., 2002.
Wilkins makes a contribution to the resurgence of evolutionary developmental biology.

Woese, Carl. "Interperting the Universal Phylogenetic Tree." *Proceedings of the National Academy of Sciences* 97, no. 15 (18 July 2000): 8392–96.
A senior biologist reviews historical findings and presents clarifications for the specification of three kingdoms of life that contain common root and branches to plants and animals. According to Woese, "the ancestors of the individual domains—bacteria, the archaea, and the eukaryotes—are each communal, and the evidence for their communal nature, in the form of elevated levels of horizontal gene transfer within each domain early on (e.g., transfer involving the ancestors of the major taxa), should still exist" (p 8395).

Zimmer, Carl. *At the Water's Edge: Macroevolution and the Transformation of Life.* New York: The Free Press, 1998.
Zimmer imparts the story of the transition from fish to tetrapod and from land mammal to whales.

Human Development

Bergman, Lars, et al., eds. *Developmental Science and the Holistic Approach.* Mahwah, N.J.: Lawrence Erlbaum Associates, 2000.
Bergman has compiled contributions from an integral and dynamic perspective relating to the formation of vision, personality, and behavior.

Cairns, Robert. "The Making of Development Psychology." In *Handbook of Child Psychology. 5th ed., vol. 1: Theoretical Models of Human Development,* ed. Richard Lerner, 25–105. New York: Wiley, 1998.
Cairns presents a century-long history of the field of developmental psychology as it grew from individual conjectures to a global collaborative endeavor.

Courage, Mary L., and Mark L. Howe. "From Infant to Child: The Dynamics of Cognitive Change in the Second Year of Life." *Psychological Bulletin* 128, no. 2 (March 2002): 250–77.
Courage and Howe provide a review of the field whose studies have ranged from the constructivism of Piaget to the new nativism and modularity theories. They argue that a continuous orderly process (e.g., the acquisition of language or the ability to walk) that is "consistent with the self-organizing properties that typify non-linear dynamic systems" (p 268) is present as an infant moves through her/his first year of life.

Kelso, Scott. "Principles of Dynamic Pattern Formation and Change for a Science of Human Behavior." In *Developmental Science and the Holistic Approach,* eds. Lars Bergman, et al., 63–84. Mahwah, N.J.: Lawrence Erlbaum Associates, 2000.
Kelso applies complexity science to individual function and development to reveal how the perception of a figure/ground, behavior/environmental context of reciprocity is crucial to its understanding. The primary impact of complexity theory, according to Kelso, "is that the key to understanding ourselves lies in the complementary nature of objective physical description and the no-less-fundamental, apparently subjective, context-dependence of living systems. The sciences of life and mind rest on this complementarity" (p 67).

Lewis, Marc D. "The Promise of Dynamic Systems Approaches for an Integrated Account of Human Development." *Child Development* 71, no. 1 (January 2000): 36–43.
This paper extols nonlinear science as a new conceptual resource, provided a common version and terminology can be worked out. Lewis argues that "[d]ynamic systems theorists

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claim that all developmental outcomes can be explained as the spontaneous emergence of coherent, higher-order forms through recursive interactions among simpler components. This process is called self-organization, and it accounts for growth and novelty throughout the natural world, from organisms to societies to ecosystems to the biosphere itself" (p 36).

Lewis, Marc D., and Isabela Granic, eds. *Emotion, Development, and Self-Organization: Dynamic Systems Approaches to Emotional Development.* Cambridge: Cambridge University Press, 2000.
Papers in this volume explore how complexity science can now explain the emergence of cerebral function and personality as the result of dynamic principles. A fractal-like self-similarity and "iterative feedback" is found across many nested scales of behavior.

Thelen, Esther, and Linda B. Smith. *A Dynamic Systems Approach to the Development of Cognition and Action.* Cambridge, Mass.: MIT Press, 1994.
Thelen and Smith provide an approach to fundamental questions of mental life by invoking general principles. "These are the principles of nonlinear dynamic systems, and they concern problems of emergent order and complexity: how structure and patterns arise from the cooperation of many individual parts (p xiii). . . . In the recent past, the biological study of the whole organism has been overshadowed by the remarkable and compelling advances made by reductionist paradigms in genetics and molecular biology. The tide is turning now with the emerging study of complex systems rooted in powerful mathematical and physical principles" (p xx).

Organic Societies

Axelrod, Robert. *The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration.* Princeton, N.J.: Princeton University Press, 1997.
A pioneering theoretician of cooperative behavior explains why helping one another brings benefit to everyone involved.

Boehm, Christopher. *Hierarchy in the Forest: The Evolution of Egalitarian Behavior.* Cambridge, Mass.: Harvard University Press, 1999.
Boehm, an anthropologist, explores concepts relating to nepotism and altruism in primate and human groups and finds a trend or bias toward egalitarian behavior as evident in democratic societies. In defense of group-level selection, this position appears to move beyond a social science paradigm that claims competitive struggle as the norm.

Bonabeau, Eric, et al. "Scaling in Animal Group-Size Distributions." *Proceedings of the National Academy of Sciences of the United States of America* 96, no. 8 (13 April 1999): 4472–77.
The authors describe a mathematical theory of power-law scale invariance found in diverse assemblies of tuna, sardinella, and buffalo.

Buck, Ross, and Benson Ginsberg. "Communicative Genes and the Evolution of Empathy." In *Empathic Accuracy,* ed. William Ickes, 17–43. New York: Guilford Press, 1997.
Buck and Ginsberg focus on the importance of relational values in evolution. They argue that ". . . empathy, rapport, intuition, altruism, and related concepts [are] . . . emergent properties of a primordial biological capacity for communication that inheres in the genes" (p 19).

Caporael, Linda, and Reuben Baron. "Groups as the Mind's Natural Environment." In *Evolutionary Social Psychology,* eds. Jeffry A. Simpson and Douglas T. Kenrick, 317–43. Mahwah, N.J.: Lawrence Erlbaum Associates, 1997.
Caporael and Baron survey how relational, developmental, and self-organizational insights are refashioning the psychological and social sciences.

Casti, John L., and Anders Karlqvist. *Cooperation and Conflict in General Evolutionary Processes.* New York: Wiley, 1995.
The authors utilize a multidisciplinary approach that explores how successful evolutionary adaptations rely on a judicious combination of self-interest and altruism.

Science Bibliography

Chase, Ivan D., et al. “Individual Differences Versus Social Dynamics in the Formation of Animal Dominance Hierarchies.” *Proceedings of the National Academy of Sciences of the United States of America* 99, no. 8 (16 April 2002): 5744–49.
Chase discusses how self-organizing dynamics are found in evidence at every instance of natural development. He argues: “[t]he importance of interaction among individuals for producing the patterns of organization in dominance hierarchies reveals these structures as self-organizing or self-structuring systems. These experiments are an empirical demonstration that dominance hierarchies are indeed self-organizing, and they confirm previous theoretical work” (p 5748).

Corning, Peter A. “Holistic Darwinism: ‘Synergistic Selection’ and the Evolutionary Process.” *Journal of Social and Evolutionary Systems* 20, no. 4 (1997): 363–400.
Corning views evolution as an emergent, multilevel development facilitated by the effects of cooperation and synergy.

Couzin, Iain, et al. “Collective Memory and Spatial Sorting in Animal Groups.” *Journal of Theoretical Biology* 218, no. 1 (7 September 2002): 1–11.
Couzin utilizes a computer simulation to study how fish schools and bird flocks maintain a self-organized coherence while also allowing individual member to employ simple, local rules.

de Waal, Frans B., and Peter L. Tyack. *Animal Social Complexity: Intelligence, Culture, and Individualized Societies.* Cambridge, Mass.: Harvard University Press, 2003.
The authors develop a unified social science that includes animal intelligence and culture.

Dugatkin, Lee. *Cooperation Among Animals: An Evolutionary Perspective.* Oxford: Oxford University Press, 1997.
Dugatkin provides a notable contribution to the field on the primacy of altruistic behavior in evolution.

Fehr, Ernst, et al. “Strong Reciprocity, Human Cooperation, and the Enforcement of Social Norms.” *Human Nature* 13, no. 1 (2002): 1–25.
In the lead article in a special collection of papers that quantify an innate tendency for cooperation, Fehr provides evidence that challenges the “self-interest” assumption that dominates the behavioral sciences and evolutionary thinking. This new evidence indicates that most people tend to voluntarily cooperate with each other, as long as they are treated fairly. It also reveals that people who do not cooperate are often punished.

Johnson, Craig R., and Marten C. Boerlijst. “Selection at the Level of the Community: The Importance of Spatial Structure.” *Trends in Ecology and Evolution* 17, no. 2 (1 February 2002): 83–90.
The growing admission that there may be a sequential evolutionary scale is supported by the fact that nonlinear spiral patterns reoccur at each stage in the evolutionary process. As evident in bacteria and symbiotic cells, aggregate groups or societies also employ an interplay of semi-autonomous individuals and modular subcommunities that interact locally to create and maintain a coherent, emergent organization.

Michod, Richard E. *Darwinian Dynamics: Evolutionary Transitions in Fitness and Individuality.* Princeton, N.J.: Princeton University Press, 1998.
Michod proposes that multilevel evolution is due more to salutary collaboration, than to debilitating competition. Cooperation, he argues, “is now seen as the primary creative force behind ever greater levels of complexity and organization” (p ix) in each of the biological fields.

Ridley, Matt. *The Origins of Virtue: Human Instincts and the Evolution of Cooperation.* New York: Viking, 1997.
Ridley describes how evolutionary biology can support the propensity for cooperation in a nested, “Russian doll” scale from genetic “teams” or networks to primate and human societies.

Sober, Elliott, and David Sloan Wilson. *Unto Others: The Evolution and Psychology of Unselfish Behavior.* Cambridge, Mass.: Harvard University Press, 1998.
The authors present philosophical and scientific arguments for reciprocal altruism among members of a society and group selection.

Science Bibliography

Wilson, David Sloan. "Introduction: Multilevel Selection Theory Comes of Age." *American Naturalist* 150, no. S1, Supplemental Multilevel Selection (July 1997): S1–S4.
In this special journal supplement on exploring and articulating a new appreciation of group selection, the author discusses how a similar conceptual framework is applied to different levels of biological hierarchy.

_______. "Animal Movement as a Group-Level Adaptation." In *On the Move: How and Why Animals Travel in Groups,* eds. Sue Boinski and Paul A. Garber, 238–58. Chicago, Ill.: University of Chicago Press, 2000.
Wilson makes a case for multilevel selection based on the adaptive and cognitive properties of social species (e.g., the African buffalo).

Wilson, Robert A. "Group-Level Cognition." *Philosophy of Science* 68, no. 3 Supplement (2001): S262–S273.
Wilson defends the quantified reappearance and appreciation of social groups with their own minds.

Wright, Robert. *Nonzero: The Logic of Human Destiny.* New York: Pantheon, 1999.
Wright applies game theory to evolution and history in order to reveal an inherent tendency toward emergent cooperation.

Dynamic Ecosystems

Dynamic Ecosystems are intricate natural domains that do not seek an equilibrium or balance as once thought but are in constant flux over many similar scales from microbes to bioregions.

Allen, T. P. H., and Thomas N. Hoekstra. *Toward a Unified Ecology.* New York: Columbia University Press, 1992.
Allen argues that ecology, as a theoretical science, should be based on the pervasive fractal, stratified anatomy and physiology of diverse, complex ecosystems.

Andrea, Rinaldo, et al. "Cross-Scale Ecological Dynamics and Microbial Size Spectra in Marine Ecosystems." *Proceedings of the Royal Society of London B* 269, no. 1504 (2002) 2051–59.
Andrea asks why a continuous spectrum of organism size emerges from the ecological and evolutionary processes that shape ecosystems over time. He finds that "[s]uch features may have their dynamic origin in the self-organization of complex adaptive systems, possibly to self-organized critical phenomena, because they are robust in the face of environmental fluctuations" (p 2051). Furthermore, he believes "[t]hat such a complex web of interacting factors, acting locally and over evolutionary time, should result in such universal patterns begs explanation, and [he] suggests a tendency of ecosystems to self-organize into states that lack a characteristic size—regardless of initial conditions and of transient disturbances" (p 2057).

Atkinson, R., Christopher I. Rhodes, David W. Macdonald, Roy M. Anderson, eds. "Scale-Free Dynamics in the Movement Patterns of Jackals." *OIKOS* 98, no. 1 (2002): 134–40.
Atkinson et al. find self-similar mathematical processes throughout a knowable nature.

Bascompte, Jordi, and Ricard V. Sole. *Modeling Spatiotemporal Dynamics in Ecology.* New York: Springer-Verlag, 1997.
The authors apply nonlinear theory to complex natural environments and argue that rainforest ecologies exemplify a recursive, self-similar system.

Brown, James H. *Macroecology.* Chicago, Ill.: University of Chicago Press, 1995.
Brown, an ecologist, seeks an appropriate framework for the multidimensional intricacy of natural habitats and defines the five common features of complex adaptive systems: "(1) they are composed of numerous components of many different kinds, (2) the components interact nonlinearly and on different temporal and spatial scales, (3) the systems organize themselves to produce complex structures and behaviors, (4) the systems maintain thermodynamically unlikely states by the exchange of energy and materials across their differentially permeable

boundaries, (5) some form of heritable information allows the systems to respond adaptively to environmental change" (p 14).

_______."Macroecology: Progress and Prospect." *OIKOS* 87, no. 1 (1999): 6–9.
Brown explains the discovery of similar, repeatable networks and scales throughout flora and fauna and argues that "[t]he promise of macroecological research is that widespread patterns imply the operation of equally general processes, and universal patterns imply the operation of universal scientific laws" (p 7).

Enquist, Brian J., et al. "General Patterns of Taxonomic and Biomass Partitioning in Extant and Fossil Plant Communities." *Nature* 419, no. 6907 (10 October 2002): 610–12.
Enquist et al utilize complexity theories to explain that the tangled fauna of forest and field reveal a hierarchical scale where the same form and dynamics hold at each nested scale.

Harte, John. "Toward a Synthesis of the Newtonian and Darwinian Worldviews." *Physics Today* 55, no. 10 (October 2002): 29–34.
In this 2001 Leo Szilard Award Lecture, Harte, a theoretical ecologist, attempts to fuse the universality of physical systems and the interdependent detail of ecosystems through the application of complexity principles.

Harte, John, et al. "Self-Similarity in the Distribution and Abundance of Species." *Science* 284, no. 5412 (19 April 1999): 334–36.
Harte et al discuss how species are distributed by a nested scale in biome habitats, an arrangement that reflects the utility of fractal geometry to describe natural systems.

Higgins, Paul, et al. "Dynamics of Climate and Ecosystem Coupling." *Philosophical Transactions of the Royal Society of London B* 357, no. 1421 (29 May 2002): 647–55.
Higgins et al argue that no phenomena can be studied in isolation from its systemic environment. When considering interactions between subunits of the global biosphere, the authors observe different behavior than when taking subunits into account individually.

Holling, Crawford S. "Understanding the Complexity of Economic, Ecological, and Social Systems." *Ecosystems* 4, no. 5 (August 2001): 390–405.
An international group of biologists, ecologists, and social scientists identify self-organizing, complex adaptive systems at every domain of the natural and human worlds. Their project, "Panarchy," combines scalar features with the dynamic interplay between change and persistence, as embodied by the Greek god Pan. More specifically, "[p]anarchy is the hierarchical structure in which systems of nature (forests, grasslands, lakes, rivers, and seas), and humans (structures of governance, settlements, and cultures), as well as combined human-nature systems and social-ecological systems . . . are interlinked in never-ending adaptive cycles of growth, accumulation, restructuring, and renewal. These transformational cycles take place in nested sets at scales ranging from a leaf to the biosphere over periods from days to geologic epochs, and from scales of a family to a sociopolitical region over periods from days to centuries" (p 392).

Jorgensen, Sven F., ed. *Thermodynamics and Ecological Modelling.* Boca Raton, Fla.: Lewis Publishers, 2001.
Jorgensen reveals new insights into ecosystems by way of nonequilibrium energy and entropy budgets.

Kaitala, Veijo, et al. "Self-organized Dynamics in Spatially Structured Populations." *Proceedings of the Royal Society London B* 268, no. 1477 (2001): 1655–60.
Kaitala et al illustrate that constant self-similar dynamics hold across many animal populations such as the Canadian lynx and the snowshoe hare.

Kawanabe, Hiroya, et al., eds. *Mutualism and Community Organization: Behavioral, Theoretical, and Food-Web Approaches.* New York: Oxford University Press, 1993.
Kawanabe et al present a revised ecology to emphasize holism, synergy, symbiosis, and connectionism.

Kay, James J., et al. "An Ecosystem Approach for Sustainability: Addressing the Challenges of Complexity." *Futures* 31, no. 7 (September 1999): 721–42.
Rather than envisioning nature as if it were a mechanism under one's control, the authors explore how to facilitate "self-organizing, holarchic open systems" so as to achieve a viable biosphere.

Keitt, Timothy, et al. "Scaling in the Growth of Geographically Subdivided Populations." *Philosophical Transactions of the Royal Society of London B* 357, no. 1421 (29 May 2002): 627–33.
By studying statistical patterns of variation in growth rates of over 400 species of birds, the authors observe common, power-law patterns, which are suggestive of general laws. These results correspond to similar studies of larger social and economic systems.

Lassig, Michael, et al. "Shape of Ecological Networks." *Physical Review Letters* 86, no. 19 (7 May 2001): 4418–21.
The authors contend that ecosystems possess a ubiquitous topology analogous to biological systems and quantum phenomena.

Lek, Sovan, and J. F. Guegan, eds. *Artificial Neuronal Networks: Application to Ecology and Evolution.* Berlin: Springer, 2000.
Lek and Guegan have compiled a primer for understanding areas from biodiversity to epidemiology by means of neural network principles.

Levin, Simon A. "Ecosystems and the Biosphere as a Complex Adaptive System." *Ecosystems* 1, no. 5 (September/October 1998): 431–43.
Levin provides the lead article from the premier issue of *Ecosystems* in order to explore and advance the complex adaptive systems approach.

_______. *Fragile Dominion: Complexity and the Commons.* Reading, Mass.: Perseus Books, 1999.
Levin explains how the science of complex adaptive systems promises to bring a novel appreciation of bioregional ecologies and biosphere viability. Through the unifying principle of self-organization, scientists can perceive order among diverse phenomena and structures.

_______. "Complex Adaptive Systems." *Bulletin of the American Mathematical Society* 40, no. 1 (2003): 3–19.
Levin's article imparts guidelines for studying the evolving biosphere that recognize the nonlinear properties of many agents, diversity, resiliency, localized interactions, cooperation, pattern emergence, etc.

Margalef, Roman. "Information Theory and Complex Ecology." In *Complex Ecology: The Part-Whole Relation in Ecosystems,* eds. Bernard C. Patten and Sven E. Jorgensen, 40–50. Englewood Cliffs, N.J.: Prentice Hall, 1995.
Margalef, a renowned ecologist, develops a linguistic model for natural ecosystems, that can be considered analogous to languages.

Marquet, Pablo A. "Of Predators, Prey, and Power Laws." *Science* 295, no. 5563 (22 March 2002): 2229–30.
Marquet provides a typical example of how complexity science can at last articulate the natural realm.

Montoya, Jose M., and Ricard V. Sole. "Small World Patterns in Food Webs." *Journal of Theoretical Biology* 214, no. 3 (7 February 2002): 405–12.
Montoya and Sole demonstrate how the property of complex networks to develop a power-law distribution of interlinked nodes applies to dynamic ecosystem communities.

Mouillot, David, et al. "The Fractal Model." *OIKOS* 90, no. 2 (September 2000): 333.
Mouillot et al argue that self-similar geometry applies to species abundance and distribution.

Naveh, Zev. "Ten Major Premises for a Holistic Conception of Multifunctional Landscapes." *Landscape and Urban Planning* 57, nos. 3–4 (15 December 2001): 269–84.
Naveh, a veteran ecologist, lists the salient features of self-organizing systems that, by their natural ubiquity, can guide the transition to a sustainable society. Naveh also perceives

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a paradigm shift in evolution—from fragmentation to integration—that finds its parallel in the post-industrial, information society. More specifically, he argues that ". . . a revolution was initiated [through] . . . a major paradigm shift from parts to wholes and from entirely reductionistic and mechanistic approaches to more holistic and organismic ones. It shifted from breaking down, analyzing, and fragmenting wholes into smaller and smaller particles toward new trends for integration, synthesis, and complementarity. . . . These should also be the properties of sustainable societies, their economy and landscapes in the emerging post-industrial information society. It constitutes a major transdisciplinary paradigm shift from the neo-Darwinian conception of evolution to an all-embracing conception of synthetic cosmic, geological, biological, and cultural co-evolution" (p 271).

Nielsen, Soren Nors. "Thermodynamics of an Ecosystem Interpreted as a Hierarchy of Embedded Systems." *Ecological Modelling* 135, nos. 2–3 (5 December 2000): 279–89.
In this article, Nielsen integrates nonequilibrium thermodynamics and nested network perspectives.

Pahl-Wostl, Claudia. *The Dynamic Nature of Ecosystems: Chaos and Order Entwined.* Chichester: Wiley, 1995.
In response to a fragmented, mechanistic paradigm, Pahl-Wostl proposes a holistic, relational approach that can perceive the pervasive pattern of interactions in self-organized environments.

Pimm, Stuart. *The Balance of Nature?: Ecological Issues in the Conservation of Species and Communities.* Chicago, Ill.: University of Chicago Press, 1991.
In this text, Pimm recognizes how nonlinear dynamics can define landscape ecology.

Recknagel, F. "Preface." *Ecological Modelling* 146, nos. 1–3 (2001): 1–2.
Recknagel introduces this special double issue on the new investigative approach of ecological informatics, which employs nonlinear methods such as neural networks to study dynamically complex, stratified ecosystems.

Ricotta, Carlo. "From Theoretical Ecology to Statistical Physics and Back: Self-Similar Landscape Metrics as a Synthesis of Ecological Diversity and Geometrical Complexity." *Ecological Modelling* 125, nos. 2–3 (2000): 245–53.
Ricotta develops a unified science based on a nature suffused by universal, multifractal patterns.

Rinaldo, Andrea, et al. "Cross-Scale Ecological Dynamics and Microbial Size Spectra in Marine Ecosystems." *Proceedings of the Royal Society of London B* 269, no. 1504 (2002): 2051–59.
Rinaldo et al ask why a continuous spectrum of organism size emerges from the ecological and evolutionary processes over long time periods and they speculate that "[s]uch features may have their dynamic origin in the self-organization of complex adaptive systems, possible to self-organized critical phenomena, because they are robust in the face of environmental fluctuations" (p 2051). That such "a complex web of interacting factors, acting locally and over evolutionary time, should result in such universal patterns begs explanation, and suggests a tendency of ecosystems to self-organize into states that lack a characteristic size—regardless of initial conditions and of transient disturbances" (p 2057).

Schneider, David. "The Rise of the Concept of Scale in Ecology." *BioScience* 51, no. 7 (July 2001): 545–53.
Schneider argues that ecosystems are best characterized by a nested, dynamic hierarchy due to a power-law that is critically self-organized.

Wu, Jianguo, and Danielle Marceau. "Modeling Complex Ecological Systems: An Introduction." *Ecological Modelling* 153, nos. 1–2 (July 15, 2002): 1–6.
Wu and Marceau introduce this double journal issue devoted to self-organizing, emergent ecosystems.

A Living Planet

The evolution of the biosphere appears to be a self-regulated process that sustains favorable geochemical and atmospheric conditions for life.

Science Bibliography

Benner, Steven A., et al. “Planetary Biology.” *Science—Paleontological, Geological, and Molecular Histories of Life* 296, no. 5569 (3 May 2002): 864–68.
Benner et al argue that as “a civilization-wide enterprise,” the global expanse of life and the human is reconstructed in a manner similar to a developing, cognizant organism.

Bunyard, Peter, ed. *Gaia in Action: Science of the Living Earth.* Edinburgh: Floris Books, 1996.
Bunyard and others present an exploration of the holistic and ecological hypothesis of Gaia. Its main founder is Vladimir Vernadsky and it is his geoscience of living matter that informs this volume.

Downing, Keith. “Exploring Gaia Theory.” In *Artificial Life VII: Proceedings of the Seventh International Conference on Artificial Life,* eds. Mark A. Bedau, John S. McCaskill, Norman H. Packard, and Steen Rasmussen, 90–102. Cambridge, Mass.: MIT Press, 2000.
Downing argues that evolutionary computation and simulation model natural selection on a global scale.

Ernst, Walter G., ed. *Earth Systems: Processes and Issues.* New York: Cambridge University Press, 2000.
Ernst and others complete a comprehensive survey of earth systems science in its nested geological and atmospheric domains and include commentary on the social policy implications of these findings.

Lenton, Timothy, and Marcel van Oijen. “Gaia as a Complex Adaptive System.” *Philosophical Transactions of the Royal Society of London B* 357, no. 1421 (29 May 2002): 683–95.
Lenton and van Oijen argue that the entire Earth system can be considered a manifestation of the way in which many local, interactive agents give rise to a self-regulating order.

Lovelock, James. *Gaia: A New Look at Life on Earth.* New York: Oxford University Press, 1979.
This is the original theoretical work of the British atmospheric chemist who initiated the modern conception of the planet as a self-sustaining entity.

_______. *Healing Gaia: Practical Medicine for the Planet.* New York: New York: Harmony Books, 1991.
Lovelock presents a lucid, graphic exposition of a “planetary medicine” that is intended to cope with the perilous human impact on the environment.

Margulis, Lynn. *Symbiotic Planet: A New Look at Evolution.* North Ponfret, V. M.: Trafalgar Square Books, 1998.
Margulis explains how symbiosis, especially in the bacterial realm, serves the maintenance of an organically unified biosphere.

Margulis, Lynn, Clifford Matthews, Aaron Haselton, eds. *Environmental Evolution: Effects of the Origin and Evolution of Life on Planet Earth.* 2nd ed. Cambridge, Mass.: MIT Press, 2000.
The editors survey atmospheric, biological, and geological conditions from their Archean origins to the industrial revolution.

Schneider, Stephen H., and Penelope J. Boston, eds. *Scientists on Gaia.* Cambridge, Mass.: MIT Press, 1991.
These proceedings from the American Geophysical Union conference explore the multifaceted technical foundations of the Gaia hypothesis.

Schwartzman, David. *Life, Temperature, and the Earth: The Self-Organizing Biosphere.* New York: Columbia University Press, 1999.
Schwartzman explicates a thermodynamic-based geophysiology whose conditions indicate a self-organizing processes. He further argues that biospheric evolution occurs in part because it is a complex adaptive whole system with material inheritance and a self-selection of relative stability.

Skinner, Brian J., et al. *The Blue Planet: An Introduction to Earth System Science.* 2nd ed. New York: Wiley, 1999.
The authors offer a basic, illustrated text on Earth system science with Gaian propensities.

Smil, Vaclav. *The Earth's Biosphere: Evolution, Dynamics, and Change.* Cambridge. Mass.: MIT Press, 2002.
Smil's comprehensive study covers physics, chemistry, biology, geology, oceanography, energy, climatology, and ecology, with an emphasis on symbiosis and the role of life's complexity in biomass productivity and resilience. He discusses the influence of solar radiation and plate tectonics along with the quarter-power scaling of animal and plant metabolisms.

Staley, Mark. "Darwinian Selection Leads to Gaia." *Journal of Theoretical Biology* 218, no. 1 (7 September 2002): 35–46.
Stanley argues that when organisms adapt to their environment, they consequently influence their biotic niche.

Volk, Tyler. *Gaia's Body: Toward a Physiology of Earth.* New York: Copernicus Books, 1998.
An earth scientist elucidates an anatomy and physiology of the biosphere through its atmospheric, oceanic, vegetative, geological, and chemical cycles and the intricate interplay that occurs between them.

Williams, George R. *The Molecular Biology of Gaia.* New York: Columbia University Press, 1996.
Williams, an evolutionary biologist, reviews the possibility of taking Lovelock's idea of geophysiology seriously and proceeds toward a theoretical synthesis of the universe. Williams suggests that "just as the physiology of cells and organisms is now understood in light of the underlying biochemistry, so the workings of the planetary ecosystem will be understood in terms of the molecular details of the relevant biological processes" (p xi).

3.3.2 The Rise of Sentience

Brain Complexity

While fossil-based evolution does not exhibit a trend, cerebral capacity grows steadily in anatomical size due to environmental and social interactions.

Arbib, Michael A., et al. *Neural Organization: Structure, Function, and Dynamics.* Cambridge, Mass.: MIT Press, 1997.
This text discusses both brain structure (e.g., "The Modular Architectonics Principle") and its self-organized function (e.g., "neurodynamical system theory"). Arbib argues that neural structure can be studied at various levels (e.g., molecular, membrane, cellular, synaptic, network, system) and finds that "[b]oth ontogenetic development and phylogenetic evolution are dynamic processes . . . identified with self-organization phenomena" (p 4).

Breidbach, Olaf, and Wolfram Kutsch, eds. *The Nervous Systems of Invertebrates: An Evolutionary and Comparative Approach.* Basel, Switzerland: Birkhauser, 1995.
These research papers suggest a common Bauplan for invertebrate nervous systems along with parallels between early embryogenesis and evolutionary neurogenesis.

Brown, William M. "Natural Selection of Mammalian Brain Components." *Trends in Ecology and Evolution* 16, no. 9 (September 1, 2001): 471–73.
Recent findings suggest that cerebral anatomy is influenced by a species specific "mosaic" evolution, an "adaptationist" view in addition to the "developmental constraints hypothesis" of a concerted size increase, which is driven by the need for expanded environmental knowledge. Brown argues further that "[b]ecause the mindbrain has visual and auditory structures, the neocortex and mindbrain expansions of the insectivores support the idea that there has been an elaboration in mammals of neural capacities to integrate multimodal information to create perceptual representations of increasingly complex 3D niches" (p 472).

Science Bibliography

Clark, Damon A., et al. "Scalable Architecture in Mammalian Brains." *Nature* 411, no. 6834 (May 10, 2001): 189–92.

This paper presents information on the growing quantification of an evolutionary linearity of brain component and structure as it expands in size.

Eisthen, Heather, and Kiisa Nishikawa. "Convergence: Obstacle or Opportunity?" *Brain, Behavior, and Evolution* 59, nos. 5–6 (May/April 2002): 232–40.

Eisthen and Nishikawa introduce this double issue on the growing evidence for convergent pathways by arguing that every level of biological organization displays convergence.

Falk, Dean, and Kathleen R. Gibson, eds. *Evolutionary Anatomy of the Primate Cerebral Cortex.* Cambridge: Cambridge University Press, 2001.

In this compendium, the editors recognize and extend the allometric studies of Harry Jerison. He explains how the evolving brain acts as a single, coordinated organ that grows in overall size through the relative enlargement of its component modules. Michel Hofman notes that the hominid brain has reached structural and energetic limits and he notes that further advances in intelligence need to take place in the realm of technological evolution.

Finlay, Barbara L., and Richard B. Darlington. "Linked Regularities in the Development and Evolution of Mammalian Brains." *Science* 268, no. 5217 (June 16, 1995): 1578–84.

Finlay and Darlington argue that as ten brain subdivisions steadily expand in size, scale remains consistent with total brain volume.

Gazzaniga, Michael S., Richard B. Ivry, and George R. Mangun, eds. *Cognitive Neuroscience: The Biology of the Mind.* 2nd ed. New York: Norton, 2002.

This text on brain and central nervous system composition presents information on lateralization, motor control, language, etc., and views them all as being set in an evolutionary frame.

Gazzaniga, Michael, ed. *The New Cognitive Neurosciences.* 2nd ed. Cambridge, Mass.: MIT Press, 2000.

This text contains essays by leading authorities in the field and explores a wide range of topics, including brain development, evolution, and cogitation.

Jerison, Harry J. "On the Evolution of Mind." In *Brain and Mind,* ed. David A. Oakley, 1–31. London: Methuen, 1985.

Jerison explores how large brains, as information processing systems, are arranged in a nested hierarchical fashion.

Kandel, Eric R., James H. Schwartz, and Thomas M. Jessell, eds. *Principles of Neural Science.* 4th ed. New York: McGraw-Hill, Health Professions Division, 2000.

The editors have compiled an encyclopedic text on the gamut of brain and nervous system structure and function.

Kishikawa, Kiisa. "Evolutionary Convergence in Nervous Systems: Insights from Comparative Phylogenetic Studies." *Brain, Behavior, and Evolution* 59, nos. 5–6 (May/April 2002): 236–47.

Kishikawa argues that convergent evolution is more widespread than previously thought. "Over the past twenty years, cladistic analyses have revolutionized our understanding of brain evolution by demonstrating that many structures, some of which had previously been assumed to be homologout, have evolved many times independently. These and other studies demonstrate that evolutionary convergence in brain anatomy and function is widespread.

One reason that convergence is so common in the biological world may be that the evolutionary appearance of novel functions is associated with constraints, for example in the algorithms used for a given neural computation. Convergence in functional organization may thus reveal basic design features of neural circuits in species that possess unique evolutionary histories but use similar algorithms to solve basic computational problems" (p 240).

Science Bibliography

MacLean, Paul D. *The Triune Brain in Evolution: Role in Paleocerebra: Role in Paleocerebral Functions.* New York: Plenum Publishing Corp., 1990.
The originator of the theory of three subsequent stages of brain development—reptilian, paleomammalian, and neomammalian—proposes that these stages are a product of self-organizing, fractal dynamics, which he describes as “fractogenesis.”

Phelps, Steven M. “Like Minds: Evolutionary Convergence in Nervous Systems.” *Trends in Ecology and Evolution* 17, no. 4 (April 1, 2002): 158–59.
Phelps presents a conference summary of how both somatic and mental development employ common solutions to various situations.

Reader, Simon, and Kevin Laland. “Social Intelligence, Innovation, and Enhanced Brain Size in Primates.” *Procedings of the National Academy of Sciences* 99, no. 7 (2002): 4436–41.
In this extensive literature search on social learning, invention, and tool use, Reader and Laland reveal a close correlation between brain size and cognitive capacity.

Roth, Gerhard, and Mario F. Wullimann, eds. *Brain, Evolution, and Cognition.* New York: Wiley, 2001.
International researchers have produced an extensive volume on the anatomy, physiology, development, and operation of invertebrate, vertebrate, and human brains. As a general theme, the editors recognize a continuity that occurs through degrees of encephalization and subsequent conscious awareness. Human beings appear to enter an extrasomatic cerebral realm through language.

Stevens, Charles F. “An Evolutionary Scaling Law for the Primate Visual System and Its Basis in Cortical Function.” *Nature* 411, no. 6834 (May 10, 2001): 193–94.
Stevens argues that allometric, scale-free laws hold for neural development. More specifically he belives that “[t]he conservation of these scaling relations raises the possibility that a similar basis for the scaling laws exists for all cortical areas. In this view, each cortical area would be provided with a map of some sort—perhaps one with very abstract quantities—and the job of the cortex would be to extract some characteristic of the map at each point that would be represented as a location code by the neurons in each map ‘pixel.’ . . . A 3/2 power relation would result” (p 195).

Zhang, Kechen, and Terrence Sejnowski. “A Universal Scaling Law Between Gray Matter and White Matter of Cerebral Cortex.” *Proceedings of the National Academy of Sciences of the United States of America* 94, no. 10 (May 9, 2000): 5621–26.
The authors show that a power law over six orders of magnitude—spanning from the pygmy shrew to elephants—describes a similarly layered architecture in the neocortex.

Self-Organizing Cerebral Dynamics

The principles of self-organization are found to similarly apply to a brain’s neural network development and thought processes.

Anderson, James A., and Edward Rosenfeld, eds. *Talking Nets: An Oral History of Neural Networks.* Cambridge, Mass.: MIT Press, 1998.
Anderson and Rosenfeld have collected a series of interviews with the pioneers of neural network theory, such as David Rumelhart and Teuvo Kokonen. Of special interest is a commentary provided by Stephen Grossberg.

Arshavsky, Yuri I. “Role of Individual Neurons and Neural Networks in Cognitive Functioning of the Brain: A New Insight.” *Brain and Cognition* 46, no. 3 (August 2001) 414–28.
Arshavsky observes that discrete neurons are not wholly controlled by network dynamics but rather operate in a specialized “cell-autonomous” manner, creating a cerebral example of the generic particle/wave, agent/relation complementarity.

Science Bibliography

Beer, Randall O. "Dynamical Approaches to Cognitive Science." *Trends in Cognitive Science* 4, no. 3 (March 1, 2000): 91–99.
Beer updates and synthesizes information relating to computational, connectionist, and complex system properties of neural operation.

Changizi, Mark. "Principles Underlying Mammalian Neocortical Scaling." *Biological Cybernetics* 84, no. 3 (2001): 207–15.
Changizi argues that the same fractal scaling that describes organic forms and metabolic functions also applies to the brain.

Cicchetti, Dante, and Geraldine Dawson. "Editorial: Multiple Levels of Analysis." *Development and Psychopathology* 14, no. 3 (August 2002): 417–20.
In their introduction to this special journal issue, Cicchetti and Dawson explore how systems neuroscience—from genetic to behavioral levels—is quantifying a self-organizing brain.

Donahoe, John W., and Vivian Packard Dorsel, eds. *Neural-Networks Models of Cognition: Behavioral Foundations.* Amsterdam: Elsevier Science, 1997.
The editors explain how self-organizing neural nets guide brain development, plasticity, perception, stimuli responses, reinforcement learning, and complex behavior.

Feinberg, Todd E. *Altered Egos: How the Brain Creates the Self.* Oxford: Oxford University Press, 2001.
Feinberg contends that the brain is arranged in the same nested hierarchy as all biological systems and argues that a unified self emerges from this system.

Freeman, Walter. *Societies of Brains: A Study in the Neuroscience of Love and Hate.* Mahwah, N.J.: Lawrence Erlbaum Associates, 1995.
Freeman, a pioneering researcher in this field, explains the self-organizing dynamics of cerebral evolution and cognitive performance.

Grigsby, Jim, and David Stevens. *Neurodynamics of Personality.* New York: Guilford Press, 2000.
The authors are working on the frontiers of the application of complexity science and its ability to elucidate both the thinking brain and personal disposition. They argue that ". . . personality reflects the emergent properties of a dynamic, hierarchically ordered, modular, distributed, self-organizing functional system, the primary objective of which is the successful adaptation of the individual to his or her physical and social environment" (p 19).

Grossberg, Stephen. "The Complementary Brain: Unifying Brain Dynamics and Modularity." *Trends in Cognitive Sciences* 4, no. 6 (June 1, 2000): 233–46.
The author explains that a pervasive reciprocity exists among neural activities such as "boundary completion" and "surface filling-in," and that these entities are mirrored the physical realm. More specifically, Grossberg finds evidence that ". . . the brain's processing streams compute complementary properties. Each stream's properties are related to those of a complementary stream in the way that two pieces of a puzzle fit together." He also reveals ". . . how the mechanisms that enable each stream to compute one set of properties prevent it from computing a complementary set of properties . . . [and] that the concept of pairs of complementary processes brings new precision to the idea that both functional specialization and functional integration occur in the brain (p 234). According to this view, the organization of the brain obeys principles of uncertainty and complementarity, as does the physical world with which brains interact (and of which they form a part)." Grossberg goes onto suggest that "these principles reflect each brain's role as a self-organizing measuring device in and of the world" (p 235).

_______. "Linking Mind to Brain: The Mathematics of Biological Intelligence." *Notices of the American Mathematical Society* 47, no. 11 (December 2000): 1361–72.
In this article, Grossberg explores further insights into the universe present within the human brain.

Halford, Graeme, et al. "Processing Capacity Defined by Relational Complexity: Implications for Comparative, Developmental, and Cognitive Psychology." *Behavorial and Brain Sciences*

21, no. 4 (December 1998): 803–31.
Halford et al argue that neural nets ought to be considered less in terms of bytes or agents and more in terms of interconnections and their capacity for distributed processing.

Hofman, Michel. “Evolution and Complexity of the Human Brain.” In *Brain, Evolution, and Cognition,* eds. Gerhard Roth and Mario F. Wullimann, 501–21. New York: Wiley, 2001.
Hofman argues that common organizing principles seem to persist in their evolutionary ramification and therefore suggest an archetypal Bauplan. He argues further that “[i]t is evident that the potential for brain evolution results not from the unorganized aggregations of neurons but from cooperative associations by the self-similar compartmentalization and hierarchical organization of neural circuits and the invention of fractal folding, which reduces the interconnective axonal distances” (p 518).

Kahn, David, et al. “Dreaming and the Self-Organizing Brain.” *Journal of Conscious Studies* 7, no. 7 (July 2000): 4–11.
Kahn et al reveals how a conception of the brain as a dynamic, fractally scaled, critically poised system can bring new understanding and rationale to dream activity.

Kelso, J. A. Scott. *Dynamic Patterns: The Self-Organization of Brain and Behavior.* Cambridge, Mass.: MIT Press, 1995.
Kelso presents a comprehensive understanding of the conduct of life and cognition through nonlinear science, with an emphasis on synergetic principles.

Koch, Christoph, and Gilles Laurent. “Complexity and the Nervous System.” *Science* 284, no. 5411 (2 April 1999): 96–98.
Koch and Laurent survey the explanatory value of dynamical theories in neuroscience. They argue that “[w]hile everyone agrees that brains constitute the very embodiment of complex adaptive systems and that Albert Einstein’s brain was more complex than that of a housefly, nervous system complexity remains hard to define. . . . Any realistic notion of brain complexity must incorporate, first the highly nonlinear, nonstationary, and adaptive nature of the neuronal elements themselves and, second, their nonhomogeneous and massive parallel patterns of interconnections whose ‘weights’ can wax and wane across multiple time scales in behaviorally significant ways” (p 98).

MacCormac, Earl A., and Maxim Stamenov, eds. *Fractals of Brain, Fractals of Mind: In Search of a Symmetry Bond.* Philadelphia, Pa.: John Benjamins Publishing Co., 1996.
The authors explain that the sciences of complexity reveal an intrinsic self-organization of brain development and behavior that takes on a fractal-like structure across many different spatial scales.

Mandelblit, Nili, and Oron Zachar. “The Notion of Dynamic Unit: Conceptual Developments in Cognitive Science.” *Cognitive Science* 22, no. 2 (April/June 1998): 229–68.
The authors present a model similar to complex adaptive systems that is applicable to every phase from physical substrates to neural processes, linguistics, and a collective social cognition. More specifically they argue that their “framework suggests a definition of unity which is based not on inherent properties of the elements constituting the unit, but rather on dynamic patterns of correlation across the elements” (p 229).

O’Brien, Gerard, and Jonathan Opie. “A Connectionist Theory of Phenomenal Experience.” *Behavioral and Brain Sciences* 22, no. 1 (February 1999): 1100–11.
The authors argue that a “[p]henomenal experience consists of the explicit representation of information in neurally realized parallel distributed processing (PDP) networks” (p 127).

Pribram, Karl H., and Joseph King, eds. *Learning as Self-Organization.* Mahwah, N.J.: Lawrence Erlbaum Associates, 1996.
This collection of innovative papers from both scientific and traditional perspectives describes the revolution in neuroscience due to nonlinear theories.

Redies, Christoph, and Luis Puelles. "Modularity in Vertebrate Brain Development and Evolution." *BioEssays* 23, no. 12 (2001): 1100–11.
Redies and Puelles provide another example of constant modularity throughout the biological kingdom, by explaining that semi-autonomous, diverse modules are at work in both the embryonic and functional phases of cerebral formation.

Spitzer, Manfred. *The Mind Within the Net: Models of Learning, Thinking, and Acting.* Cambridge, Mass.: MIT Press, 1999.
Spitzer presents an introduction to self-organizing neural networks. He argues that the composition of the neural network allows the human brain to engage in information processing and pattern recognition. This latter function has been excluded from mechanistic science because integrative patterns are not expected in its left-hemisphere emphasis and therefore are not seen.

Thompson, Evan, and Francisco J. Varela. "Radical Embodiment: Neural Dynamics and Consciousness." *Trends in Cognitive Sciences* 5, no. 10 (October 1, 2001): 418–25.
Thompson and Varela argue that sentient awareness is rooted in an "enactive" brain-body-world interplay rather than being confined to purely neuronal events.

Treffner, Paul J., and Scott Kelso. "Dynamic Encounters: Long Memory During Functional Stabilization." *Ecological Psychology* 11, no. 2 (1999): 103–37.
Treffner and Kelso argue that "[e]vidence and theory suggest that the coordination of human perception and action may be understood as a self-organizing complex system that exhibits great flexibility by operating nearby critical points of instability" (p 103).

Tsuda, Ichiro. "Toward an Interpretation of Dynamic Neural Activity in Terms of Chaotic Dynamical Systems." *Behavioral Brain Sciences* 24, no. 5 (October 2001): 793–810.
Tsuda argues that the conventional view of dynamic neural activity emphasizes static elements whereas newer insights emphasize the fluid, shifting relations between the modular components. The active brain then self-organizes via the interplay of both retained representation and creative perception.

Van Gelder, Tim. "The Dynamical Hypothesis in Cognitive Science." *Behavioral and Brain Sciences* 21, no. 5 (October 1998): 615–28.
Van Gelder affirms that an integrative mental activity supplants the digital computational model.

Van Orden, Guy. "Nonlinear Dynamics and Psycholinguistics." *Ecological Psychology* 14, nos. 1–2 (2002): 1–4.
Twentieth century cognitive psychology was founded on reductionism and linearity but Van Orden's introduction to this special journal issue affirms the irreducible relations between agents and environments. These relations, according to Van Orden, take on the characteristic form of fractally nested self-organizing systems.

Varela, Francisco, et al. *The Embodied Mind: Cognitive Science and Human Experience.* Cambridge, Mass.: MIT Press, 1991.
Varella engages in bridge building from the expansive self of Madhyamika Buddhist psychology over a computational view of a fragmented self toward a novel "enactive" theory drawing on connectionist, self-organizing networks.

An Increasing Intelligence and Representation

As the brain evolves, it achieves a better degree of cognition and memory, which enhances an organism's survival.

Arbib, Michael A. "Towards a Neuroscience of the Person." In *Neuroscience and the Person: Scientific Perspectives on Divine Action,* eds. Robert Russell, et al., 77–100. Vatican City: Vatican Observatory; Berkeley, Calif.: Center for Theology and the Natural Sciences, 1999.
Arbib theorizes that the brain employs "schemas" or mosaic representations that constantly

assimilate and accommodate new experiences. As an individual lives out her/his life, the "self" serves as an encyclopedia of thousands of these schemas.

Avital, Eytan, and Eva Jablonka. *Animal Traditions: Behavioral Inheritance in Evolution.* Cambridge: Cambridge University Press, 2000.
Avital and Jablonka contribute to the incipient witness of culture in primates and mammals which introduces a new domain of behavioral inheritance to supplant molecular genetic effects.

Balda, Ralph D., et al., eds. *Animal Cognition in Nature: The Convergence of Psychology and Biology in Laboratory and Field.* San Diego, Calif.: Academic Press, 1998.
This compendium of essays illustrates the integration of cognitive abilities in nonhuman species with their ecological and evolutionary context. Especially noteworthy are papers by Alan Kamil and Colin Beer.

Bekoff, Marc. *Minding Animals: Awareness, Emotions, and Heart.* Oxford: Oxford University Press, 2002.
A professor of biology at the University of Colorado argues that animals should qualify as persons and be treated with due consideration and respect. Bekoff relates that Charles Darwin argued for an evolutionary mental continuity of behavior, emotion, and sentience, and now, a century and a half later, this view of animan mentation is receiving articulation through new studies on animal cognition.

Bekoff, Marc, et al., eds. *The Cognitive Anima: Empirical and Theoretical Perspectives on Animal Cognition.* Cambridge, Mass.: MIT Press, 2002.
The recent paradigm shift that suggests that animals have mental activity comparable to humans, prompts a wide array of papers on such faculties in each kingdom.

Bickerton, Derek. *Language and Species.* Chicago, Ill.: University of Chicago Press, 1990.
A senior linguist argues that evolution is ultimately a process of better cognitive representations of one's external environment in the appropriate "language" code.

Cartmill, Matt, and Irene Lofstrom, eds. "Animal Consciousness: Historical, Theoretical, and Empirical Perspectives." *American Zoologist* 40, no. 6 (2000): 7–11.
Researchers focusing on different species (e.g., parrots, primates) affirm the presence of cognitive sentience by degree throughout the animal kingdom.

Churchland, Patricia S. "Self-Representation in Nervous Systems." *Science* 296, no. 5566 (April 12, 2002): 308–10.
One's self-concept is due to a "set of representational capacities of the physical brain" or "organizational tools," that bring a unified coherence to the being. Churchland views evolution as the achievement of more coherent, informed states of retained knowledge, which then facilitate an increased sentience.

Deacon, Terrence W. *The Symbolic Species: The Co-Evolution of Language and the Brain.* New York: Norton, 1997.
Deacon, a biological anthropologist, contends that human uniqueness is due to an ensemble of evolved steps such as "laryngeal descent and syntactic complexity," brain restructuring for speech, tool use and group hunting, along with the effects of male provisioning, pair bonding, and mating contracts. From this array, he distills the primary qualities of the emergence of symbolic representation and argues that humans internally store knowledge about their expanding, dynamic societal and environmental niche.

Griffin, Donald R. *Animal Minds: From Cognition to Consciousness.* Chicago, Ill.: University of Chicago Press, 2001.
Griffin updates his 1992 book that pioneered the theory of perceptual and reflective states in animals who are able to think, remember, plan, and deceive in a nature similar to that of humans. Griffin speculates that the difference between human brains and animal brains is not the presence versus lack of consciousness, but rather the content of their conscious experience.

Science Bibliography

Hardy, Christine. *Networks of Meaning: A Bridge Between Mind and Matter.* Westport, Conn.: Praeger, 1998.
Hardy theorizes that semantic fields or constellations in the brain dynamically represent knowledge in order to reunite mind and matter.

Hauser, Marc O. *Wild Minds: What Animals Really Think.* New York: Henry Holt, 2000.
Hauser proposes that nonhuman creatures, in their specific habitats, are capable of mentation and emotion similar to that found in humans.

Heyes, Cecilia, and Ludwig Huber, eds. *The Evolution of Cognition.* Cambridge, Mass.: MIT Press, 2000.
These reports on "evolutionary psychology" studies imply that the driving force toward the evolution of homo sapiens is social interaction. Social interaction, according to authors in this book, builds bigger brains.

Marino, Lori. "Convergence of Complex Cognitive Abilities in Cetaceans and Primates." *Brain Behavior Evolution* 59, nos. 1–2 (January/February 2002): 19–31.
In contrast to the prevailing view, new studies suggest that the rise of intelligent cognition and societies will persistently occur across widely diverse species. Using the examples of primates and cetaceans, Marino argues that these species display convergence in social behavior, language skills, and self-recognition, despite their evolutionary divergence.

Markman, Arthur B., and Eric Dietrich. "Extending the Classical View of Representation." *Trends in Cognitive Sciences* 4, no. 12 (December 2000): 470–75.
Markman and Dietrich attempt to explain several conflicting approaches to understanding how the brain remembers and responds by considering theories of perceptual symbol systems, situated action, embodied cognition, and dynamical systems.

Martin, Cristofre, and Richard Gordon. "The Evolution of Perception." *Cybernetics and Systems* 32, nos. 3–4 (March/April 2001): 12–18.
Martin and Gordon share insights into a "perceiving universe," arguing that such a universe or "perceptogenesis," may have its own self-recognition as a purpose or goal.

Pepperberg, Irene M. *The Alex Studies: Cognitive and Communicative Abilities of Grey Parrots.* Cambridge, Mass.: Harvard University Press, 2000.
Pepperberg's sophisticated research depicts a grey parrot able to verbalize and converse so well that his extensive cognitive abilities could be quantified and documented.

Pinker, Steven. *How the Mind Works.* New York: Norton, 1997.
Pinker elucidates how the mind coordinates an array of dedicated, modular information-processing domains that are vestiges from hunter-gatherer days.

Rendell, Luke, and Hal Whitehead. "Culture in Whales and Dolphins." *Behavioral and Brain Sciences* 24, no. 2 (April 2001): 309–24.
The authors' research supports the notion that language and cultural behavior is not the sole province of humans but occurs throughout the animal kingdom, in this case with cetaceans.

Shettleworth, Sara J. *Cognition, Evolution, and Behavior.* New York: Oxford University Press, 1998.
Shettleworth endeavors to sort the many facets of naming, categorizing, and validating animal intelligence and consciousness, and comments on its implications for humanity.

Sternberg, Robert J., and James C. Kaufman, eds. *The Evolution of Intelligence*. Mahwah, N.J.: Lawrence Erlbaum Associates, 2002.
A spectrum of authors explores the seven geometric, computational, biological, epistemological, anthropological, sociological, and system metaphors for the evolved properties of mental acumen.

Suddendorf, Thomas. “The Rise of the Metamind.” In *The Descent of Mind: Psychological Perspectives on Hominid Evolution,* eds. Michael C. Corballis and Stephen E. G. Lea, 218–60. New York: Oxford University Press, 1999.
Suddendorf submits a natural history of the representational mind from birds to primates to collective human thought, and includes current work on animal and human intelligence.

Suddendorf, Thomas, and Andrew Whiten. “Mental Evolution and Development.” *Psychological Bulletin* 127, no. 5 (September 2001): 629–50.
The authors adduce how new research on representational capacities in great apes and other animals suggests an evolutionary progression of environmental and behavioral knowledge. Utilizing this evidence, Suddendorf and Whiten specify a central trajectory of increased cognitive awareness.

Taube, Mieczyslaw, and Klaus Leenders. *The Search for Terrestrial Intelligence.* Singapore: World Scientific Publishing Co., 1998.
Taube and Leenders explore cosmic to human evolution in terms of the rise of cognitive qualities and their knowledge content. They argue that in its emergent course, the universe creates life, which breeds biotic information processing and cerebral ramifications that lead to a global sentience that is potentially able to care for and protect the planet from which it has arisen.

Wheeler, M., and A. Clark. “Genic Representation: Reconciling Content and Causal Complexity.” *British Journal for the Philosophy of Science* 50, no. 1 (March 1999): 103–35.
Wheeler and Clark provide careful synthesis of conflicting positions that emphasizes either the primacy of internal representations (nativist) or external, ecological influences (constructivist). The balance between these positions holds at both the genetic level, where genes encode within dynamic systems, and at neural domains, through the interaction of prior memory and new experience.

Wuketits, Franz M. *Evolutionary Epistemology and Its Implications for Humankind.* Albany, N.Y.: State University of New York Press, 1990.
Wuketits argues that evolution is a type of universal cognition and/or learning process. These processes form a nested hierarchy in a range of species from unicellular animals to humanity.

The Bicameral Brain

An evolutionary trajectory of general brain hemisphere specialization is being described and illustrated by recent research.

Andrew, Richard J., et al. “Motor Control by Vision and the Evolution of Cerebral Lateralization.” *Brain and Language* 73, no. 2 (June 15, 2000): 220–35.
The authors report on the ancient roots of complementary functions.

Chernigovskaya, Tatiana V. “Evolutionary Perspective for Cognitive Function: Cerebral Basis of Heterogenous Consciousness.” *Semiotica* 127, nos. 1–4 (1999): 227–37.
In this article, a Russian neuroscientist discovers a sequential path in phylogeny and ontogeny for brain function of an initial right hemisphere emphasis followed by left side maturation. The entire journal issue is devoted to “biosemiotica,” or the communicative signs of life.

Chiron, C., et al. “The Right Brain Hemisphere Is Dominant in Human Infants.” *Brain: A Journal of Neurology* 120, no. 6 (June 1997): 1057–65.
The authors claim that visuospatial and emotional abilities influenced by the right brain hemisphere develop earlier for purposes of individual and species survival. A child’s left hemisphere, however, begins its growth spurt at about two years of age.

Corballis, Michael C. *The Lopsided Ape: Evolution of the Generative Mind.* New York: Oxford University Press, 1991.
Corballis argues that right hemisphere spatial representation appears earlier in evolution. It is complemented by a later arriving left hemispheric development as it takes up the role of language and the generation of technical detail.

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Epstein, Seymour. "Integration of the Cognitive and the Psychodynamic Unconscious." *American Psychologist* 49, no. 8 (August 1994): 709–24.
Epstein makes a strong case for complementary holistic and analytical thought processes. More specifically, he argues that "[t]here is no dearth of evidence in everyday life that people apprehend reality in two fundamentally different ways, one variously labeled intuitive, automatic, natural, nonverbal, narrative, and experiential, and the other analytical, deliberative, verbal, and rational" (p 710).

Falk, Dean. "Brain Evolution in Females: An Answer to Mr. Lovejoy." In *Women in Human Evolution,* ed. Lori D. Hager, 114–36. New York: Routledge, 1997.
Falk concludes that, on average, males have larger left hemispheres, while females have a brain lateralization that favors the right side along with more corpus callosum interconnections in between.

Glezerman, Tatyana, and Victoria I. Balkoski. *Language, Thought, and the Brain.* New York: Kluwer Academic Publishers, 1999.
Glezerman and Balkoski contend that cognition and speech involve reciprocal activities of an analytic left hemisphere and a synthetic right hemisphere, that is reflected in their neural substrates. They argue that "[m]odern anatomical data regarding cortical connections have tended to support the concept 'two hemispheres—two cognitive styles.' For example, in the right hemisphere the dendritic overlap among cortical columns is greater than in the left hemisphere, allowing for the possibility of more joint (synchronous) responses, which may correspond to a more 'holistic processing' style. The much greater center-center distance between columns in the left hemisphere is consistent with a better segregation of input and more independence in the left [hemisphere]" (p 22).

Grimshaw, Gina M. "Integration and Interference in the Cerebral Hemispheres: Relations with Hemispheric Specialization." *Brain and Cognition* 36, no. 2 (March 1998): 108–27.
Grimshaw argues that ". . . the left hemisphere performs computations that extract local features (or high spatial frequencies), while the right hemisphere performs computations on the stimuli that are relevant to global form (or low spatial frequencies). At some point, local and global analyses are integrated to produce a unified precept" (p 109).

Ivry, Richard B., and Lynn C. Robertson. *The Two Sides of Perception*. Cambridge, Mass.: MIT Press, 1998.
Ivry and Robertson summarize three decades of theory and experiments that affirm a holistic propensity in the right brain hemisphere and a discrete, narrower focus in the left. With regard to connecting dots, the right side glimpses the whole but misses its necessary points, while the left notes all the dots with no idea that they make up a larger image.

MacNeilage, Peter F. "Toward a Unified View of Cerebral Hemispheric Specializations in Vertebrates." In *Comparative Neuropsychology,* ed. David Milner, 167–83. New York: Oxford University Press, 1998.
MacNeilage proposes that, as a general rule, the right hemisphere processes a topological, holistic aspect while the left attends to specific, localized details.

Ornstein, Robert E. *The Right Mind: Making Sense of the Hemispheres.* New York: Harcourt Brace, 1997.
The psychologist who popularized the brain's reciprocal hemispheres reflects on thirty years of research in the field. His central focus concerns hemispheric processing of information. He argues that the specialization of the left hemisphere appears better able to analyze smaller elements of information whereas the right hemisphere operates in a synthetic or holistic manner and is better for processing larger picture. The left hemisphere, for example, understands the "text" or literal meaning of language whereas the right hemisphere is able to understand the "context" or intonation and indirect meaning of the linguistic communiqué.

Rodgers, Lesley J., and Richard J. Andrew, eds. *Comparative Vertebrate Lateralization.* Cambridge: Cambridge University Press, 2002.
The editors summarize research studies on bilateral brain asymmetry in fish, birds, mammals,

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and primates. Long thought to be only a human attribute, bilateral brain asymmetry is now thought to extend throughout the entire evolutionary development of all animals. The same characteristics also hold for the development of each individual brain hemisphere. The right hemisphere surveys the overall scene or forest, while the left hemisphere discerns separate objects or trees. The right half ponders and the left half responds.

Thatcher, Robert C. "Cyclic Cortical Reorganization: Origins of Human Cognitive Development." In *Human Behavior and the Developing Brain,* eds. Geraldine Dawson and Kurt Fischer, 232–59. New York: Guilford Press, 1994.
Thatcher discusses the prime properties and formative sequence of the bicameral brain. More specifically he argues that ". . . the left-hemisphere expanding sequence reflects a process of functional integration of differentiated subsystems, whereas the right-hemisphere contracting sequence is a process of functional differentiation of previously integrated subsystems. These left- and right-hemisphere cycles are repeated throughout the life span and are postulated to represent a process that iteratively narrows the gap between structure and function by slowly sculpting and refining the microanatomy of the brain" (pp 232–33).

Vallortigara, Giorgio, et al., "Possible Evolutionary Origins of Cognitive Brain Lateralization." *Brain Research Reviews* 30, no. 2 (August 1999): 164–75.
The authors hypothesize that the presence of asymmetrical, hemispheric cerebral faculties extends to primates, mammals, birds, amphibians, and fish. This long evolution proceeds by the merger of initially separate modules toward a synthesis in humans, an example of the symbiotic complex system.

Studies of Consciousness

The emergence of sentience from quantum realms to human intellect is enhanced by an informational quality.

Arhem, Peter, and Hans Liljenstrom. "On the Coevolution of Cognition and Consciousness." *Journal of Theoretical Biology* 187, no. 4 (21 August 19997): 601–12.
The authors explore the parallel increase of complexity and mind, suggesting that cognition displays the same features as non-neural adaptive processes. Consciousness is therefore manifested at different stages of evolution. Arhem and Liljenstrom argue that ". . . cognition, that is knowledge processing mediated by a centralized nervous system, shows the same principal features as non-neural adaptive processes. Similarly, consciousness can be said to appear, to different degrees, at different stages in evolution" (p 610).

Baars, Bernard J. "The Conscious Access Hypothesis: Origins and Recent Evidence." *Trends in Cognitive Science* 6, no. 1 (1 January 2002): 47–52.

Bieberich, Erhard. "Recurrent Fractal Neural Networks: A Strategy for the Exchange of Local and Global Information Processing in the Brain." *BioSystems* 66, no. 3 (August/September 2002): 145–64.
A neuroscientist asserts that the brain is composed of self-similar systems from a "global coding structure" to neuronal networks. The brain's many-layered, dendritic architecture displays a consistent mapping. Bieberich proposes that a "fractally structured memory" may be formed in the same manner as the fractal data and pixel compression systems utilized in computers. This theory appears to converge with Bernard Baars' "global workspace model" as the seat of consciousness.

Chalmers, David John. *The Conscious Mind: In Search of a Theory of Conscious Experience.* Oxford: Oxford University Press, 1996.
Chalmers, a philosopher, makes a strong case for the reality of consciousness as more than a neural epiphenomenon. He argues that, for a full appreciation of consciousness, a close relation with information is required.

_______. Website. updated n. d. http://www.u.arizona.edu/~chalmers/ (cited 27 July 2005).
Chalmers' website features more than 1,100 papers on various aspects of the study and philosophy of mind and sentience.

Dehaene, Stanislas, and Lionel Naccache. "Toward a Cognitive Neuroscience of Consciousness: Basic Evidence and a Workspace Framework." *Cognition* 79, nos. 1–2 (April 2001): 1–37.
This landmark paper summarizes an international attempt to find neuronal correlates of awareness. Its working model is a dynamic merger, or symbiosis, of specific modules to compose a global workspace. In an evolutionary frame, these schemas are seen to increasingly empower organisms. Dehaene and Naccache argue that "[a]ny theory of consciousness must address its emergence in the course of phylogenesis. The present view associates consciousness with a unified neural workspace through which many processes can communicate. The evolutionary advantages that this system confers to the organism may be related to the increased independence that it affords. . . . By allowing more sources of knowledge to bear on this internal decision process, the neural workspace may represent an additional step in a general trend toward an increasing internalization of representations in the course of evolution, whose main advantage is the freeing of the organism from its immediate environment" (p 31).

Di Biase, Francisco, and Mario Sergio F. Rocha. "Information, Self-Organization, and Consciousness: Towards a Holoinformational Theory of Consciousness." *World Futures* 53, no. 4 (1999): 309–27.
Di Biase and Rocha posit that, in a holistic, nonlocal universe, consciousness arises from its quantum source as emergent information. Arguing with David Bohm, they believe that the human mind [should be] . . . seen as a "holoinformational" enfoldment of the implicit, self-organizing cosmos.

Gabora, Liane. "Amplifying Phenomenal Information: Toward a Fundamental Theory of Consciousness." *Journal of Consciousness Studies* 9, no. 8 (2002): 3–29.
Drawing on the work of David Chalmers and others, Gabora proposes that consciousness, a property of the universe, has an informational component. The degree to which an entity is conscious then depends on its ability to amplify and enhance this quality. If brains are understood as a self-organized web of autopoietic systems, this emergence can be said to have been achieved through a process of conceptual closure. The result, according to this argument, is that evolution comes to possess a central axis, an arrow of informed sentience.

Goerner, Sally, and Allan Combs. "Consciousness as a Self-Organizing Process: An Ecological Perspective." *BioSystems* 46, nos. 1–2 (April 1998): 123–27.
Goerner and Combs argue that conciousness is a self-organizing process that can be viewed as if it were "an ecological system in which streams of cognitive, perceptual, and emotional information [join to] form a rich complex of interactions, analogous to the interactive metabolism of a living cell. The result is an organic, self-generating or 'autopoietic' system continuously [engaging] in the act of creating itself" (p 123).

Hameroff, Stuart R., et al., eds. *Toward a Science of Consciousness: The First Tucson Discussions and Debates.* Cambridge, Mass.: MIT Press, 1996.
This book stands as an indication of the growing philosophical and scientific study available on the phenomena of consciousness.

_______. *Toward a Science of Consciousness II: The Second Tucson Discussions and Debate.* Cambridge, Mass.: MIT Press, 1998.
In this compendium of papers from the second meeting on the many facets of mind science, evolution is primarily perceived as a learning process.

_______. T*oward a Science of Consciousness III: The Thrid Tucson Discussions and Debates.* Cambridge, Mass.: MIT Press, 1999.

King, James E., et al. "Evolution of Intelligence, Language, and Other Emergent Processes for Consciousness: A Comparative Perspective." In *Toward a Science of Consciousness II,* eds.

Stuart Hameroff, et al., 383–96. Cambridge, Mass.: MIT Press, 1998.
The authors report on primate researchers who find a phylogenetic gradation in animal behavior and awareness. King et al hypothesize that the evolution of consciousness in mammals paralleled the development of independent behavioral control. They further speculate that as the sophistication of independent control increased, a corresponding increase in consciousness also occurred.

Mangan, Bruce. "Against Functionalism: Consciousness as an Information-Bearing Medium." In *Toward a Science of Consciousness II,* eds. Stuart Hameroff, et al., 135–42. Cambridge, Mass.: MIT Press, 1998.

Metzinger, Thomas, ed. *Neural Correlates of Consciousness: Empirical and Conceptual Questions.* Cambridge, Mass.: MIT Press, 2000.
In this compendium, Metzinger surveys consciousness studies at the turn of the millennium. While emphasizing a neural basis, the emergence, both personally and collectively, of a knowing mindfulness can be quantified by its degree of represented knowledge content.

Pestana, Mark Stephen. "Complexity Theory, Quantum Mechanics, and Radically Free Self Determination." *Journal of Mind and Behavior* 22, no. 4 (Autumn 2001): 365–87.
Pestana maintains that self-similar patterns of neural activity possess quantum and nonlinear properties that substantiate an indeterminate "radically free will." More specifically, he explains how complex physical systems that possess fractal-like self-similarities can exhibit both self-consciousness and self determination.

Pickering, John. "The Self is a Semiotic Process." *Journal of Consciousness Studies* 6, no. 4 (April 1999): 31–47.
Pickering writes on the symbolic, content-rich essence of sentience and personhood.

Roth, Gerhard. "The Evolution of Consciousness." In *Brain Evolution and Cognition,* eds. Gerhard Roth, and Mario Wullimann, 147–84. New York: Wiley; Heidelberg: Spektrum, 2001.
In this summary, Roth finds a modular basis for sentience grounded in an increasing informational content. He argues that at the human phase, everything changes due to language, because language raises cognitive discourse to a collective social plane.

Scott, Alwyn. *Stairway to the Mind: The Controversial New Science of Consciousness.* New York: Copernicus Books, 1995.
In a universe moved by nonlinear dynamics, Scott theorizes that consciousness emerges from the resultant self-organizing hierarchy.

Seager, William. *Theories of Consciousness: An Introduction and Assessment.* London: Routledge, 1999.
A philosopher fuses quantum physics and connectionism to affirm that mental awareness requires information, and this information leads toward a "representational" model. Consciousness depends on content, which places it in an evolutionary scale of the emergence of knowing mind. These features revive a "panpsychic" view of the universe in which "all matter, or all nature, is itself psychical."

Singer, Ming. *Unbounded Consciousness: Quaha, Mind, and Self.* London: Free Association Books, 2001.
This work in progress promotes a synthesis of philosophy, psychology, quantum physics, and nonlinear systems that argues for a complementarity and superposition of *qualia* (felt awareness) and *quanta* (objective aspects) of the dynamically emergent self.

Tannenbaum, Arnold S. "The Sense of Consciousness." *Journal of Theoretical Biology* 211, no. 4 (August 21, 2001): 377–91.
Tannenbaum speculates that, as sense organs evolve and merge their neural, complex system, an emergent, informed awareness results.

Science Bibliography

3.3.3 The Expansion of Knowledge

This developmental scale of body, brain, representation, and sentience is further characterized by the appearance of a genetic-like template from molecules to language.

A Universe of Information

Information itself is becoming recognized as a significant quality, along with matter and energy.

Chaitin, Gregory J. *The Unknowable.* Singapore: Springer, 1999.

A senior mathematician theorizes that information is primary while matter is secondary. Chaitlin suggests that since information is immaterial and consciousness appears to be immaterial, consciousness may indeed be "sculpted" in information.

Deutsch, David. *The Fabric of Reality.* London: Allen Lane Co., 1997.

Deutsch, utilizing work in the fields of physics and philosophy, finds the central character and measure of the universe is an increase in relative knowledge embodied in intelligent human beings. This perception, based on four strands of quantum theory, evolution, epistemology, and computation, joins life as "knowledge-bearing matter" with the developmental cosmos. According to Deutsch, "physical reality is self-similar on several levels: among the stupendous complexities of the universe and multiverse, some patterns are nevertheless endlessly repeated" (p 95). Science, and other forms of knowledge, are therefore made possible by a "special self-similarity property of the physical world" (p 97). "Despite appearances," Deutsch argues, "life is a significant process on the largest scales of both time and space. The future behavior of life will determine the future behavior of stars and galaxies" (p 193).

Emmeche, Claus, and Jesper Hoffmeyer. "From Language to Nature: The Semiotic Metaphor in Biology." *Semiotica* 84, nos. 1–2 (1991): 1–42.

Considering analogy, metaphor, and communication in biological evolution, the authors conclude that life is a linguistic phenomenon.

Goonatilake, Susantha. *The Evolution of Information: Lineages in Gene, Culture, and Artefact.* London: Pinter, 1991.

The author presents a number of innovative ideas on the operation of informative codes in genetic, neural, and cultural settings in a self-organizing universe. Goonatilake believes that examining information flow lines can allow scientists to discuss phenomena throughout many disciplines.

Haefner, Klaus, ed. *Evolution of Information Processing Systems: An Interdisiplinary Approach for a New Understanding of Nature and Society.* New York: Springer, 1992.

In this technical survey of the information perspective, Haefner presents the basic concepts of a hierarchy of information processing at physical, genetic, neural, and social levels.

Hao, Bai-Lin, et al. "Fractals Related to Long DNA Sequences and Complete Genomes." *Chaos, Solutions, and Fractals* 11, no. 6 (May 2000): 825–36.

The authors argue that a self-similar geometry underlies the genetic code and they reveal that this code can be seen as a reflection of the underlying structure of nature.

Hayles, Nancy Katherine. *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics.* Chicago, Ill.: University of Chicago Press, 1999.

Hayles' book argues that active information is at the root of living systems. She contends that bodies are like books—our world is becoming virtual as informational patterns take over materiality.

Hoffmeyer, Jesper. "Life and Reference." *BioSystems* 60, nos. 1–3 (May 2001): 123–30.

Hoffmeyer's article develops a concept of life that emerges from a complementary analog and digital or agency and communion modes of interaction. In an evolutionary context these modes of interaction foster an intensifying individuation. The synthesis implies a "semiotic" universe composed of this archetypal dynamic from quantum, to molecular, cellular, and on to cognitive realms. This volume of *BioSystems,* entitled, "The Physics and Evolution of Symbols and Codes," expands on the work of systems theorist Howard Pattee.

Hofkirchner, Wolfgang, ed. *The Quest for a Unified Theory of Information: Proceedings of the Second International Conference on the Foundations of Information Science. World Futures General Evolution Studies.* vol. 13. Australia: Gordon & Breach, 1999.
Scholars from information and computer science, semiotics, complex systems, evolutionary theory, physics, biology, psychology, consciousness research, sociology, science, and technology studies explore and expand upon the concept of information in order to bridge the gap between "hard" and "soft" sciences.

Igamberdiev, Abir. "Semiokinesis—Semiotic Autopoiesis of the Universe." *Semiotica* 135, nos. 1–4 (2001): 1–23.
Igamberdiev argues that a fractal universe proceeds in its organic development by means of a recursive "self-representation of its Logos." In Igamberdiev's theory, life generates and organizes itself through open, nonequilibrium systems via internal semiotic definitions. This theory affirms an emerging Platonic, textual reality that awaits our collective recognition. A radically different cosmos can be visible if one's paradigm permits one to see it.

Kay, Lily. "*Who Wrote the Book of Life?" A History of the Genetic Code.* Stanford, Calif.: Stanford University Press, 2000.
Kay offers a proficient study describing how a linguistic metaphor came to represent the genetic code. The author goes on to note a correspondence between molecular genetics, language, and the Chinese divination system, the *I Ching.*

Lehn, Jean-Marie. "Toward Complex Matter: Supramolecular Chemistry and Self-Organization." *Proceedings of the National Academy of Science of the United States of America* 99, no. 8 (16 April 2002): 4763–68.
Lehn provides an introductory perspective to a computer-based revolution to recognize and factor in an innate "informed dynamics" and subsequent selection at work in chemical and biological reactions and the "designed" creation of new materials. According to Lehn, "[a]s the winds of time blow into the sails of space, the unfolding of the universe nurtures the evolution of matter under the pressure of information. From divided to condensed and on to organized, living, and thinking matter, the path is toward an increase in complexity through self-organization" (p 4763).

Loewenstein, Werner. *The Touchstone of Life: Molecular Information, Cell Communication, and the Formation of Life.* New York: Oxford University Press, 1999.
A veteran biochemist contends that information and its communicative flow is the fundamental essence of life from molecules to the sentient mind. The book also describes recursive circles in internal cellular communication, external intercellular networks, and neuronal webs that foster an informed consciousness. Such content evolves by a principle of information economy on a path of least cost. Loewenstein claims that the guiding principle of biological evolution is this principle of information economy in self-developing systems.

Marijuan, Pedro. "Bioinformation: Untangling the Networks of Life." *BioSystems* 64, nos. 1–3 (January 2002): 111–18.
Marijuan argues that "[l]ife is knowledge-bearing matter . . . the story is about genes or Darwinian replicators that embody knowledge about thier niche, laws of nature included, causing the niche to keep that knowledge in existence" (p 112). Following Gell-Mann, Marijuan argues further that "from the point of view of information, this organization of the living cell represents the emergence of a very special 'complex adaptive system': it is a quasi-universal problem solver based on the cytoplasm-genome representation interrelationship" (p 114).

Sebeok, Thomas. "Global Semiotics." In *Semiotics Around the World: Synthesis in Diversity,* vol. 1, eds. Irmengard Rauch and Gerald F. Carr, 105–30. Berlin: de Gruyter, 1997.
Sebeok claims that life is most distinguished by a "semiosis" manifested in various genetic, immune, metabolic, and neural codes.

Siegfried, Tom. *The Bit and the Pendulum: From Quantum Computing to M-Theory—The New Physics of Information.* New York: Wiley, 2000.
Siegfried, a science writer, conveys how information is being considered as the prime characteristic of the evolving universe. Information, in this view, is quite literally the "ultimate substance from which all things are made" (p 6). "Life" is therefore an interplay of dynamical self-organization and computational processing.

Taborsky, Edwina, ed. *Semiosis, Evolution, Energy: Toward a Reconceptualization of the Sign.* Aachen: Shaker, 1999.
This compendium of conference papers explores an informational quality and distinguishes a "post-Darwinian" emergent evolution founded on self-organized relations. Roberta Kevelson traces this process "from matter to meaning." According to Jesper Hoffmeyer, "our universe has a built-in tendency . . . to produce organized systems possessing increasingly more semiotic freedom . . . relative to its material basis" (p 110). Stan Salthe argues that as entropy increases, the universe is not dissipating in meaning but gaining capacity to "inform" or establish relational networks.

The Ascent of a Generative Program

An informative system reappears in novel form at each evolutionary phase from DNA networks to recorded language.

Almirantis, Yannis, and Astero Provata. "An Evolutionary Model for the Origin of Non-Randomness, Long-Range Order and Fractality in the Genome." *BioEssays* 23, no. 7 (July 2001): 647–56.
Almirantis and Provata explain how self-similar, power law distributions characterize genomic systems.

Avise, John. "Evolving Genomic Networks: A New Look at the Language of DNA." *Science* 294, no. 5540 (5 October 2001): 86–87.
Avise proposes a new metaphor for the twenty-first century genome. He argues that this metaphor is "a social collective whose DNA sequences display intricate divisions of labor and functional collaborations." Rather than envisioning the genome as "beads on a string," Avise advocates that a "miniature cellular ecosystem" or "interactive community" would serve as a better image for the genome's structure.

Beurton, Peter, et al., eds. *The Concept of the Gene in Development and Evolution: Historical and Epistemological Perspectives.* Cambridge, Mass.: Cambridge University Press, 2000.
The editors review the history of genetics—from an initial molecular emphasis to recent notions of a complex, integrative systems. This synthesis of particulate and developmental aspects then takes on the guise of a complex adaptive system with these discrete and epigenetic complements.

Eggermont, Jos J. "Is There a Neural Code?" *Neuroscience and Biobehavioral Reviews* 22, no. 2 (March 1998): 355–70.
Eggermont argues that the neural code is analogous to the genetic code. "The neural code can be loosely defined as the way information (in the syntactic, semantic, and pragmatic sense) is represented in the activity of neurons" (p 358).

Ideker, Trey, Timothy Galitski, Leroy Hood, eds. "A New Approach to Decoding Life: Systems Biology." *Annual Review of Genomics and Human Genetics* 2 (September 2001): 343–72.
Through the process of mapping the sequence of the human genome, an informational science emerged. Ideker et al argue that the next research phase will need to learn to appreciate the complementary network properties of gene expression. With this in mind, the authors construct a multilevel informational hierarchy of complex processes that can be found in everything from DNA and protein interactions to organisms and ecologies.

Jablonka, Eva, and Eors Szathmary. "The Evolution of Information Storage and Heredity." *Trends in Ecology and Evolution* 10, no. 5 (May 1995): 206–11.
The authors comment on the appearance of major evolutionary transitions due to novel inheritance systems from molecules to epigenetic and linguistic systems.

Science Bibliography

Jablonka, Eva. "Information: Its Interpretation, Its Inheritance, and Its Sharing." *Philosophy of Science* 69, no. 4 (December 2002): 578–605.
Jablonka examines the idea that life's evolution is characterized primarily by an emergent sequence of new ways to store and transmit (e.g., genetic, epigenetic, behavioral, and cultural-symbolic inheritance systems) information. She argues that communal sharing of environmental information is a factor that facilitates specialization, division of labor, and new levels of organization and individuality.

Keller, Evelyn Fox. *The Century of the Gene.* Cambridge, Mass.: Harvard University Press, 2000.
Keller makes a case against the limited, erroneous fixation on particulate genetic molecules and advances an expanded, dynamical system of epigenetic expression.

Kirby, Kevin G. "The Informational Perspective." *BioSystems* 46, no. 1 (April 1998): 9–11.
Kirby's article provides an overview to this special journal issue in which twenty-six papers survey the programmatic aspects of self-organizing systems that appear with fractal similarity from biochemical reactions to the Internet.

Lander, Eric, and Robert Weinberg. "Genomics: Journey to the Center of Biology." *Science* 287, no. 5459 (10 March 2000): 1777–82.
In this essay on sequencing the human genome, Lander and Weinberg recognize the need for a global biology to appreciate whole living organisms. The authors assert that twenty-first century biology will take a more holistic approach than the twentieth-century focus has taken on analyzing individual components of biological systems.

Lewontin, Richard. *The Triple Helix: Gene, Organism, and Environment.* Cambridge, Mass.: Harvard University Press, 2000.
In response to the widespread acclaim over the mapping of the human genome, Lewontin, a geneticist, advises that DNA alone is not sufficient to specify even a folded protein much less an entire organism.

Loritz, Donald. *How the Brain Evolved Language.* New York: Oxford University Press, 1999.
Loritz suggests that language evolved through a process primarily characterized by a self-similarity at each subsequent scale that then intensified the value of communication.

Marijuan, Pedro. "Information and the Unfolding of Social Life: Molecular-Biological Resonances Reaching Up to the Economy." *BioSystems* 46, no. 1 (April 1998): 145–51.
Marijuan presents information regarding a universal convergence from "cellular signaling systems and vertebrate nervous systems" to "entrepreneurial accounting systems."

Maynard Smith, John, and Eörs Szathmáry. *The Major Transitions in Evolution.* Oxford: W. H. Freeman Spektrum, 1995.
The authors' outline a series of emergent levels generally cited as atomic, molecular, cellular, orgasmic, neuronal, primate, and human. They argue that each stage is distinguished by a new template or vehicle to transmit hereditary information such as DNA or language.

_______. *The Origins of Life: From the Birth of Life to the Origin of Language.* Oxford: Oxford University Press, 1999.
With this publication, the authors update their 1995 treatise on the origins of life for a general audience.

Moss, Lenny. *What Genes Can't Do.* Cambridge, Mass.: MIT Press, 2003.
In a review of the twentieth-century study of genetics, Moss, a philosopher, argues that the concept of particulate genes and a predetermined program has been superseded by their inclusion within complex, dynamic, epigenetic systems that are inherited in parallel with the genomic sequence. Altogether these aspects then form a complementarity of discrete and systemic influences.

Oiwa, Nestor, and James Glazier. “The Fractal Structure of the Mitochondrial Genomes.” *Physica A* 311, nos. 1–2 (January-February 2002): 218–31.
Oiwa and Glazier discover one more sign of a universal recurrence—an identical scale-free genetic pattern that occurs across a wide range of plants and animals from algae to sharks and homo sapiens.

Ridley, Matt. *Genome.* New York: HarperCollins, 1999.
Ridley views the twenty-three chromosomes of the human genetic code through the metaphor of a book of life.

Rzhetsky, Andrey, and Shawn Gomez. “Birth of Scale-Free Molecular Networks and the Number of Distinct DNA and Protein Domains per Genome” *Bioinformatics* 17, no. 10 (October 2001): 7–11.
Rzhetsky and Gomez argue that the same invariance that is evident throughout nature is also found in dynamic genetic systems.

Strohman, Richard. “The Coming Kuhnian Revolution in Biology.” *Nature Biotechnology* 15, no. 3 (March 1997): 197–99.
Strohman argues that a shift is underway from a determinism of particulate genes to an embryonic development because of information connected to informed dynamic systems that are similar to neural networks. “An alternative theory of evolution that emphasizes the importance of nonrandom (epigenetic) changes during development could explain the problems now being encountered by evolutionary theory” (p 195). “The cell is starting to look more like a complex adaptive system rather than a factory floor of robotic gene machines . . . Many of us are guessing at some kind of complex adaptive system theory that can embrace discontinuous change at all levels of life’s organization” (p 197).

Zweiger, Gary. *Transducing the Genome: Information, Anarchy, and Revolution in the Biomedical Sciences.* New York: McGraw-Hill, 2001.
Zweiger documents the paradigm shift in biology from a molecular to an informational basis of discrete genes and biomolecules engaged in dynamic communication. This coded content is now being transduced into an electronic format, which brings novel potentials and responsibility. Zweiger likens molecular communication to human communication and describes the goal of the molecular biologist as translating cellular language.

A Cultural Code

The principles of self-organization are evident in human language which is found to have a linguistic affinity with the molecular genetic code.

Aunger, Robert, ed. *Darwinizing Culture: The Status of Memetics as a Science.* Oxford: Oxford University Press, 2000.
Scholars explore the evolutionary and psychological aspects of Richard Dawkins’ theory of memetics, whereby cultural “memes” such as ideas, phrases, and paradigms may propagate in a manner similar to that of molecular genes.

Briscoe, Ted, ed. *Linguistic Evolution Through Language Acquisition.* Cambridge: Cambridge University Press, 2002.
The editors explore the quest for an evolutionary context within the emergence of language.

Cavalli-Sforza, Luigi. *Genes, Peoples, and Languages.* New York: North Point Press, 2000.
Cavalli-Sforza reports the latest findings on how human migrations can be tracked by parallel divergences in both genes and dialects.

Christiansen, Morten, and Nick Chater. “Connectionist Natural Language Processing.” *Cognitive Science* 23, no. 4 (April 1999): 279–87.
Christiansen and Chater explore how dynamical theories can describe the self-organizing network properties of language. This complements the older symbolic approach and takes on the appearance of a complex adaptive system.

Science Bibliography

Christiansen, Morten, and Nick Chater, eds. *Connectionist Psycholinguistics.* Westport, Conn.: Ablex Publishing, 2001.
Christiansen and Chater illustrate how parallel distributed processes and neural networks are helping to explain language and its learned usage.

de Boer, Bart. *The Origin of Vowel Systems.* Oxford: Oxford University Press, 2001.
De Boer describes how the universal properties of language evolve and emerge by self-organization within a population of users and learners.

Dorogovtsev, S. N., and J. F. F. Mendes. “Language as an Evolving Word Web.” *Proceedings of the Royal Society of London B* 268, no. 1485 (2001): 2603–2606.
Dorogovtsey and Mendes, utilizing a complexity science, propose a theory relating to the evolution of language. This theory treats language as a self-organizing network of interacting words. They further argue that the basic characteristic of a world web structure, the degree distribution, “does not depend on the rules of language but is determined by the general principles of the evolutionary dynamics of the word web” (p 2603).

Durham, William H. *Coevolution: Genes, Culture, and Human Diversity.* Stanford, Calif.: Stanford University Press, 1991.
Durham explores the notion of a “social heredity” and argues that this type of heredity implies that human society possesses the properties of an organism. He argues that human beings possess two major information systems, one cultural and one genetic, and that both have the potential to be transmitted and/or to influence behavior in every human being.

Gomes, M. A. F., et al. “Scaling Relations for Diversity of Languages.” *Physica A* 271, nos. 3–4 (April 1999): 489–92.
The authors report that languages diverge by the same fractal power laws as species in an ecosystem.

Hauser, Marc, et al. “The Faculty of Language” *Science* 298, no. 11 (November 2002): 1566–71.
This article, written with Noam Chomsky, calls for the interdisciplinary (e.g., biology, psychology, anthropology, and neuroscience) study of language and its evolutionary roots. Human language, according to the editors, “appears to be organized like the genetic code—hierarchical, generative, recursive, and virtually limitless with respect to its scope of expression” (p 1569).

Howe, Charles, et al. “Manuscript Evolution.” *Trends in Genetics* 17, no. 3 (March 2001): 264–66.
The authors examine the correspondence between mutations in DNA and changes in a hand-copied text and argue that people should appreciate both the textual essence of natural DNA and the genetic character of human language.

Kay, Lily. “A Book of Life?: How the Genome Became an Information System and DNA a Language.” *Perspectives in Biology and Medicine* 41, no. 4 (April 1998): 75–82.
Kay investigates the parallels between verbal and genetic codes.

Manrubia, Susanna, and Damian Zanette. “At the Boundary Between Biological and Cultural Evolution: The Origin of Surname Distributions.” *Journal of Theoretical Biology* 216, no. 4 (May 2002): 122–29.
Manrubia and Zanette demonstrate that the same statistical mathematics, scaling relations, and taxonomies are found to apply for both species and language.

Moore, David. *The Dependent Gene: The Fallacy of “Nature vs. Nurture.”* New York: W. H. Freeman, 2001.
To counter the emphasis on a particulate DNA determinism, More argues that genetic expression depends on interactive developmental systems. He believes that “[t]o produce such an understanding, we need to adopt a more complex and genuine interactionism—a developmental systems perspective—born of the detailed study of how traits emerge from gene-environment interactions” (p 10).

Science Bibliography

Mufwene, Salikoko. *The Ecology of Language Evolution.* Cambridge, Mass.: Cambridge University Press, 2001.
Mufwene contends that languages can be understood as being similar in structure to bacterial or parasitic species that compete and evolve by both Darwinian and Lamarckian means. In Mufwene's view, the macroecology of languages is formed by nonlinear dynamics. Beginning with the presupposition that languages are complex adaptive systems, Mufwene argues that "[t]hey consist of numerous components of many different kinds which interface with each other—some linguists will argue that such systems are modular. . . . The components interact nonlinearly and on different temporal and spatial scales. . . . They organize themselves to produce complex structures and behaviors" (p 157).

Nowak, Martin, et al. "Computational and Evolutionary Aspects of Language." *Nature* 417 (6 June 2002): 611–17.
The authors theorize that a universal dynamics and grammar specify the biological and cultural evolution of language.

Pagel, Mark. "The History, Rate, and Pattern of World Linguistic Evolution." In T*he Evolutionary Emergence of Language: Social Function and the Origins of Linguistic Form,* eds. Chris Knight, Michael Studdert-Kennedy, James R. Hurford, 391–416. Cambridge: Cambridge University Press, 2000.
In this article, Pagel investigates the similarities between genetic and spoken languages, especially the correlations between the methods and ideas that are used to study evolution.

Pinker, Steven. *Words and Rules: The Ingredients of Language.* New York: Basic Books, 1999.
Pinker, a linguist, aims for a union of intrinsic, symbolist grammar with associative neural networks.

Pollack, Robert. *Signs of Life: The Language and Meanings of DNA.* Boston, Mass.: Houghton Mifflin, 1994.
A biologist applies linguistic analysis to the "natural literature" of the genetic code and finds that the two contain many structural similarities.

Searls, David. "Reading the Book of Life." *Bioinformatics* 17, no. 7 (October 2001): 7–15.
Searls summarizes findings from a conference between geneticists and linguists that explores the deep, systematic affinities between the DNA molecular code and human language.

_______. "The Language of Genes." *Nature* 420 (14 November 2002): 211–17.
Searls affirms that the molecular DNA code, now studied by the field of computer-based bioinformatics, is in fact a true language with its own grammar and syntax. These techniques are now also being used to explore the structures of literature. He argues that ". . . nucleic acids may be said to be at about the same level of linguistic complexity as natural human languages (p 213) . . . genes do convey information, and furthermore this information is organized in a hierarchical structure whose features are ordered, constrained, and related in a manner analogous to the syntactic structure of sentences in a natural language" (p 213).

Sigman, Mariano, and Guillermo A. Cecchi. "Global Organization of the Wordnet Lexicon." *Proceedings of the National Academy of Sciences of the United States of America* 99, no. 3 (5 February 2002): 1742–47.
Sigman and Cecchi describe how languages exhibit the same universal dynamics found in genetic networks. They believe that "[s]emantic links follow power-law, scale-invariant behaviors typical of self-organizing networks. . . . If meaning not only results from a correspondence with external objects, but also depends on the interrelationships with other meanings, an understanding of the lexicon as a collective process implies a characterization of the structure of the graph, i.e., the global organization of the lexicon" (p 1742).

Science Bibliography

3.3.4 An Enhanced Individuality

As cerebral capacity and its represented knowledge/content evolves, another quality and/or parameter emerges as an increased self-awareness and sense of personal identity.

Buss, Leo W. *The Evolution of Individuality.* Princeton, N.J.: Princeton University Press, 1987.
Buss attempts to expand the modern evolutionary synthesis beyond an emphasis on genes and/or organisms to include sequential levels of the selection of whole “individuals.”

Freeman, Walter J. *How Brains Make Up Their Minds.* New York: Columbia University Press, 2001.
Freeman’s life’s work can be summed up as a synthesis of nonlinear dynamics and experimental neuroscience. This view of self-organized brain hierarchies and thought processes leads to a strong advocacy of intentional actions and free will. From an evolutionary context, a directional vector of manifest intentionality can then be appreciated. As a result, neural activity, personal behavior, and the consequent social network seek to maintain a balance of semiautonomous entities and a contextual basis. Freeman argues that “[i]ndividual minds, with their isolated meanings, assimilate to each other and create transcendent social entities that enhance and empower the individuals. Some people like to call these entities ‘group minds.’ . . . The model I propose for social self-organization is an extension of the micro-meso interactions we saw between neurons and populations and between meso-populations and macroscopic, global amplitude modulation (AM) patterns. In each level, the individual retains autonomy but accepts constraint in respect to the embedding surround” (pp 142–43).

Gilbert, Scott, and Steven Borish. “How Cells Learn, How Cells Teach: Education in the Body.” In *Change and Development: Issues of Theory, Method, and Application,* eds. Eric Amsel and K. Ann Renninger, 61–75. Mahwah, N.J.: Lawrence Erlbaum Associates, 1997.
Gilbert and Borish discuss the accord between organic and mental embryogenesis as a homologous biological and social learning process.

Gould, Stephen Jay, and Elizabeth Lloyd. “Individuality and Adaptation Across Levels of Selection: How Shall We Name and Generalize the Unit of Darwinism?” *Proceedings of the National Academy of Sciences of the United States of America* 96, no. 21 (October 12, 1999): 11904–09.
Gould and Lloyd interpret a stepwise evolution, formed by a means other than Darwinian mutation and adaptation, in which species are to be appreciated as true individuals.

Hoffmeyer, Jesper. “Code-Duality and the Epistemic Cut.” In *Closure: Emergent Organizations and Their Dynamics,* eds. Jerry Chandler and Gertrudis Van de Vijver, 175–86. Annals of the New York Academy of Sciences, vol. 901, New York: New York Academy of Sciences, 2000.
Hoffmeyer argues that a semiotic, textual universe in its developmental stage is engaged in “natural individuation,” which proceeds its “selfication process.”

Jablonka, Eva. “Inheritance Systems and the Evolution of New Levels of Individuality.” *Journal of Theoretical Biology* 170, no. 3 (November 1994): 301–309.
Jablonka examines the nested stages of emergent individuation due to “epigenetic inheritance systems.”

Mathews, Freya. *The Ecological Self.* London: Routledge, 1991.
This innovative work by an environmental philosopher articulates a cosmic course of progressive individuation.

McShea, Daniel. “The Minor Transitions in Hierarchical Evolution and the Question of a Directional Bias.” *Journal of Evolutionary Biology* 14, no. 3 (March 2001): 500–505.
McShea finds an increase in organic complexity by wholes (rather than branching bushes) contained within wholes. This graphical depiction takes on the generic form of a self-organizing system. He argues that “[t]he history of life shows a clear trend in hierarchical organization, revealed by the successive emergence of organisms with ever greater numbers of levels of nestedness and greater development, or ‘individuation,’ of the highest level” (p 502).

Michod, Richard. *Darwinian Dynamics: Evolutionary Transitions in Fitness and Individuality.* Princeton, N.J.: Princeton University Press, 1999.
This work is an important resource for outlining an emergent individuality in evolution.

Parker, Sue Taylor, et al., eds. *Self-Awareness in Animals and Humans: Developmental Perspectives.* Cambridge, Mass.: Cambridge University Press, 1994.
Parker et al argue that an evolutionary vector is evident through ever better self-recognition, because of its adaptive value. From invertebrate rudiments it rises through mammalian families to prosimians and great apes and on into human knowing, a path generally retraced in infants and children.

Salthe, Stanley N. *Development and Evolution: Complexity and Change in Biology.* Cambridge, Mass.: MIT Press, 1993.
Salthe presents a biological and philosophical image of nature in terms of a "developmental cosmology" rather than in terms related to a vicarious Darwinism. This scenario is based on the new sciences of complexity and thermodynamics that reveal a hierarchical emergence due to open systems guided by an "infodynamics." The primary movement of this integral, dialectical, and semiotic process is toward greater individuation.

Sagan, Dorion, and Lynn Margulis. "Epilogue: The Uncut Self." In *Organism and the Origins of Self,* ed. Albert I. Tauber, 361–74. Amsterdam: Kluwer Academic, 1991.
The authors have written an innovative essay on autopoietic tendences in evolution that start with bacterial domains to create and sustain a bounded "sense of self."

Siegel, Daniel. *The Developing Mind: How Relationships and the Brain Interact to Shape Who We Are.* New York: Guilford Press, 1999.
In this authoritative work on brain development in children, Siegel emphasizes a cycle of lateralization and the presence of complex systems. As our psychological life unfolds, he argues, we seek an "integrating self" that is achieved by "coherent narratives" that help us to make sense of the world and our own personal identities.

Sedikides, Constantine, and John Skowronski. "The Symbolic Self in Evolutionary Context." *Personality and Social Psychology Review* 1, no. 1 (February 1997): 77–81.
The authors examine the vectorial manifestation of a unique, aware self. They "propose that the capacity for a symbolic self (a flexible and multifaceted cognitive representation of an organism's own attributes) in humans is a product of evolution. In pursuing this argument, [they] . . . note that some primates possess rudimentary elements of a self (an objectified self) and that the symbolic self is: a) trait that is widely shared among humans, b) serves adaptive functions, and c) could have evolved in response to environmental pressures" (p 80).

Varela, Francisco. "Organism: A Meshwork of Selfless Selves." In *Organism and the Origins of Self,* ed. Albert Tauber, 79–107. Amsterdam: Kluwer Academic, 1991.
Varela, the co-founder of autopoietic systems theory, illustrates the recursive dynamics of an emergent complexity. He argues that his "purpose for bringing up this issue of the self as 'I' . . . is to emphasize the continuity of the same motif that we discussed at greater length for the cellular and basic cognitive selves. Like a fractal, this motif is repeated over and over again for the various regional selves of the organism" (p 102).

_______. "Patterns of Life: Intertwining Identity and Cognition." *Brain and Cognition* 34, no. 2 (February 1997): 71–83.
Varela argues that "organisms are fundamentally a process of constitution of an identity" (p 73). Furthermore, the nature of neurocognitive identity is similar to that of the basic cellular self, it is an emergence through a distributed process. He concludes by saying that "lots of simple agents having simple properties may be brought together, even in a haphazard way, to give rise to what appears to an observer as a purposeful and integrated whole, and this does not require a need for central supervision" (p 83).

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3.3.5 Ontogeny Recapitulates Phylogeny

New support grows for a general recapitulation between individual development and phylogenetic evolution across the embryonic, cognitive, behavioral, and linguistic realms.

Arthur, Wallace. *The Origin of Animal Body Plans: A Study in Evolutionary Developmental Biology.* New York: Cambridge University Press, 1997.

In this extensive study of systematic hierarchies with regard to morphological, lineage, and genetic types, Arthur verifies the basic unity of ontogeny and phylogeny. He also advocates that there is a relationship between developmental and evolutionary hierarchies and recognizes that there is a correspondence between morphology and genealogy.

Calvin, Wiliam H., and Derek Bickerton. *Lingua ex Machina: Reconciling Darwin and Chomsky with the Human Brain.* Cambridge, Mass.: MIT Press, 2000.

In this dialogue between a neuroscientist and a linguist about the evolution of language, Calvin and Bickerton describe the parallels between language acquisition and the course of language evolution in human beings.

Ekstig, Borje. "Condensation of Developmental Stages and Evolution." *BioScience* 44, no. 3 (March 1994): 77–84.

The author argues for a recapitulation due to the continuous shortening of developmental stages. He demonstrates that there is a direct correlation between the age of appearance of each trait in an organism and the evolutionary age in which that particular trait emerged.

Fell, David, and Alice Wagner. "The Small World of Metabolism." *Nature Biotechnology* 18, no. 11 (November 2000): 1120–24.

Fell and Wagner hypothesize that if metabolic networks grew by adding new metabolites early in the evolution of life, then the metabolites that are most connected should also be phylogentically the oldest. Their theory is consistent with "Morowitz's claim that intermediary metabolism recapitulates the evolution of biochemistry" (p 1121).

Gibson, Kathleen. "The Ontogeny and Evolution of the Brain, Cognition, and Language." In *Handbook of Human Symbolic Evolution,* eds. Andrew Lock and Charles Peters, 407–31. Oxford: Clarendon, 1996.

Gibson examines the parallels between how a child learns language and the way the human species began to speak.

Gopnik, Alison. "Theories, Language, and Culture." In *Language Acquisition and Conceptual Development,* eds. Melissa Bowerman and Stephen C. Levinson, 45–69. Cambridge: Cambridge University Press, 2001.

Gopnik provides insights into parallels found between a child's learning process and the course of scientific understanding. In this "interactionist" view, the previous options of nativism, empiricism, or constructivism are joined into a common theory. As a corollary, Benjamin Whorf's hypothesis that a culture's language influences how reality is perceived can be readmitted through cross-linguistic studies, such as one in which Korean speakers are found to emphasize relational verbs whereas an English speakers focus on objective nouns.

Gould, Stephen Jay. *Ontogeny and Phylogeny.* Cambridge, Mass.: Belnap Press of Harvard University Press, 1977.

The classic statement of the relationship between ontogeny and phylogeny that clarified its history, sorted definitions, and prepared the ground for this increasingly valid association.

_______. "Ontogeny and Phylogeny: Revisited and Reunited." *BioEssays* 14, no. 4 (April 1992): 112–14.

In this update of his classic work on ontogeny and phylogeny, Gould reviews new evidence and goes on to suggest that genetic homologies and a scale of increasing specificity revive the idea of a common archetypal plan for animal life.

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Hurford, James R., et al., eds. *Approaches to the Evolution of Language: Social and Cognitive Bases.* Cambridge, Mass.: Cambridge University Press, 1998.
Several authors make note of linguistic recapitulation in this compendium. Of special significance is Michael Studdert-Kennedy's essay that finds support from the "general biological principles of self-organization."

Knight, Chris, et al., eds. *The Evolutionary Emergence of Language: Social Function and the Origins of Linguistic Form.* Cambridge, Mass.: Cambridge University Press, 2000.
A subsequent volume to Hurford's *Approaches to the Evolution of Language* that further perceives the rise of a verbal and represented code from aspects of its recapitulation, genetic parallels, self-organization, etc.

Longuet-Higgins, Christopher. "Issues in Mental Development." In *Modelling the Early Human Mind,* eds. Paul Mellars and Kathleen Gibson, 153–57. Cambridge: McDonald Institute for Archaeological Research, University of Cambridge; Oakville, Conn.: Oxbow Books, 1996.
Longuet-Higgins reviews the relation between ontogeny and phylogeny in the mind and finds that not only does one copy the other more closely than previously expected but that their resemblances may be due to "a plausible genetic interpretation: the most novel characters of a species will tend to emerge late in an individual's development, for essentially logistic reasons" (p 156).

Martindale, Mark, and Billie Swalla. "Introduction to the Symposium: The Evolution of Development Patterns and Process." *American Zoologist* 38, no. 4 (June 1998): 17–21.
The authors summarize the interdisciplinary understanding of how embryology informs evolution. Martindale and Swalia contend that prokaryotic symbionts aid organisms through a "détente" similar to that existing between nations.

Mayr, Ernst. "Recapitulation Revisited: The Somatic Program." *Quarterly Review of Biology* 69, no. 2 (February 1994): 227–31.
Mayr, renowned founder of modern Neo-Darwinian synthesis, argues that recapitulation can, in a mature biology, now be understood as completing the spiral from general (but unproven) beginnings to its rejection in the analytical mode to a new quantified integration.

McKinney, Michael. "The Juvenilized Ape Myth: Our 'Overdeveloped' Brain." *BioScience* 48, no. 2 (February 1998): 92–98.
McKinney describes how a child's mental development repeats the acquisition of cerebral capacity by early humans, fulfilling the conviction held by both Darwin and Freud.

Mithen, Steven. *The Prehistory of the Mind: The Cognitive Origins of Art, Religion, and Science.* New York: Thames & Hudson, 1996.
Mithen presents a cogent read of parallel species and individual learning paths. He argues that phylogeny and ontogeny progress through three stages: general intelligence, specialized intelligence (includes social, natural history, technical, and linguistic functions), and an interactive combination of the various specialized intelligences.

Parker, Sue Taylor, and Michael L. McKinney. *Origins of Intelligence: The Evolution of Cognitive Development in Monkeys, Apes, and Humans.* Baltimore, Md.: Johns Hopkins University Press, 1999.
Parker and McKinney summarize more than twenty years of work from a "neorecapitulationist" position with an emphasis on the development of mental capacities. The authors claim that increases in morphological and behavioral complexity define an obvious evolutionary progress.

Richards, Robert J. "Darwin's Romantic Biology: The Foundation of His Evolutionary Ethics." In *Biology and the Foundation of Ethics,* eds. Jane Maienschein and Michael Ruse, 113–53. Cambridge: Cambridge University Press, 1999.
Richards examines Darwin's *naturphilosophie* roots and argues that Darwin never thought of natural selection as a mechanistic principle. Darwin, according to Richards, perceived nature as a "teleologically self-organzing structure" (p 130).

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Singer, Wolf. "Consciousness and the Binding Problem." In *Cajal and Consciousness: Scientific Approaches on the Centennial of Ramón y Cajal's Textura.* Annals of the New York Academy of Sciences, vol. 929, ed. Pedro Marijuán, 123–46. New York: New York Academy of Sciences, 2001.
Singer argues that similarities of perception and thought lead to a general accord between individual and evolutionary brain development.

Zelditch, Miriam, ed. *Beyond Heterochrony: The Evolution of Development.* New York: Wiley-Liss, 2001.
Zelditch presents an the effort to reunite embryology and evolution by arguing that while changes in the rate or timing of development (heterochrony) are important, other factors, such as heterotopy and changes in embryonic locations, must be considered.

4.0 The Emerging Vision of a Developmental Universe

Prescient attempts earlier in the twentieth century sketched the outlines of a self-organizing universe. These references are followed by current efforts to articulate this discovery as it gains verification.

4.1 Historical Precedents

Dyson, Freeman. "Time Without End: Physics and Biology in an Open Universe." *Reviews of Modern Physics* 51, no. 3 (March 1979): 452–67.
Dyson's paper refutes Stephen Weinberg's concept of a pointless universe by expounding a theory of developing cosmos. The cosmos itself becomes filled with and is transformed by, life and intelligence.

Jantsch, Erich. *The Self-Organizing Universe: Scientific and Human Implications.* Oxford: Pergamon, 1980.
Jantsch's innovative scenario depicts a dynamic creation that spontaneously develops life, mind, and meaning. "Life," according to Jantsch, "appears no longer as a phenomenon unfolding in the universe—the universe itself becomes increasingly alive" (p 9). Meaning, the central theme of the dynamic connectedness of humans with an unfolding universe is re-evoked toward the end of the book. Jantsch argues that "in a world that is creating itself, the idea of a divinity does not remain outside, but is embedded in the totality of self-organization dynamics at all levels" (p 18).

Koestler, Arthur. *Janus: A Summing Up.* New York: Random House, 1978.
Koestler provides an attempt to move beyond scientific reductionism by constructing a theory of "holoarchy" that reflects the systemic, modular rise of life. He argues that ". . . each member of this hierarchy, on whatever level, is a sub-whole or 'holon' in its own right—a stable, integrated structure, equipped with self-regulatory devices [that enjoys] . . . a considerable degree of autonomy or self-government. Cells, muscles, nerves, organs, all have their intrinsic rhythms and patterns of activity . . . they are subordinated as parts to the higher centres in the hierarchy, but at the same time function as quasi-autonomous wholes. They are Janus-faced. The face turned upward, toward the higher levels, is that of a dependent part; the face turned downward, towards its own constituents, is that of a whole of remarkable self-sufficiency" (p 27). According to Koestler, "[o]ntogeny and phylogeny, the development of the individual and the evolution of species, are the two grand hierarchies of becoming" (p 43).

Sagan, Carl. *Cosmos.* New York: Random House, 1980.
Sagan provides a comprehensive overview of universal evolution from its origin to networks of galactic civilizations. As humans awaken to this vista, Sagan argues, they will encounter an immense challenge, for they will need to unite as a species in order to eliminate nuclear arsenals. This obligation to survival is important not just for humans, but also for the cosmos from whence we came.

Teilhard de Chardin, Pierre. *The Phenomenon of Man.* New York: Harper Torchbooks, 1961.
Teilhard's many writings in a scientific, philosophical, and spiritual genre range in topic from World War I, to expeditions and exile in China, to final years in New York. His project aimed to integrate an evolutionary dimension of the temporal ascent from matter to life, mind, and spirit into Christianity. He describes an expansive cosmic genesis that develops by tiers of complexity and consciousness. Teilhard argues that these stages trace an axis of intensified personal interiority and freedom along with an enhanced community.

_______. *The Human Phenomenon.* Brighton: Sussex Academic Press, 1999.
Sarah Appleton-Weber presents a more faithful translation and annotated edition of Teilhard's synthetic overview of evolution.

Vernadsky, Vladimir. *The Biosphere.* New York: Copernicus, 1998.
This book is Mark McMenamin's full translation and annotation of Vladimir Vernadsky's 1929 French edition entitled, *La Biosphere.* Vernadsky, an internationally respected Russian scientist, strongly rejected Marxism. He spent some years at the Sorbonne in Paris with Pierre Teilhard de Chardin and Edouard LeRoy, who together formed the concept of a noosphere. Vernadsky, who was more scientifically based, shared Leo Tolstoy's and Pierre Teilhard de Chardin's spiritual values. In Teilhard's view, life is a cosmic and geological force that is engaged in the progressive transformation of "living matter" into complex organisms and the phenomenon of sentient humankind. The next step in the evolution is a recreation of the Earth by the collective action of thought and reason. Vernadsky agrees with Teilhard that such an event would enhance personal liberty and welfare.

Whitehead, Alfred North. *Process and Reality: An Essay in Cosmology.* New York: The Free Press, 1978.
Whitehead presents his principia of an organic philosophy of a cosmos in creation. In his prolific period in the 1920s, Whitehead envisioned a worldly and universal organism still developing in and through its conscious entities. His endeavor is carried on in a school known as process philosophy.

Younghusband, Francis Edward. *The Living Universe.* New York: Dutton, 1933.
In this book, Younghusband envisions an embryonic cosmos innately spawning life and consciousness in a sympathetic fashion. He argues that, "[i]f the universe is an organism of the kind described above, with each of its component parts also an organism, then, as Whitehead shows, each part will repeat in microcosm what the universe is in macrocosm—each unit will be a microcosm repeating in itself the entire all-inclusive macrocosm" (p 144).

4.2 Current Vistas

Berry, Thomas. *The Dream of the Earth.* San Francisco, Calif.: Sierra Club Books, 1988.
Berry, a cultural historian, contemplates human presence in an immense, still-developing cosmos and details the responsibilities humans have in this context. Topics include: the Earth community, the ecological age, bioregions, the historical role of the American Indian, and a cosmology of peace.

_______. *The Great Work: Our Way Into the Future.* New York: Bell Tower, 1999.
In this collection of essays, Berry offers his perspective on the Earth story, wilderness, the university, and provides suggestions for reinventing the human. The path ahead, he argues, must involve a fourfold wisdom of indigenous peoples, the nurturing empathy of women, classic Western and Asian traditions, and the scientific story of evolution. Berry describes the "great work" of a people as transitioning from an era of ecological devastation caused by human beings to an epoch of mutually beneficial behavior toward the Earth.

Capra, Fritjof. *The Hidden Connections: Integrating the Biological, Cognitive, and Social Dimensions of Life into a Science of Sustainability.* New York: Doubleday, 2002.
Capra's cogent essay illustrates how systemic relations between component entities or

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objects, as exemplified by the symbiotic cell, can provide natural, ecological principles to self-organize and guide sustainable, humane communities. "When we study living systems from the perspective of form," Capra argues, "we find that their pattern of organization is that of a self-generating network. From the perspective of matter, the material structure of a living system is a dissipative structure, i.e., an open system operating far from equilibrium. From the process perspective . . . living systems are cognitive systems in which the process of cognition is closely linked to the pattern of autopoiesis" (p 71).

Damasio, Antonio, et al., eds. Unity of Knowledge: The Convergence of Natural and Human Science. New York: New York Academy of Sciences, 2001.
These conference papers generally contrast Edward O. Wilson's views of an indifferent cosmos, reducible to chemistry and physics, with those of Stuart Kauffman, who argues in favor of a self-organizing universe.

Ferris, Timothy. *Life Beyond Earth.* New York: Simon and Schuster, 2000.
Ferris presents an illustrated tour of the starry galaxies from which sentient beings on an infinitesimal planet appear to wonder over other intelligences and their own purpose. Within this vista, a sharp contrast is set up between the prevalent view that humans are an "afterthought . . . in an uncaring universe" and the "new vision on the horizon" that views humanity as the expected result of an innately self-organizing complexity. Ferris argues that science has traditionally utilized reductionistic (focus is on individual parts) paradigms in its research but this new information, he argues, seems to demand new, holistic ways of thinking about/studying the universe. The latest scientific findings present the world as a very complex entity. Ferris argues that if, for example, "intelligence is an emergent property, arising as natural as clouds gathering to make a storm, then thought may not be incidental to the workings of the universe, but, in some sense, the point of it all—the central theme in a cosmic symphony" (p 184). Humanity comes to play a central role in the continuous creation of the universe in a manner best described by astrophysicist Freeman Dyson, "[s]o we can imagine that over billions of years, intelligence has grown and developed far beyond any sort of intelligence we now have, and that it might, in fact, become a major player in the physical development of the universe—from one part of the universe to another. We might, in fact, become creatures in producing a universe in which we can live forever. That's at least a dream which is not altogether pointless to think about" (p 208).

Goodenough, Ursula. *The Sacred Depths of Nature.* New York: Oxford University Press, 1998.
Goodenough, a cellular biologist, conveys, in her "religious naturalism," a scientific epiphany of belief in a providential and nurturing evolutionary unfolding.

Gregersen, Neils Henrik, ed. *From Complexity to Life: On the Emergence of Life and Meaning.* New York: Oxford University Press, 2003.
A revolution in thought seems to be occurring in regard to our understanding of the universe. Rather than promoting an expiring universe as mandated by the second law of thermodynamics, the scientists represented here, some whom are theologians, argue that complex systems have a natural tendency to self-organize into nested scales of increased information and sentience. As a result, these scientists perceive evidence of a radically different cosmos engaged in a developing process of self-creation. Harold Morowitz, Paul Davies, Stuart Kauffman, Ian Stewart, Werner Loewenstein, and others explore the implications of this theory and propose a "fourth law of thermodynamics," that runs counter to the nineteenth-century second law formulation.

Harris, Errol E. *Cosmos and Anthropos: A Philosophical Interpretation of the Anthropic Cosmological Principle.* Atlantic Highlands, N.J.: Humanities Press, 1991.
Harris, a philosopher, offers a rare synopsis of a self-arranging, complementary, divinely-oriented development that springs from and epitomizes a universally recurrent principle. In summary, Harris argues that ". . . the course of evolution has unfolded a complex branching series of forms, consisting of wholes within wholes, systems within systems, organisms within organisms. Each embodies and exemplifies, in its specific degree, the same principle of organization, while, as the scale proceeds, the form in which that principle specifies itself is a

more adequate expression of its character, progressing from metabolic self-adaption, through increasing degrees of physiological and then behavioral efficiency, to conscious (perspective) appreciation of the presented situation" (p 92).

Jolly, Alison. *Lucy's Legacy: Sex and Intelligence in Human Evolution.* Cambridge, Mass.: Harvard University Press, 1999.
An anthropologist finds more evidence for cooperation than competition in investigating the evolution of sex and intelligence. Jolly also finds that a consistent, widespread pattern of diverse, nested systems appears in various realms: the bacterial realm, in cells, organisms, and human groupings. She finds that "[a]t each stage a larger, coherent whole emerged from the linkage of independent parts. Each is a holon, simultaneously one and many, a single organism and yet a community of individuals" (p 408).

Liebes, Sidney, et al. *A Walk Through Time: From Stardust to Us: The Evolution of Life on Earth.* New York: Wiley, 1998.
Liebes' work, written with Brian Swimme and Elisabet Sahtouris, reveals a new creation story of a self-organizing cosmic genesis. The universe, they argue, operates with a bias toward complexity. For example, although the universe began as elementary particles, it constellated into galactic structures. The creative force within the universe accomplishes this complexity through "its own intrinsic self-assembling or self-organizing dynamics. An atom, for instance, is not put together by some agent outside itself. An atom is a group of particles that organizes itself into a whole and coherent system. So too on larger scales. A galaxy is more that just an aggregation. A galaxy is a self-organizing community of stars" (p 15). The organizational structure of this complexity is seen as relational. Relationships among organisms can be best understood through Arthur Koestler's conceptual model of "halons in holarchy." This model views living entities as embedded within each other like Chinese boxes or Russian dolls. Other holistic modelers have adopted this concept for its usefulness in describing the relationships within and among living systems. "Everything in nature can be seen as belonging to such arrangements—molecules within cells within cells, communities within ecosystems" (p 164).

Matthews, Clifford N., et al., eds. *When Worlds Converge: What Science and Religion Tell Us About the Story of the Universe and Our Place in It.* Peterborough, N.H.: Open Court Publishing, 2002.
This book contains the work of a notable selection of authors from the new sciences as well as a variety of ecumenical theologians who explore their common affirmation of life, people, and spirituality. One of the authors, anthropologist Terrence Deacon, writes about a self-complexifying evolution, arguing that "[f]rom this perspective life and consciousness can be seen to be deeply interrelated, not just because consciousness has evolved in living things, but because they are each manifestations of a common underlying creative dynamic" (p 152).

McNeill, William. "Passing Strange: The Convergence of Evolutionary Science with Scientific History." *History and Theory* 40, no. 1 (January 2001): 2–7.
McNeill, a world historian, proposes uniting historical studies with an evolutionary cosmology arising from the physical, biological, and complexity sciences.

Morowitz, Harold. *The Emergence of Everything: How the World Became Complex.* New York: Oxford University Press, 2002.
A senior systems biologist describes a new view of nature, life, and the mindful human as an intrinsically emergent process. Rather than reducing the cosmos to mechanism, Morowitz's theory describes a persistent emergence that is evident at all stages from its origin to planetary formation, animal sociability, and the spiritual quest.

Swimme, Brian, and Thomas Berry. *The Universe Story: From the Primordial Flaring Forth to the Ecozoic Era—A Celebration of the Unfolding of the Cosmos.* San Francisco, Calif.: HarperCollins, 1992.
This unique collaboration from a mathematical cosmologist and a cultural historian conveys an epic sense of a self-organizing creation from its primordial fireball to a humane, sustainable "Ecozoic" age.

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Taylor, Mark C. *The Moment of Complexity: Emerging Network Culture.* Chicago, Ill.: University of Chicago Press, 2001.
Taylor, a humanities professor, perceives the outlines of a globally emerging network culture through a collage of art, architecture, and nonlinear science. The work offers a review of complex systems theory. Taylor finds that complex adaptive systems evolve. In fact, he argues, the process of evolution itself is a complex adaptive system.

Wilber, Ken. *A Theory of Everything: An Integral Vision for Business, Politics, Science, and Spirituality.* Boston: Shambhala, 2000.
This book expresses the most cogent statement of Wilber's worldview—a view that is not based on a bottom-level physics but is distinguished by a universal pattern, an "integral psychology," that is present everywhere. He argues that four quadrants of internal and external self and society track the sequential ascent of a spiritual consciousness. As a synthesis of many traditional and current contributions, his working model cites dynamic parallels between personal and national behaviors.

Wilson, Edward O. *Consilience: The Unity of Knowledge.* New York: Knopf, 1998.
Wilson argues for a reunification of knowledge to complete the Enlightenment agenda. He suggests that materialist reductionism is the way to achieve this reunification. He argues that the central idea of consilience is that all tangible phenomena, from the birth of stars to the workings of social institutions, are based on material processes that are ultimately reducible, however long and tortuous the sequence, to the laws of physics" (266).

Wright, Robert. *NonZero: The Logic of Human Destiny.* New York: Pantheon, 2000.
Wright undertakes an innovative study that finds an inherent penchant and trend for salutary cooperation in both evolution and history.