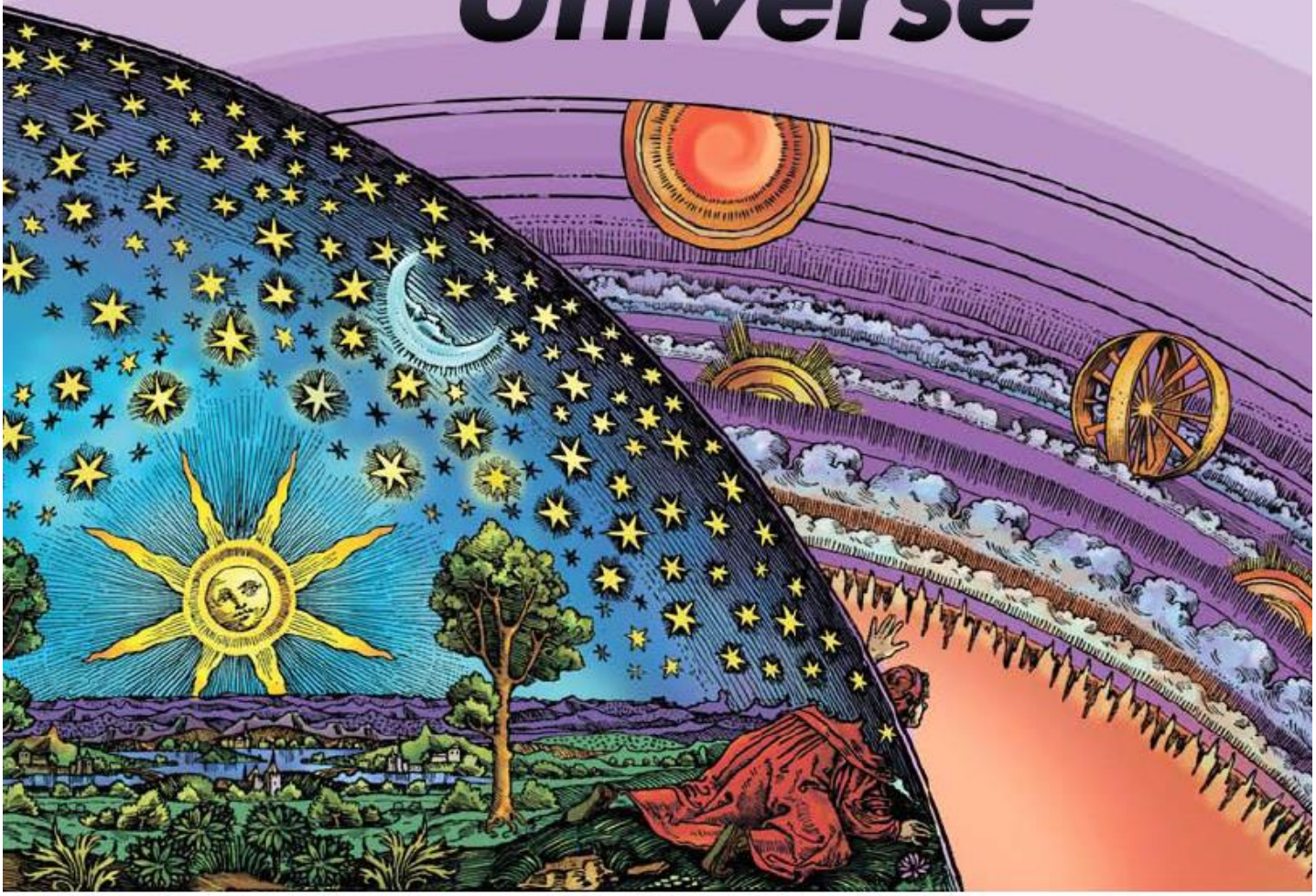
Evo Devo Universe



A Framework for Speculations on Cosmic Culture

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Evo Devo Universe? A Framework for Speculations on Cosmic Culture

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Abstract

The underlying paradigm for cosmology is theoretical physics. In this paper we explore ways this framework might be extended with insights from information and computation studies and evolutionary developmental (evo-devo) biology. We also briefly consider implications of such a framework for cosmic culture. In organic systems, adaptive evolutionary development guides the production of intelligent, ordered and complex structures. In such systems we can distinguish *evolutionary processes* that are stochastic, creative, and divergent, and *developmental processes* that produce statistically predictable, robust, conservative, and convergent structures and trajectories.

We will briefly model our universe as an evolutionary, computational, and developmental system–as an "*evo compu devo" universe* (abbreviated "*evo devo" universe* hereafter). Our framework will try to reconcile the *majority* of unpredictable, evolutionary features of universal emergence with a *special subset* of potentially statistically predictable and developmental universal trends, including:

- *accelerating advances* in universal complexity (under particular metrics, e.g. Chaisson 2003), seen over the last half of the universe's life history, in contrast to *deceleration* during the first half
- increasing spatial and temporal (space-time) *locality* of universal complexity development
- apparently hierarchical emergence of increasingly matter and energy *efficient* and matter and energy *dense* substrates (platforms) for adaptation and computation
- apparent accelerating emergence, on Earth, of increasingly *postbiological* (technological) forms of intelligence, and their likely future trajectories.

By the close the paper, the reader should have some concrete and at least partially testable ideas on what is likely to be intrinsically unpredictable and what may be statistically predictable about cosmic culture (what we call an evo devo framework), and some understanding of how processes of universal development may constrain cosmic culture, chaining it to particular patterns of hierarchy emergence, communication, behavior, and life cycle, and thereby explaining the Fermi Paradox, as we shall propose.

We use the phrase "evo devo" without the hyphen here, to distinguish this speculative philosophy and systems theory from the legitimate science of "evo-devo" biology, from which we seek insights. An international research and critique community in evo compu devo systems theories, free and open to all qualified scholars, may be joined at EvoDevoUniverse.com. Author's email: johnsmart@accelerating.org.

Introduction: Culture and Technology in Universal Context

What are human culture and technology, in relation to the cosmos? How do they change over time? To what extent may intelligence (human culture, science, engineering, technology, and successors) reshape our universe in the future? To what extent are intelligent systems constrained or directed by our universe? What universal role, function, or "purpose" may culture and technology serve?

Such humbling questions are the province of astrosociology, the philosophical study of the likelihood, characteristics, and dynamics of universal civilizations, by analogy to our still-poorly-understood and singular example on Earth. Although today it is a field with few journals and conferences, questions in astrosociology are informed by astrobiology, evolutionary biology, paleontology, evolutionary psychology, behavioral ecology, macrohistory, and other life, social, informational, physical, and technological sciences and philosophies. Such questions are also regularly contemplated by SETI practitioners, science fiction writers, futures scholars, and other communities (Wikipedia 2007).

These questions are also central to an even more speculative field we may call astrotechnology, the long-term evolutionary development of technology in universal context. Extrapolating accelerating computer developments a few generations hence, some scholars foresee a coming "technological singularity" (Adams 1909; Meyer 1947; Good 1965; Wesley 1974; Vinge 1993; Broderick 1997; Dennett 1998; Coren 1998; Kurzweil 1999,2001,2005; Smart 1999; Clarke 2003) a time when Earth's leading computing systems may encompass and even surpass human cultural intelligence, performance, and autonomy. Dick has argued (1999,2000,2003,2006) that considering the long-term future of Earth's cultural behavior seems critical to understanding the nature of extraterrestrial intelligence, and that higher intelligence may become postbiological, which would in turn impact extraterrestrial behavior in unknown ways.

Figure 1. Matrioshka dolls.

To consider the cosmic future of culture and technology this paper will introduce three biologically inspired sets of hypotheses (simple models) of universal change. Like descending Matrioshka dolls (Figure 1), each later model is a subset of the prior in a logical-specification hierarchy (Salthe 2002), and each is also increasingly speculative and poorly grounded. All three models can generate testable implications for astrosociology and astrotechnology, though each may need further mathematical and quantitative representation before that can occur.

- The first model, the *informational physical universe* (IPU) hypothesis, considers the universe as a system in which information and physics together create emergent intelligence and computation, which in turn partially shape universal dynamics. This model proposes that future forms of culture and technology, as they presumably arise throughout the universe, have the potential to play some integral (e.g., anthropic) yet transient universe-guiding role.
- The second model, the *evo devo universe* (EDU) hypothesis, considers the universe as engaged in both processes of *evolutionary* creativity and processes of hierarchical *development*, including a specific form of *accelerating* hierarchical development we call "STEM compression" of information encoding and computation.
- The third model, the *developmental singularity* (DS) hypothesis, proposes our universe's hierarchical and energetically dissipative intelligence systems are developmentally constrained to produce, very soon in cosmologic time, a very specific outcome, a *black hole analogous computing system*. Per other theorists (see Smolin 1997) such a structure is likely to be a core component in the *replicative life cycle* of our evo devo universe within the multiverse, a postulated *environment* of universes.

Our arguments will be guided by theories and analogies of emergence (Holland 1995,1998). As shown in mathematics (Gödel 1934; Chaitin 1998) and computing (Church 1936; Turing 1936), all theories have areas of utility and areas of incompleteness and undecidability. Likewise all analogies have strengths and shortcomings (Hofstadter 1995). We need not assume our universe is *in essence* "computational," "alive," or even "hierarchically dissipative," only that these computational, organic, thermodynamic and relativistic analogies may serve to advance our understanding of processes far more complex than our models.

We must also acknowledge the present empirical and quantitative shortcomings of anthropic universe models, on which all three of our hypotheses depend. Anthropic (biocentric, intelligence centric) models propose that life and intelligence are developmentally destined to emerge in our particular universe, and serve some universal function/purpose/telos that is yet unclear. Such models range from the mathematical (the apparent fine tuning of fundamental universal parameters, e.g. Rees 1999), to the empirical (special universal chemistry that promotes precursors to biogenesis, e.g. Henderson 1913,1917; Miller 1953; Lazcano 2004), to the teleological (analogies and arguments for systemic function or purpose to cosmic intelligence, e.g. this paper). Today, as acknowledged by even their most adept practitioners (Barrow and Tipler 1986; Krauss et al. 2008), anthropic universe models proceed more from ignorance and assumption than from knowledge. Though we will introduce one here, we cannot yet validate a framework for generating a probability distribution for possible universe creation, and from there, critiquing anthropic arguments with any rigor. Our theoretical and experimental capacities are quite poor by comparison to the complexities and apparent degrees of freedom in the universe we are modeling. And if there is a multiverse, a space in which universes like ours live, die, and are reborn, framing difficulties only multiply.

Nevertheless, there is a sizable community of scientists, scholars, and students willing to engage in anthropic systems theory, even as such philosophy is not always grounded on testable scientific theory, but rather speculation, induction, analogy, argument, and circumstantial evidence. It is to this audience, and to the hope of near-future emergence of testable anthropic hypothesis and theory, that this paper is addressed
.

1. The Informational Physical Universe (IPU) Hypothesis

In addition to physics, how fundamental a property of our particular universe is information? How applicable is the analogy of our universe as an information processing system? What system properties do information processing systems and our universe potentially share?

Figure 2. One of the most fundamental realities and control systems of our universe seems to be not only physics, but also information and its emergents.

We do not yet know, and perhaps universal intelligence may never know, the deepest relations between physics, mathematics, information, computation and mind in our universe. Which of these systems, or others, is the best general reference frame for understanding universal complexity? Does our universe contain all of mathematics, and is mathematics a subset of information theory (Chaitin 1998), or is mathematics more fundamental than physics (Tegmark 2008)? Is all information in reality inevitably physical (Landauer 2002) or are there informational aspects of our universe that precede and extend beyond its particular physics (Smolin 1997)?

The IPU hypothesis proposes that informational and physical processes appear, at least to a first approximation, as equally fundamental perspectives on change, and that by considering them as equally fundamental, we can make important advances in our understanding of universal complexity, capacities and constraints. Philosophically, this dyadic model is as old as the Greek philosophers, who will be briefly discussed. It is central to the qualitative dichotomy between the human mind (informational) and the body/brain (physical), as discussed in Plato's *Phaedo*, ~360 BCE, which began the philosophical argument over whether these truly were two fundamental categories of nature, an argument famously continued by Descartes (1641). Less famously, we find a related dyad in panexperientialist philosophy (Whitehead 1926, Bloom 2000), which

proposes an informational-computational or *'modeling'* aspect to all physical processes (e.g., "all matter models" to the greatest extent that it can, given its limitations), ranging from the simplest galaxies and molecules to Earth's emerging collective 'mind'. This perspective is also captured in its triadic form in the works of ecological psychologists (Gibson 1979) and some cognitive neuroscientists (Fuster 2002), with their focus on the perception-action (informational-physical) cycle as the fundamental framework for understanding intelligence, autonomy, and cognition, as a third or emergent perspective.

Perhaps most fundamentally, the laws of thermodynamics, which are among the most foundational physical theories we have yet discovered, express an informational-physical duality in their formal structure. Since Jaynes (1957a-b), thermodynamics can be understood as an application of information theory (Shannon 1948), a discovery which suggests that all physical law may be an application of information theory, or that physics and information are two transformable theoretical frameworks for all universal process. Frank (2009) explains how the classic probability distributions observed ubiquitously in nature (Gaussian, exponential, power law, and other curves) result from *informational constraints* (preserved universal information) which are as real as (and perhaps equivalent to) *physical constraints* (preserved physical law) on universal dynamics. Salthe (2003) talks of "infodynamics," an emerging developmental framework for the informational component of thermodynamics in guiding complexity. Our universe is running downhill (on average) in entropy potential, while running uphill (multilocally) in information potential, when we use a definition of universal information that is of opposite sign to the Shannon definition. Noting this, Teilhard (1955) and others have speculated that some undiscovered conservation law (transferring universal potential from energy to information) may be in operation. We are in sore need of some fusion of information theory and physics that can explain accelerating intelligence emergence on Earth and presumably in parallel environments in our universe. Jaynes, developer of the theory of maximum entropy thermodynamics (2003) has started down this road, but we have a long way still to go.

Beyond the thermodynamic clues listed above we have not yet had, as Tim Ferris (1998) aptly puts it, an "Einstein of information theory" to illuminate the relation of information and computation to physics in our universe. While the mathematics of *physical theory* has made progress on all scales during the twentieth century, from nuclear and atomic physics to physical chemistry to biophysics to engineering and cosmology, the mathematical context for *information theory* across space and time has been much harder to work out. We do not presently deeply understand information creation, flow, processing, and destiny across a variety of physical systems and scales. It is possible that much of our philosophical uncertainty and incompleteness on these issues may be a result of being ourselves entities of low and finite formal complexity. Nevertheless, as our species intelligence has grown, we seem to know enough to make some important provisional statements. Furthermore, given historical trends, we have a reasonable expectation of further progress on these issues.

The IPU hypothesis proposes a cosmos of both fundamental informational and physical structure and process which interact to create *computation*, modeling, mind, complexity and change via hierarchies of prebiological, biological and postbiological systems. A simple cartoon of the hypothesis is expressed in Figure 3.

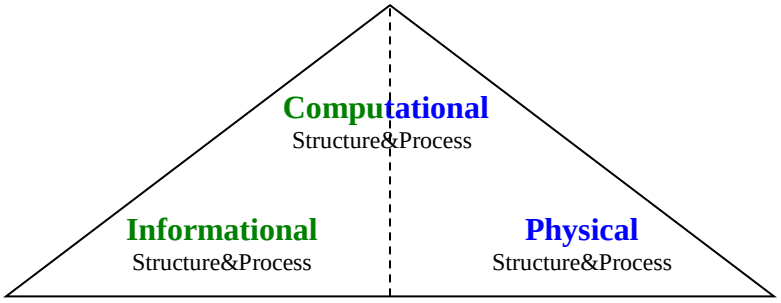


Figure 3. A simple cartoon of the IPU hypothesis. Universal computation, modeling, and mind are tentatively portrayed as emergents of more fundamental informational (I) and physical (STEM) processes.

We will attempt no general definitions of information or computation in this paper. Like related terms (complexity, emergence, intelligence) there are many useful models for universal information and computing (Pagels 1988; Hofkirchner 1999; Floridi 2003, 2008; von Baeyer 2003; Siefe 2006; Brier 2008),

but as yet no commonly accepted general theory for either. Issues that should be addressed in any truly general theory of information and computation would include such phenomena as reduction of uncertainty (Shannon 1948), evolution (Gershenson 2008), development, complexity, structure, math/symbol, physical law, relation, difference, perception, abstract idea, intelligence, meaning, human consciousness, and any form of postbiological "hyperconsciousness" (Wallace 2006) that may one day come.

As mentioned earlier, the information vs. physics duality of the IPU hypothesis originates in ancient Greece. It was Parmenides, in *On Nature*, circa 500 BCE, who first proposed that we live in a universe of constancy, where underlying conditions do not change, and a "way of truth" that may be followed to find these constancies, as opposed to the world of opinion, which is illusory and false. Along with Thales, Democritus, and others, Parmenides is considered a founder of the scientific hypothesis, and he describes a *physical* universe perspective, one of universal laws, or constancies, as seen in the invariant processes of classical physics. Directly opposing his view was his contemporary Heraclitus, who saw the only constancy as change, and a universe driven by "logos", or the word, measure, account, or opinion of its actors. This is an *informational* universe perspective, a scientific view that has been equally strong since the 1930's as expressed in the observer dependencies of quantum physics. Combining these, we have two polar perspectives, a fundamental duality. Democritus, circa 400 BCE, identified this duality as chance (information, statistics) versus necessity (physics, constraint), in a famous phrase "Everything existing in the universe is the fruit of chance and necessity" (Monod 1970).

Much early philosophical work explored variations of these two perspectives. The Pythagoreans, circa 530 BCE, proposed that the ultimate laws of the universe may be expressed as mathematical ideals. The Pythangoreans would posit that mathematics, which we may consider a special type of information, underlies physics, and this philosophical intuition remains popular with many scientists today. Alternatively, Plato (*Timaeus* ~360 BCE) proposed that a "perfect realm" of ideal (informational) forms and ideas undergirds the physical world and is imperfectly executed in it, thus again privileging information over physics. We may never know if information or physics are of equal importance to the universe, or if one is more "fundamental" than another. But from the IPU perspective, both views can be considered incomplete as long as they leave out the "third way", the computational-complexity-consciousness perspective.

We can find early antecedents to the triadic IPU hypothesis in Aristotle's triadic syllogistic logic (*Analytics* ~330 BCE), and in the three critiques (*Critique of Pure Reason, Critique of Practical Reason, Critique of Judgment*) of Immanuel Kant (1781-1790). Kant saw aesthetic judgment, what we may interpret today as computation-complexity-consciousness, as a bridge between pure reason (logic, law) and practical reason (ethics, practice). We can also see an IPU-like structure in the philosophy of Hegel (1807) who proposed such categorical triads as being-nothingness-becoming and abstract-negative-concrete, later popularized by others as "thesis-antithesis-synthesis." More recently we find this perspective in the philosophy of C.S. Peirce (1868), whose theory of three categories may be oversimplified as the interplay of chance (vagueness, possibility, ideas, feeling, *information*), necessity (representation, habits, logic, laws, *physics*) and discreteness (precipitation, complexity, consciousness, morality, love, *computation*). Peirce's work is consistent with a biological (evolutionary and developmental) perspective on complexity emergence, and we shall briefly return to him in discussion of the EDU hypothesis to come.

In this paper, the more easily observable and quantifiable *physical* features of our universe, such as space, time, energy, and matter/mass, will be referred to as STEM. Such features have been surprisingly well-characterized mathematically by general relativity and quantum theory. When such features are described in concert with the more abstract and harder-to-quantify manifestations of *information* and *computation* described above, we shall call this combination a STEM+IC universe (Smart 2002b).

To recap, the IPU hypothesis begins with the apparent mind/body, perception/action, and informational/physical thermodynamic dualities, and seeks self-similar manifestations of this dyad at multiple scales. This can be expressed as a STEM+I=C relationship, as in Figure 3. Such simplification must surely introduce bias and limitations, and yet to this author seems a reasonable place to start.

In the IPU model, we can expect that a digital physics may one day emerge—an understanding of our universe as a quantized informational-physical computing system (Zuse 1969; Wheeler 1983,1990; Deutsch 1985, 1997; Chaitin 1987; Fredkin 1990, 1992; Wolfram 2002; Lloyd 2006) that is discrete (at the Planck scale) but never complete (in its calculations). Information theorist Ed Fredkin calls what we have today a collection of *digital philosophies*. His dream is that they will one day be rigorous enough to be called *digital physics*, a grand unification of information theory and physics. While we wait for a digital physics to materialize (or not), what we can observe today is that "mind" in all physical systems has an accelerating and ever more pervasive impact on "matter" as a direct function of its complexity (Dyson 1988; Kurzweil 1999). Thus we may responsibly speculate that, over time, the leading complex adaptive systems become increasingly active *guiders* and *shapers* of at least their *local* universal physical dynamics. We have more to say about this in the EDU and DS hypotheses to come, where we approach the question of the future of complex systems from the perspectives of their *freedoms*, *capacities*, and *constraints* (evolutionary, computational, and developmental perspectives).

We may now define the IPU hypothesis as *any* set of provisional models of physics, information, and computation which seem to have the potential to be fundamental, quantitative, predictive, and constraining perspectives on local and universal dynamics. To that end, the following incomplete collection of IPU claims (subhypotheses) may turn out to be particularly important:

Information, Thermodynamics, and Computation Claims:

- Maximum Entropy (MaxEnt) Thermodynamics (Shannon 1948; Jaynes 1957a-b, 2003; Frank 2009). Shannon (1948) pioneered a measure of "information" as uncertainty or disorder in a signal from a sender [Technically, "Shannon information" is actually *information entropy*. True information (certainty, order, constraint) is the opposite in sign. It is what happens to the *receiver* of Shannon information (Siefe 2006)]. Jaynes (1957) showed that physical entropy (the inability to do work) is just one application of Shannon's information entropy (probabilistic uncertainty, disorder), and that both tend to maximum entropy states. Frank (2009) shows how Jaynes's maximum entropy approach is the most economical way to explain the classic probability distributions (Gaussian, exponential, power law, etc.) in nature. These are fascinating advances, but we have a long way to go use thermodynamics and information theory to understand accelerating change. We intuitively suspect that the emergence of accelerating islands of *local order* (true information), like Earth, are a direct necessity of the highly ordered conditions of our early universe, and the *global decay* of the universe with time. But we cannot yet predict or model this acceleration as a consequence of non-equilibrium thermodynamics. In fact, modern science *does not even acknowledge the acceleration signature*, as it implies a *universal teleology toward increasing local order*, something that is anathema to the evolutionary worldview. Dewar (2003, 2005) in particular has done MaxEnt work which is empirically promising (Lorenz 2003, Martyushev and Seleznev 2006) but which also has mathematical mistakes (Grinstein and Linsker 2007). There are few scientists willing to risk their reputation to do this work, and the non-equilibrium calculations are extremely difficult. We may need smarter-than-human minds for the MaxEnt proof of locally accelerating universal complexity to materialize.
- Church-Turing Thesis on Computational Equivalence (Church 1934; Turing 1936, Wolfram 2002). The C-T thesis holds that any physically computable process can be performed on a Turing machine (a universal generic computer), thus proposing a universal theory of computation. Wolfram recently restated this with respect to all non-simple universal processes in his principle of computational equivalence.

- Gödel's Thesis on Computational Incompleteness (Gödel 1934; Chaitin 1998). Gödel's thesis holds that all formal logical systems and physical (finite state) computing systems have *areas of incompleteness and undecidability*, e.g., cannot be omniscient. Chaitin argues that even some fundamental mathematical facts cannot be proven with mathematical logic, are "true for no reason," and *were inherited* in our particular universe, e.g., no physical system can ever fully understand itself (be 'self-omniscient').
- Participatory Anthropic Principle (Wheeler 1983; Lloyd 2006). The PAP proposes our physical universe may be usefully considered as both *information* and *information processing system*, engaged in *collective observational interactions* that may be modeled on both quantum mechanical and emergent levels of universal structure. It is arguably the most explicit description of an 'informational-physical universe' to date. Wheeler proposed *information* as the core of the physical universe. Lloyd updates the PAP to propose *computation* as the core, an output of informational and physical process.
- Hierarchical Universe of Increasingly Intelligent and Energetically Dissipative Complex Adaptive Systems (Simon 1962; de Vaucouleurs 1970; Pattee 1973; Nicolis and Prigogine 1977; Allen and Starr 1982; Salthe 1985,1993; Moravec 1988; Paul and Cox 1996; Kurzweil 1999; Chaisson, 2001). This hypothesis proposes that our universe generates an *emergence hierarchy* of energetically dissipative "complex adaptive systems" (CAS) (Holland 1995,1998), and that the leading edge of this computational hierarchy increasingly understands and influences universal processes. Furthermore, the dissipation hierarchy is somehow *integral* to universal purpose, structure, and function in a way yet to be determined. In our hierarchical universe, cultural change on Earth, and at least in other Earth-like environments, can be expected to produce *an even more advanced and energetically dissipative intelligence*, some coming form of postbiological "life." As a result, Earth's human culture has the potential to play an *important yet transient role* in the hierarchical lineage of universal intelligence emergence.

Complexity Emergence Claims:

- Strong Anthropic Principle (Barrow and Tipler 1986). Our universe must possess properties that "allow life to develop within it at some stage in its history" [e.g., properties that make life *developmentally* likely, in a statistical sense]. The SAP may be drawn from the fine tuning problem in cosmology, in which our universe's apparently fundamental constants and initial conditions seem very narrowly restricted to values which may *statistically determine* the emergence of life and complexity (Barrow 2002,2007).
- 'Final' Anthropic Principle (Barrow and Tipler 1986). "Intelligent information processing must emerge in the universe, and persist [e.g., as a *developmental* process]." In other words, not only life, but intelligent life is statistically likely to emerge and persist, due to the special structure of our universe. The FAP may be inferred from both fine tuning and our universe's accelerating emergence history , e.g., an evolutionary developmental emergence record that has run increasingly rapidly over the last six billion years (Sagan 1977) the more intelligent the local system becomes (Coren 1998).
- Intelligence Principle (Dick 2003). This hypothesis holds that "the maintenance, improvement and perpetuation of knowledge and intelligence is the *central driving force of cultural evolution* [in biological systems in the universe, at least], and to the extent intelligence can be improved, it will be improved." Generalizing from Earth's history, it connects cultural change to universal intelligence improvement.
- Melioristic Universe (James 1921). Life has an innate tendency to *improve* (ameliorate, make better or more tolerable) some definable aspects of itself (complexity, intelligence, survivability and perhaps other measures) over its lifespan. This hypothesis is a variant of the intelligence principle, and may be proposed by quantifying life's melioristic record of complexity and capacity improvement on Earth.

Observation Bias Claims:

- Observer Selection Bias Exists But Does Not Invalidate All Anthropic Insights (Barrow and Tipler 1986). Observer selection bias (Bostrom 2002) must accompany all anthropic reasoning (universe hypotheses made from our position as intelligent observers). *But if processes of universal development exist*, and *if*

they bias intelligence to be a central observer in the universe system, as they apparently do with intelligence in all developing biological systems, then *theories of universal development* should prove an even more fundamental framework to test and ground anthropic insights. In such case, all observer selection models must be a subset of *universal evolutionary development* models, which we will consider in the EDU hypothesis to come.

Note the IPU hypothesis simply collects potentially fundamental informational, physical, and computational perspectives on universal dynamics. Some are framed in *proto*-evolutionary or developmental fashion, but without explicitly (except in the last subhypothesis) using these terms.

The privileging of information, physics, and computation/mind as apparent universal fundamentals feels appropriate for several intuitive reasons. First, there is the tautological (and confounding) reason that we, as computing conscious observers, are biased to see consciousness and its generative processes as special. Second, as explained earlier, mind/body duality, perception-action cycles, and thermodynamics all seem potentially central to universal process, even in light of our observation bias. Third, information, physics, and their computational emergents have apparently manifested on an unreasonably smooth hierarchy emergence continuum over known universal history, beginning from a featureless and isotropic void and ending with today's highly variegated and at least locally intelligent cosmos. Finally, information production, physical complexification and computation are perhaps the only processes that have *continually accelerated* over the last six billennia of universal history. This last clue may turn out to be most constraining of all, as we will discuss in the EDU hypothesis to come.

To some degree, the IPU hypothesis as described above represents the current perimeter of respectable scientific and philosophical conjecture on the "meaning" or "purpose" of universal dynamics. Note that the central assumptions and biases of the hypothesis are intelligence-centric or perhaps "*info- and physics-morphic*" rather than "anthropo-morphic." Nevertheless, the only anthropomorphisms we have fully escaped in the IPU are a class of ancient ones that place *Homo sapiens* at the center of the universe in some singular, enduring, or guaranteed fashion (as in Figure 4).

It is beyond our scope here to carefully evaluate whether IPU assumptions and biases are justified, or are anthropic mistakes (observation selection effects). Bostrom (2002) and others would invoke some form of random-observer self-sampling assumption to critique IPU-related thinking. Yet as our last IPU subhypothesis argues, if random observer-moments exist only in *evolutionary* processes, and are an incorrect evaluative framework for all *developmental* processes in the cosmos, then observer selection theory must be revised to conform with our emerging understanding of universal observer intelligence development. In models of the universe, it is today far from clear what the most fundamental frameworks are from which to launch a critique of observer bias. Let us grant that bias exists and move on.

Figure 4. Christian Aristotelian cosmos, Peter Apian's *Cosmographia*, 1524.

The IPU hypothesis starts us thinking carefully about the impact of and relationships between cosmic information, physics, and computation, but in this era of still-missing information and computation theory, it is unsatisfyingly vague and only mildly prescriptive. As a result, we propose that the next two models, though each is an increasingly specific and speculative subset of IPU hypothesis space, may prove even more useful, testable, and predictive descriptions of universal dynamics.

2. The Evo Devo Universe (EDU) Hypothesis

How applicable is the analogy of our universe as an information processing system engaged simultaneously in *both* evolutionary (variational, in our definition) and developmental (hierarchical, hereditary) process? Which macroscopic aspects of our universe seem engaged in evolutionary process? Which seem to be engaged in developmental process? How closely may potential universal evolutionary and developmental processes parallel better-known processes in evo-devo biology?

When theorists refer to both biological and non-biological systems as complex adaptive systems, the term "evolution" is often used to describe any process of complexity growth and change with accumulation of historical information (Myers 2009). The EDU hypothesis proposes that what we commonly call evolution can much more accurately be called *evolutionary development*, or evo devo, a dyadic process involving *both* evolutionary (variational, creative, experimental) and developmental (hierarchical, directional, generational) change. Unfortunately, those who use the term evolution to describe long range change in complex systems often *ignore or minimize developmental process*, the fact that our universe is not only varying, creating, and experimenting, it is also *developing* toward a particular, predestined direction (for example, increasing total entropy over time). Standard evolutionary theory in biology, for example, ignores universal development as a constraint on long-term biological variety, and it mostly ignores even biological development as such a constraint. In the biological sciences, those who think this perspective incorrect call themselves evolutionary developmental (evo-devo) biologists. They use the phrase evo-devo to describe a paradigm for biological change that emphasizes both evolutionary and developmental process. In particular, evo-devo biologists show the importance of developmental genes and environment in constraining long-term evolutionary variety. The EDU hypothesis proposes that development at *all* scales (universal, planetary, genetic, social-cognitive, economic, and technological) is a constraint on evolution at all scales.

Therefore, in this text, we will only occasionally use the term evolution to refer to universal complexity growth and change, including intelligence, adaptation, and computation. We'll instead favor the more useful term evo devo, to emphasize that universal development appears just as fundamental as universal evolutionary process in the long-term dynamics of complex adaptive systems at all scales. We will also seek to describe evo devo in its component (evolutionary/evo and developmental/devo) processes throughout.

There would be many potential benefits to constructing and verifying even a primitive and tentative model of our particular universe as an *evo devo universe*, one where both evolutionary and developmental processes can be understood and modeled at both universal and subsystem scales. Whenever we can discover and validate evolutionary process and structure in our universe, we can better *describe evolutionary possibilities* for complex systems. Likewise, wherever we can find and model developmental process we can *predict developmental constraints*, including constraints for universal culture and technology. More generally, we may also come to understand some of the functional (evo and devo) roles of culture and technology in the cosmos.

Consider the following very partial set of polar word pairs represented in Table 1. Compare these words with your knowledge of evolutionary and developmental processes as they express in biological systems, at the molecular, cellular, organismic, population, and ecosystem levels. As we will propose, *if we allow for the possibility of both evolutionary and developmental process at the universal scale*, a good case may be made for commonly and statistically, though certainly not exclusively, associating the first column with evolutionary and the second with developmental processes in both living and nonliving complex systems.

Like the terms evolutionary and developmental themselves, each subordinate word pair suggests, in *some future evo devo systems theory*, complementary processes contributing to adaptation in complex systems, as well as polar (competing and cooperating) models for analyzing change. In considering these dichotomies, the easy observation is that each process has explanatory value in different contexts. The deeper question is when, where, and how the polar processes in Table 1 interrelate to create, manage, and sustain adapted complexity, on average and in specific cases.

Table 1. Some Linguistic Dichotomies (Polar Word Pairs) with Good Homology to Evolutionary and Developmental Process.

Evolutionary Process	Developmental Process
Unpredictability	**Predictability** (*statistical*)
Chance	Necessity
Creativity (of options)	Discovery (of constraint)
Indeterminate	Predestined
Random	Predetermined
Divergent	Convergent
Segregation	Integration
Branching	Funnelling
Novelty	Conservation
Reversible	Irreversible (*on average*)
Possibilities	Constraints
Variety/Many	Unity/Monism
Variability	Stability
Reductionism (Primary) and Holism (2ndary)	Holism (Primary) & Reductionism (2ndary)
Uniqueness	Sameness
Transformation	Transmission
Accidental	Self-organizing
Bottom-up	Top-down
Local	Global
Immaturity	Maturity
Individual	Collective
Instance	Average
Short-term	Long-term
Analysis (breaking)	Synthesis (joining)
Amorphous/Anarchic	Hierarchical/Directional
Freedom	Security
Explicit	Implicit
Practical	Theoretical
Freewill	Determinism
Period-doubling/Chaos	Period-halving/Order
Experimental	Optimal
Dedifferentiation	Differentiation
STEM recombination	STEM compression
Symmetry breaking	Symmetry constraints
Nonergodicity	Ergodicity
Innovation	**Sustainability**
Mind	**Body**
Belief (unproven)	**Fact (verified)**

Unfortunately, when theorists describe change in systems larger or smaller than the individual biological organism today, the term "evolution", as described above, has been nearly the sole term of art, and outside of biology, even that term is only inconsistently applied. This is true even as a number of apparently irreversible, statistically predictable, and directional universal processes (entropy, acceleration, locality, hierarchy) have been obvious for more than 150 years, processes which on their surface seem very good candidates for being described as "development."

This bias toward evolutionary nomenclature may exist because reductionist analysis has always been easier than holistic synthesis for human-initiated science. Evolutionary biology achieved early theoretical characterization (Darwin 1859), and early quantification via reductionist science (Mendelian genetics), while until recently, both embryology and ecosystem development have remained holistic mysteries, too complex for comparatively quantitative or theoretical investigation. Consequently, hypotheses of macrodevelopment (orthogenesis, complexity ratchets, etc.) have not risen above the realm of philosophical speculation, even with great advances in the explanation of evolutionary mechanisms.

Fortunately, this state of affairs may soon change. Beginning in the mid-1990's a new generation of evo-devo biologists have emerged (Steele 1981,1998; Jablonka and Lamb 1995,2005; Raff 1996; Arthur 2000; Wilkins 2001; Hall 2003; Müller and Newman 2003; Verhulst 2003; West-Eberhard 2003; Schlosser and Wagner 2004; Carroll 2005; Callebaut and Rasskin-Gutman 2005, many others), whose inquiries are guided by new conceptual and technical advances in the study of evolution and development. The interdisciplinary field of evo-devo biology explores the relationship between evolutionary and developmental processes at the scale levels of cells, organisms and ecologies (Carroll 2005). It includes such issues as:

- how developmental processes evolve
- the developmental basis for homology (similarity of form in species with a common ancestor)

- the process of homoplasy (convergent evolution of form in species with unique ancestors)
- the roles of modularity and path dependency in evolutionary and developmental process
- how the environment impacts evolutionary and developmental process.

Though this community is just over a decade old, it shows potential to deliver the meta-Darwinian paradigm we have long been seeking in biology, one that reconciles evolutionary variety production, and natural selection's contingency and famous *lack* of directionality (e.g., Gould 1977), with the smoothly accelerating and apparently developmental emergence of increasing intelligence and complexity in a special subset of biological systems on Earth over the last four billion years (e.g., Sagan's 'Cosmic Calendar,' 1977).

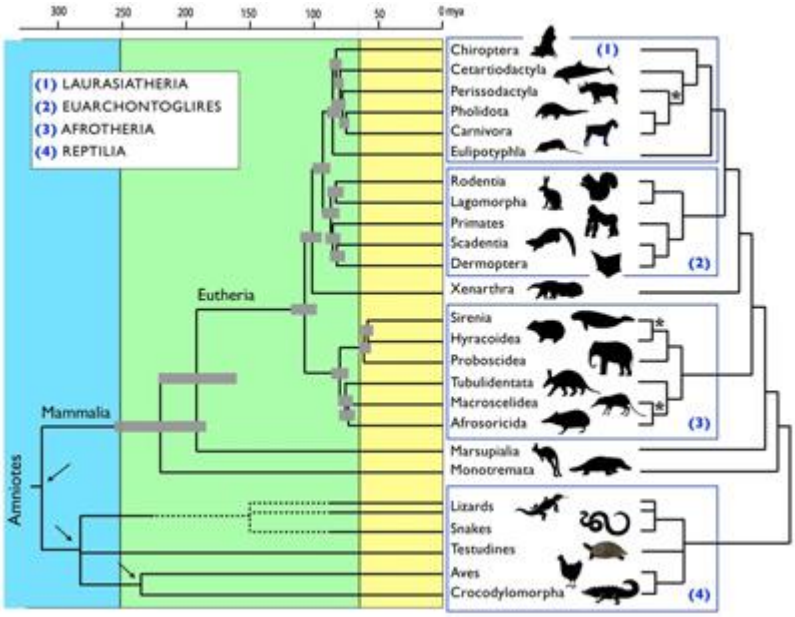


Figure 5. An evo-devo systematics diagram (Milinkovitch and Tzika 2007).

A number of scholars in the orbit of the evo-devo biology community, such as paleontologist Simon Conway Morris (*Life's Solution*, 2004) are also contributing greatly to this emerging paradigm. Morris has done persuasive work on 'evolutionary convergence' (homoplasy) in the record of life's evolutionary development, documenting the *independent emergence, conservation, and convergence* with respect to a growing subset of functional systems and morphologies (eyes, jointed limbs, body plans, emotions, imagination, language, opposable thumbs, tool use, etc.). Many of these homoplasies powerfully advance *individual and cultural information processing and adaptation* over a broad range of evolutionary environments, for all organisms that acquire them.

The streamlined shape of fish fins, for example, while invariably first created as an *evolutionary* morphological experiment, must persist in the genes of all organisms seeking to move rapidly through water on all Earth-like planets, as a generic *developmental constraint* imposed by universal physics. In a competitive and computational universe, this makes such advances evolutionary "ratchets" (function that is randomly acquired but likely to be statistically irreversible once acquired, over long spans of time and a broad range of environments), a type of *developmental optima* (for a given level of environmental complexity) in *all universes of our type*. As Morris proposes, if the "tape of life" were played twice, on two Earth-like planets, many such "universals" of biological form and function (e.g., the 35 or so generic body plans of the Cambrian) should predictably emerge, persist, and converge in both environments. Such convergence must occur even as the *great majority* of details of evolutionary path and species structure in would remain contingently, unpredictably different in each environment. Such claims must one day be testable via our search for extraterrestrial intelligence (SETI), and by advances in science and simulation. Empirically, we can also look for universal developmental outcomes of experiments in rapid evolutionary systems, such as Richard Lenski's studies of *E. coli* mutation (Lenski 2004). Evolutionary convergences (developmental optima) should be increasingly demonstrable in multigenerational experiments in such systems, whenever their attractor states can be formally or even informally predicted using our advancing theories of physical chemistry, supramolecular chemistry, molecular biology, or genetics.

Just as in the discovery of biological development, the discovery of universal developmental process, where it exists, would not diminish or negate the great evolutionary creativity of our universe. Rather, it would

help us understand how universal creativity is also constrained to maintain particular ends, including *hierarchy emergence, universal life cycle, and (future) universe replication*, a superstructure that allows evolutionary variation to flourish, but always within circumscribed universal developmental boundaries.

The evo devo universe hypothesis (simple model) will now be presented in brief. It is an aggregation of the following claims and subhypotheses (and others omitted in this sketch):

● The IPU hypothesis (in some variant) as outlined earlier, and:

● The Evo Devo Analogy. Our universe seems analogous to a quasi-organic evolutionary and developmental information processing system. As in living systems within it, our universe appears engaged in both unpredictable, creative, and variation-creating evolutionary process and in predictable, conservative, and uniformity-sustaining developmental process. By uncovering the intricacies of evolutionary and developmental processes in biology, we may begin to understand them in other substrates, including the universe as a system.

Figure 6. "Cosmic embryogenesis:" universe as an evo devo system

Recalling Teilhard's (1955) evocative phrase, "cosmic embryogenesis," if we consider the Big Bang like a germinating seed, and the expanding universe like an embryo, it must use stochastic, contingent, and localized/reductionist variety-creating mechanisms—what we are calling "evolutionary" process—in its elaboration of form and function, just as we see at the molecular scale in any embryo (Figure 6). *At the same time*, all embryos transition through a special subset of statistically predictable, convergent, and global/systemic differentiation milestones, culminating in reproduction, senescence, and the unavoidable termination of somatic (body) life—what is commonly called "development." In other words, if the evo devo analogy has applicability to the universe as a system, there must be both unpredictable new creativity and a predictable set of developmental milestones, reproduction, and ending to our universe.

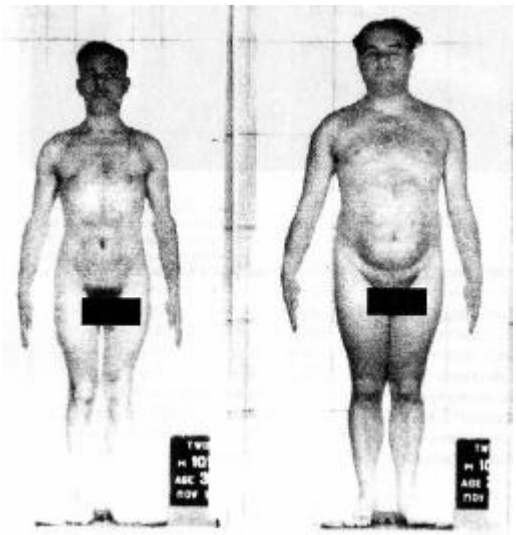


Figure 7. Monozygotic 'identical' twins are always *highly unique* in their 'evolutionary' microarchitecture, and occasionally even partly so in their convergent developmental macrostructure, as with these twins, one malnourished at birth (Watters 2006).

Consider how two genetically identical twins are always microscopically ("evolutionarily") unique (organogenesis, fingerprints (Jain et al. 2002), neural connectivity, etc.) yet also macroscopically ("developmentally") similar in a range of convergent emergent aspects (metrics of physical appearance, key psychological attributes, maturation rates, lifespan, etc.). The central mystery of evo-devo biology—and of evo devo universes—is how locally unpredictable variety-creating processes nevertheless generate globally predictable, convergent developmental outcomes, in a way robust to environmental variation (Figure 7).

● Definition of Evolutionary Processes. Evolutionary processes in biology, and perhaps also in physical, chemical, cultural, technological, and universal systems, are stochastic, creative, divergent (variety- creating), nonlinear, and unpredictable. This intrinsic systemic unpredictability, irrespective of context or environment, may be our most useful quantitative definition and discriminator of evolutionary processes at all systems levels. The dynamics of evolutionary change are *random within constraints*, as with genetic drift in neutral theory (Kimura 1983; Leigh 2007). Its fundamental dynamic is *variation and experiment*.

Biological evolution has been aptly called "tinkering" (Jacob 1977). It has *no foreknowledge* of which strategy will be most successful, so it tries all at hand. It is based on a discrete, quantized set of constraining parameters (such as genes and cellular factors), yet it is continually *shuffling and modifying those parameters in unpredictable ways*. In the universe at large, any process with unpredictability, contingency, generative creativity, and divergence seems at least a candidate for being evolutionary.

- Definition of Developmental Processes. Developmental processes in biology, and we assume also in physical, chemical, cultural, technological, and universal systems, are directional, constraining, convergent, with many previously independent processes *integrating* to form a special subset of outcomes, self-assembling/self-organizing, and statistically predictable *if* you have the right empirical or theoretical aids. This systemic predictability may turn out to be our most useful quantitative definition and discriminator of developmental processes at all systems levels. For example, we can collect empirical evidence of the number and order of stages in the life cycle of any apparently developing system (cell, organism, ecology, solar system, technology platform, etc.) and use this to predict what stage must come next. We are also improving the theory in our models of physical, chemical, and biological development. For example, see Newman and Bhat 2008 for impressive work on how genes discovered a universal set of "dynamical patterning modules" in the evolutionary development of multicellularity on Earth. Nevertheless, high-level predictive quantitative models in developmental biology are today mostly beyond our simulation capacity.

Development in biology is also a cyclical, or *replicative* process (Fig 11), a movement from seed, to adapting organism in the environment, to a new seed. For example, the higher (sexual) developmental life cycle includes at least the following irreversible and directional stages:

1. birth (fertilization, cleavage, gastrulation, organ formation)
2. growth
3. maturation
4. courtship/replicative selection (when successful)
5. reproduction (when successful)
6. senescence
7. death (recycling)

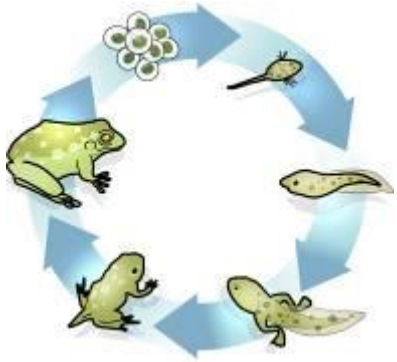


Figure 8. A developmental life cycle.

Salthe and others have proposed simplifications of each of these stages in every replicating, dissipative complex adaptive system in our universe. For 150 years we have known that even our universe is an increasingly senescent, life-limited system, due to the 2nd law of thermodynamics, leading us to look for its replication system. *Replication*, disspation, and (evolutionary) variation of the replicants, seem central to all universal complex systems, except galaxies (which replicate with the universe, if it replicates in the multiverse). Stars have replicated *adaptively* (beating out other uses of star-material) over three population types (III, II, and now I), generating increasingly complex planets. Self-replicating RNA and lipids (Ricardo and Szostak 2009) may have catalyzed life on Earth. Organisms replicate via genes in cells. Languages, ideas, social and org. structures replicate via "memes" (reproducible, communicable patterns) stored in brains (Dawkins 1976; Aunger 2000). Now, at the apparent leading edge of Earth's learning/ computation/ change, some sci. and tech. data and algorithms can replicate adaptively as "technemes" inside our computers and technology (Baudrillard 1968; also called "temes" by Blackmore 2008). *Human-independent* replication is what defines technemes differently from memes, which need brains to replicate. Various theorists consider self-replication key to the emergence of adapted complexity at all scales. Eigen (1979) proposes the theory of hypercycles, Varela (1986), autopoesis, Kauffman (1993), autocatalytic sets, Sipper (1999) and many others explore replication-oriented computing (cellular automata, genetic algorithms, developmental genetic programming, artificial life, etc.) as a path to complexity.

In the universe at large, any process with predictability, macrodirectionality, and convergence, or any replicative and dissipative process with a predictable beginning, ending, and rebeginning (either demonstrated or expected) seems at least a candidate for being developmental.

- Evolutionary and Developmental Interactions and Functions: A Basic Triadic Model. Integrating these, evolutionary process comprises the variety of unpredictable and creative pathways by which statistically predictable developmental forms, stages and destinations (ends, telos) are constructed. Evolutionary process creates novel developmental architecture, but does so very *slowly*, over many developmental cycles. Evolutionary process is also *constrained* to act in ways that do not disrupt critical developmental processes or terminate the life cycle in each generation. Thus in one sense (variation of form) evolutionary process is the most fundamental, and in another (continuity of form) development is the most fundamental of these processes. The two operating together create complexity, computation, natural selection, adaptation, plasticity, and universal intelligence.

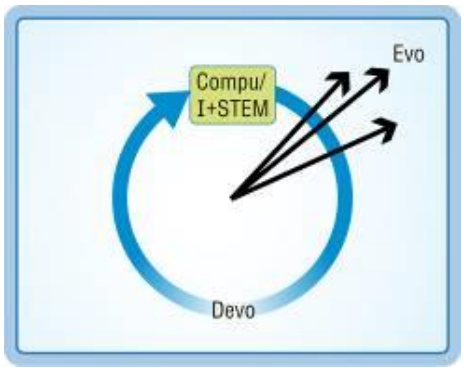


Figure 9. Cartoon of the evo compu devo triad.

Our basic evo compu devo (ECD) triad model is a universe of computation (intelligent patterns of physical STEM and relational information as adapted structure) as the central feature, with the twin processes of evolutionary and developmental process as *complementary modes* of information processing in all complex adaptive systems, including the universe as a system (Figure 9). In this model, the primary function of evolutionary process is basic or neutral *information/intelligence creation and variation*, what may be called *preadaptive* radiation, parameterization, and experimentation, *not* selection. By contrast, the primary function of development is *information/intelligence preservation* (system sustainability), which it does via *hierarchical emergence* and *intelligence transmission* to the progeny. Their interaction, evo devo, is a complex system's way of learning and engaging in natural selection, or "*meaningful" information/intelligence accumulation*, thereby adapting to and shaping its environment to the greatest extent allowable by that system's internal structure and external environment.

Figure 10 is a more detailed cartoon of this triadic ECD dynamic. Note that the ECD model proposes that *evolutionary process*, *developmental process*, and their *intersection* (evo devo, natural selection, adaptation, "evolution", intelligence) are each useful and semi-independent (partially decomposable) analytical perspectives on the dynamics of complex systems.

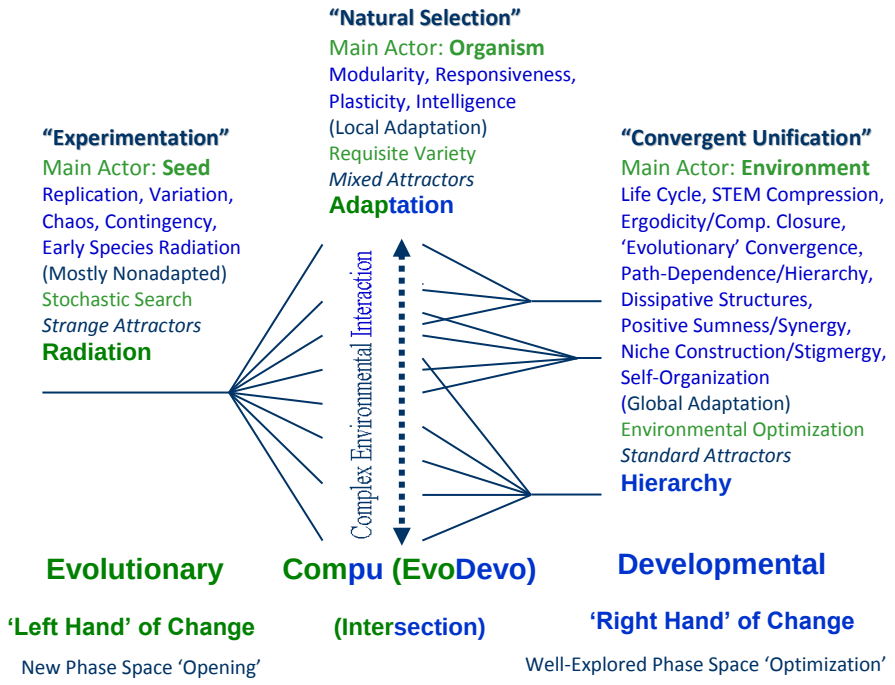


Figure 10. A more detailed cartoon of evo compu devo (ECD) triad dynamics.

Note again that the ECD model differs subtly but importantly from standard evolutionary terminology. In the traditional neo-Darwinian view, evolution is described as an adaptive process, and is equated with natural selection on phenotypes in a competitive environment (Gould 2002). So far so good, but unfortunately, neo-Darwinian evolution also alternately ignores or minimizes development (Salthe 1993; Carroll 2005). In contrast, the evo devo model defines *divergent variation* (change-creating experimentation) as the essential *evolutionary* process (see Reid 2007 for an independent version of this approach). We define natural selection (adaptation) as an *evo devo process*, a result of the *interaction* of evolutionary and developmental process, *not fully describable* by either process alone.

In summary, the ECD triad model proposes that what biologists typically call "evolution" can be usefully analyzed as *three distinct simultaneous universal processes*: evolutionary process, natural selection/ adaptation/ evo devo, and developmental process. Unfortunately most biologists today, excepting a few astrobiologists, evo-devo biologists and theoretical biologists (e.g., Morris 2004), are only willing to consider the *first two* of these three fundamental processes. Even worse, most do not make useful distinctions between the first two processes (again see Ried 2007 for an excellent exception). But perhaps the greatest shortcoming of traditional models is that the third apparently universal process (development, hierarchy, orthogenesis) has always been unwelcome in evolutionary theory. From one perspective, this is perhaps as one should expect it to be. Even the name evolution telegraphs a concern only with accidental, contingent, and selectionist processes in complex systems. Nevertheless accelerating change, replicative and dissipative systems forming intelligence hierarchies, universal replication, and other apparently universal developmental processes continue, waiting patiently for our wits to grow sharp enough to recognize them.

Fortunately, there are interesting early connections emerging between natural selection and information theory. The evo devo process of natural selection, as it "learns" which of many varieties are most fit for a niche, can be said to *create information* in at least the Shannon (1948) definition (reduction of uncertainty) (Devezas and Modelski 2003; Baum 2006; Heylighen 2007a). At the level of the ecosystem, it has also been observed that biological natural selection leads reliably to *increased variety or diversity* of extant forms over time (Gould 1977,2007, Figure 11). Others (Smith and Szathmary 1995; Kelly 2005) have proposed such additional "evolutionary" (read: evolutionary process plus natural selection) trajectories as increasing ubiquity, increasing specialization, increasing socialization, and increasing complexity of the whole ecosystem, but not necessarily of individuals or even the average organism. Innovative biological theorists (Margulis 1999, Corning 2003) are also building the case that *both competition and cooperation* must be fundamental agents of experimentation, adaptation, and hierarchy creation. As with evolutionary theory, reductionist models of competition have been much easier to describe and defend than systemic-holistic-network models of cooperation and selection for symbiosis and synergy. Fortunately in a world of growing technological connectivity and simulation capacity, this bias is beginning to change.

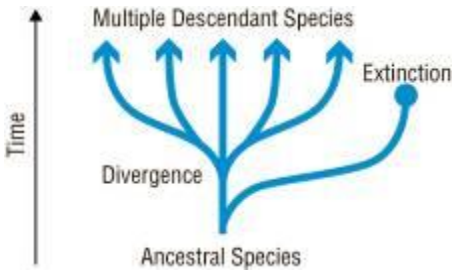


Figure 11. Adaptive radiation in evolution.

As we seek evidence for or against the triadic ECD model we would best begin by investigating a number of physical systems in which the *interplay* of experimental, unpredictable (evolutionary) processes and conservative, predictable (developmental) processes appears to have guided the emergence of *adapted* (computational) complexity. At the level of the cosmos, or fundamental physics, good candidates for creative evolutionary process are nonlinear dynamics, chaos, reversible thermodynamics, and quantum mechanics. Examples of apparently developmental physical process are irreversible thermodynamics, classical mechanics, galactic development, stellar nucleosynthesis cycles (building out the periodic table and irreversibly moving from Population III to II to I suns), and (real world) relativity, with its observed irreversible production of black holes. It has been even been proposed that classical physics emerges in a developmental manner from quantum selectionism (e.g. Blume-Kohout and Zurek 2005 and "Quantum Darwinism"). In living systems, candidates for developmental process include biogenesis (Smith and Morowitz 2006), multicellularity (Newman and Bhat 2008), and obviously, brain development (Edelman 1989 and 'Neural Darwinism'). We also can look for special developmental process within evolutionary psychology, in cultural or 'memetic' selection, in evolutionary computation and 'artificial life', in technological change—and as we shall explore soon—even in the universe itself, considered as a complex system (Smolin 1992 and "Cosmological Natural Selection"). In each of these cases we can identify locally creative and stochastic evolutionary systems that interact to produce *both* selectionist, contingent adaptation *and* predictable developmental hierarchy and trajectory.

Another core concept in evo-devo biology, and in any theory of an evo devo universe, is *modularity*, the study of how discrete adaptive biological modules (gene networks, tissues, organs, organ systems, individuals, etc.) emerge and interact in organic systems. In biology, and perhaps other complex systems, modules are defined by evo-devo theorists as adaptive systems which exist at the *interface* of evolutionary and developmental process. They strike a "critical balance" between variability and stability (Gershenson 2008), segregation and integration (Kelso 1995; Heylighen 1999), and other evo vs. devo attributes, and may be self-organized for criticality (Bak et al. 1987; Adami 1995). See Schlosser and Wagner 2004 for more on biological modularity, and Callebaut and Rasskin-Gutman 2005 for more on CAS modularity.

- The Evolutionary Development of Self-Similar Hierarchies: A Quintet of Generic Universal Hierarchies. One of the great lessons of systems research to date is that our universe has great isotropy, self-similarity and even some scale invariance across all its CAS (von Bertalanffy 1968; Oldershaw 1981,1989; Nottale

et al. 2000a,b). Replicating evolutionary, developmental, and informational-computational processes are found across 30 orders of mass-size magnitude in biology, and may have produced all non-biological universal complexity as well (Miller 1978; Jantsch 1980; Poundstone 1985; Wolfram 2002; Winiwarter 2008). Furthermore, the more evidence we find for evolutionary and developmental process at all *intra*universal systems scales, the parsimonious it becomes to assume our universe itself has self-organized its own complexity (fundamental laws, constants, boundary conditions, and emergent evolutionary mechanisms and developmental outcomes) in a manner self-similar to its major subsystems. In other words, a straightforward application of modularity, self-similarity, and quasi-organic analogies to our evo devo universe would argue that its impressive internal complexity would be most likely to have emerged via *a long chain of historical cycling of prior universes in some extrauniversal environment*, some "multiverse" or "metaverse" (Smolin 1997). We will explore this idea and some of its potential cultural and technological implications in a coming section on Cosmological Natural Selection (CNS).

In the modern science story, our universe has progressed through a small number of semi-discrete physical and informational/computational platforms, or STEM+IC "substrates" for computation and adaptation. These major substrates can be placed on a developmental specification hierarchy, as each seems likely to emerge from the former at some predictable point in time in universes of our type, each represents a major advance over its progenitor in computational complexity (modeling intelligence), and each relates to the other in a mostly *noncompetitive*, nonevolutionary fashion. Each substrate has also generated (or with astrotechnology, is proposed to soon generate) many semi-independent complex adaptive systems within it. A quintet of hierarchies that may be developmentally generic to universes of our type, and proposed examples of CAS within each hierarchy, are listed in Table 2.

Table 2. Five Apparently Universal Developmental Hierarchies and Example Complex Adaptive Systems in Each Hierarchy.

Universal Hierarchies	Example Complex Adaptive Systems
1. Astrophysics	**Universe-as-CAS, constants and laws, space-time, energy-matter**
2. Astrochemistry	**Galaxies, stars, planets, molecules in inorganic and organic chemistry**
3. Astrobiology	**Cells, organisms, populations, species, ecologies**
4. Astrosociology	**Culture, economics, law, science, engineering, etc.**
5. Astrotechnology	**Cities, engines, biology-inspired computing, postbiological 'life'**

A number of insightful systems scholars (Turchin 1977; Miller 1978; Heylighen 1999,2007b-c) have noted evolutionary processes at all five of these substrate levels. If the EDU hypothesis is correct we must also discover basic developmental processes in these substrates, processes which predictably generate hierarchy and trajectory independent of local, chaotic evolutionary variation (see Jantsch 1980; Salthe 1985,1993; Morris 1998,2004,2008 for a range of promising work of this type). As future astrobiological and information theory research must consider, the above five substrates may represent a generic quintet hierarchy of platforms for cosmic computation, a developmental series that is statistically inevitable in all universes of our type. From *stars onward* in the above list, the replicative, self-organized emergence, and thus potentially evo devo nature of each complex system is apparent from current science (e.g., stars engage in a stelliferous replication cycle, molecules engage in templated replication with variation, and social structure and technology are replicated and varied by human culture).

From *galaxies backward* (Figure 12) in the above list (e.g., the Universe-as-CAS, physical laws, matter-energy, space time, and galaxies) we cannot yet see these as evo devo CAS *unless* we propose a

replication and variation cycle for such systems which expresses *outside of our universe*, in the multiverse, as we will do shortly.

Figure 12. Infrared image of Andromeda galaxy (M31).

For the last three of these five major substrates, consider how intelligence plays increasingly important evolutionary and developmental roles in the shaping of system dynamics. One type of intelligence effect can be seen in the variety of increasingly sophisticated (simulation-guided) evolutionary experiments (unique thoughts, behaviors, products) conducted by each individual agent in a (biological, social, technological) population. Another is stigmergy (Abraham et al. 2006; Heylighen 2007a), where *individual evolutionary agents* add signs of their intelligent interactions/learning to the environment, permanently altering its selection dynamics in ways that seem *increasingly developmental with time*. A closely related topic is niche construction (Laland et al. 2000; Odling-Smee 2003), which also describes the *increasingly developmental (nonrandom, predictable, constrained) nature of biological evolution* in environments that collect signs and structures of artifactual-semiotic intelligence (from foraging trails, to termite mounds, to social rules, to city structure). Stigmergic models explain the "civilizing effect" (Elias 1978) of culture and technology development on individual (evolutionary) behavior, including such understudied long-term trends as the ever-decreasing frequency and severity of human-to-human violence relative to past average behavior (Pinker 2007). As culture and tech develop, humans as evolutionary systems are *increasingly predictably constrained* into special types of ethical social interactions (e.g., laws, codes, positive sum games) irrespective of contingent social history or geography (Johnson 1998; Wright 2000; Gintis 2005). In summary, if in coming decades we can demonstrate the ECD framework, in some variant, to be useful across the hierarchy of past universal and human complexity, it can in turn help us predict several aspects of the far future of universal intelligence.

Evo Compu Devo Triad
These three telos (goals/ values/ drives) may be universal to all complex adaptive systems. They can be observed in:

- **Physical Systems**
- **Chemical Systems**
- **Biological Systems**
- **Societal Systems**
- **Technological Systems**
- **Universe as a System**

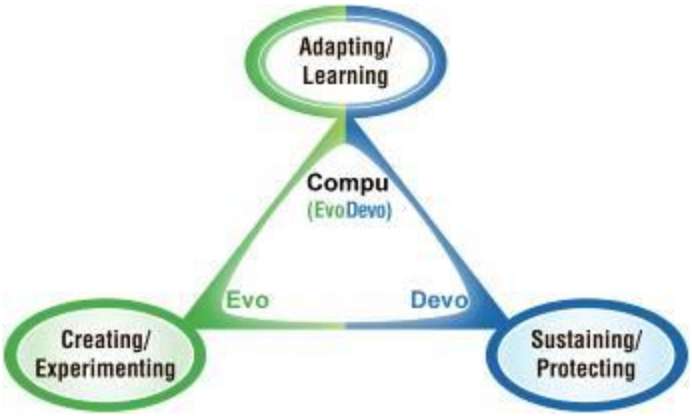


Figure 13. Evo, compu, and devo (creating, adapting, and sustaining) processes seem fundamental to all complex adaptive systems. Consequently, the *telos* (intrinsic goals/ends/values/drives) of these three processes may be *increasingly constraining* on CAS as a function of their complexity.

How so? As the Evo Compu Devo Triad proposes (Figure 13), we can analyze complex adaptive systems as: 1) Computational/ adaptive systems, keeping their evo and devo processes implicit, as 2) Evo Devo systems, making their info processing implicit, or as 3) Evo, Compu, and Devo (ECD) systems, keeping all three of these useful perspectives explicit. Using the ECD framework, we can propose that the *three most basic telos* (goals, ends, values, drives) of complex adaptive systems are *creating* (evo), *adapting* (compu), and *sustaining* (devo) system complexity. Therefore, if the ECD model is a valid framework, we may discover that these three telos act as *increasingly powerful constraints on the emergent morality of biological, societal, and technological/postbiological systems*.

In other words, if evo, compu and devo values increasingly constrain CAS dynamics as intelligence improves, and discovers itself to be an evo compu devo system, then advanced intelligent life may be expected to be *even more innovation-, adaptation-, and sustainability-oriented than human culture is*

today. Elias (1978), Wright (2000), Ridley (2010) and others would argue the history of human culture has shown such developmental macrodirectionality to date. Anthropology and sociology have documented all three telos in history, with different weightings in different cultures. From the cognitive science and natural philosophy perspective, I would suggest that these three processes may also be understood as *all unverified beliefs, including our religious beliefs* (evo), *all verified practice and science* (devo), and the *adaptive/ provisional knowledge and philosophy* (compu) that bridges them. Subsequent speculations on the future of culture and technology in this paper assume at least partial validity of the ECD model.

- Evo Devo in Creation and Control: The 95/5 Percent Rule. This EDU subhypothesis proposes that an average of 95 percent bottom-up/evo and 5 percent top-down/devo creation and control processes operate in complex adaptive systems. In other words, the vast majority (we tentatively propose an average of 95%) of the computation we use to describe and model both *creation* of a new CAS (or hierarchy) and *control* in a mature CAS (or hierarchy) will typically involve *bottom-up, local, and evolutionary* processes, with only a very minor, yet critical contribution (again, let us propose an average of 5%) coming from *top-down, systemic, developmental* processes.

Figure 14. Iceberg as metaphor for 95% bottom-up/evo and 5% top-down/devo creation and control in all evo devo complex adaptive systems.

For example, only a small percentage of organismic DNA is expressed in the "developmental toolkit" of any species (e.g., perhaps 2-3 percent of the *Dictyostelium* genome of 13,000 genes, Iranfar et al., 2003). Such developmental genes are also *highly conserved* over macrobiological time. Compare this to the "evolutionary" 97–98 percent of each species genome that recombines and varies far more frequently.

For another example, while roughly 50% of human genes are expressed at some point during complex activities like organogenesis (Yi et al. 2010), less than 10% of our genome is highly regulated organogenesis, and only 5% of our DNA is 'ultra-conserved' across complex species (eg. human, mouse, rat) (Wagman and Stephens 2004). Preliminary work has shown that this conserved DNA (both genes and noncoding regions) can no longer undergo change without terminating or seriously damaging developmental processes. It is the core set of "top down" instructions for creating the organism. I would also bet that of the 10% of our genome that is highly regulated during organogenesis, more than half of these genes are evolutionary (capable of creative, bottom-up change without deleterious effects to the organism). The rest are part of the core "developmental toolkit". They conserve and funnel biological events into critical and predictable top-down choices and processes in the emergence of modularity, hierarchy, and life cycle for the organism.

For another example, only a very small fraction of cells in a developing metazoan organ (e.g., radial glial cells in the cerebellum) have spatiotemporal destinations that are locationally prespecified (and predictable) in advance, as verified in cell tagging experiments. The *vast majority* (perhaps 95% or more) of cells in organogenesis have stochastic destinations (random, contingent "evolutionary" destinations within the scaffolding of the "developmental" cells).

The reasons for the operation of this rule are presently unclear to this author. Nevetheless, some initial speculations may be of help. First, to the extent that it is tuned to find and express hidden universal "optima", developmental process may be far more economical than evolutionary process in its use and generation of information. Perhaps also when human actors try to model evo devo systems with our reductionist science, we may initially see, describe and quantify far more of the evolutionary than the developmental processes. That may be a result of our low formal complexity, biasing us to see pieces of

evolutionary mechanism much more easily than complex holistic developmental process. Whatever the reason(s), this 95/5% rule can be roughly observed with respect to physical phase transitions (almost all molecular interaction is random, yet a critical subset of predictable interactions occur in all transitions), in DNA libraries and expression, in neural wiring, in ecology, and in variable vs invariant 'laws' (power laws, scaling laws, etc.) in cultural and technological change. In each of these and other apparent developmental transitions, we need theorists to further investigate and either prove or disprove the rule. In other words, to recall Kant's epistemic dualism (Stent 1998,2002), the vast majority '95%' of universal events may be variable and contextual 'practice', and only '5%' conserved and invariant 'principle'.

If true, the 95/5% rule may help explain why the *discovery* of universal developmental processes (predictable patterns of long-range change) has been so difficult not in physics and chemistry, where we have made great strides (e.g., mechanics, relativity, particle physics) but in higher substrates of complexity (biology, society, and technology). These substrates are both more complex and closer to our point of observation. It is particularly here that rare ('5%') predictable developmental 'signal' would be easily overwhelmed by plentiful ('95%') near-random evolutionary 'noise.' If the 95/5% rule is as generic as we suspect, it will increasingly be confirmed in future CAS and modularity research in biological and universal systems.

- Evo Devo, Life Cycle, and Intelligence: Seed, Organism, and Environment (SOE) Intelligence Partitioning. The Disposable Soma theory of aging (Kirkwood 1977,1999,2005) highlights the very different choices in energy and information flow that all organisms make with respect to their germline (seed/sperm/egg) versus their somatic (organism/body) tissues. Our "immortal" germline cells are highly repaired/sustained, but engage in little creative/ evolutionary activity, except during a *brief period* of reproduction. Cells of the organism (soma) make the exact opposite choice, putting most of their energy and information flow into creative/ evolutionary activities, and as a result being mortal and "disposable" (Figure 15). All complex adaptive systems, both living and nonliving, seem to make this tradeoff through their life cycle, having an 'immortal' (read: very slowly changing) set of developmental structures (seed, template) and a 'mortal' (rapidly changing but finite) evolutionary body. At the same time, both seed and organism extensively use historical regularities in the *environment* (the often-underestimated third actor in every complex system) to create their evolutionary and sustain their developmental intelligence. In other words, complex adaptive intelligence partitions itself into three places over its life cycle: the seed (evo), the organism (compu), and the environment (devo).

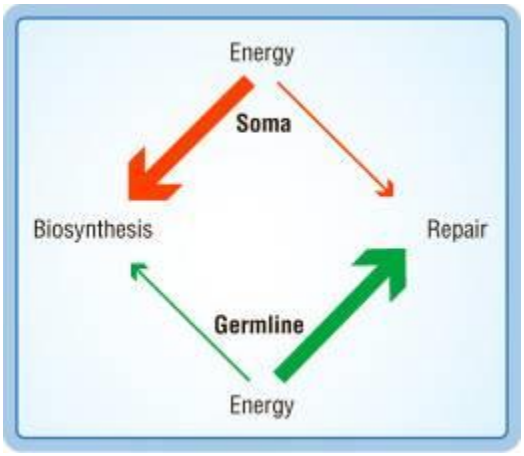


Figure 15. Somatic tissues spend their limited energy budget on biosynthesis, leaving little for repair. Germline tissues make the opposite choice (Kirkwood 1977; Tavernarakis 2007)

Note the close homology of the three SOE actors to our ECD triad. In an anthropic (intelligence-centric) evo devo universe, the seed's primary role (during formation) is to vary and explore (evolve), the organism's role is to adapt and model (evo devo), and the environment's role is to maintain conditions that ensure intelligence processes will reliably and predictably continue (develop, replicate). All three actors contain significant portions of total system complexity. In other words, only a minority of system complexity dies with the individual *organism*, or *universe*, in robust evo devo systems, as intelligence is also partitioned into the seed and the environment. Each of these systems seems likely to be accounted for as partially decomposable, partially independent actors in any future universal theory of computation.

The strategy of SOE intelligence partitioning can be demonstrated in all five major substrates in the quintet hierarchy, and thus seems likely to maximize adaptive intelligence. The *mortal organism* phase affords a brief period of particularly high levels of energy density flow, and active competition and cooperation in a naturally selective *environment*, at the cost of somatic mortality, and with learning from adaptation flowing to the *immortal seed/germline*. The individual periodically dies, but the individual's *lineage* becomes far more adaptive and environmentally dominant than it would have been otherwise. If there is a generic optimization function at work here, it seems reasonable to expect that the postbiological intelligences of tomorrow must also gravitate to an SOE partitioned structure, and thus, like us, have *mortal, disposable, constantly changing bodies*.

In the EDU framework, if our universe is an evo compu devo system, it must also be energetically and informationally partitioned between a seed ('germline') of special initial conditions/parameters and laws which replicate it, a finite universal body ('soma') that grows increasingly senescent with time, and a surrounding environment (the multiverse). An evo devo universe will have *self-organized* its present somatic complexity through many prior reproductive cycles in the multiverse. Astrophysicists know our universe has finite matter, energy, and time of origin, an ever-increasing entropy, and may now be decomposing under accelerating 'dark energy' dynamics (Krauss and Scherrer 2008). If it is developmental it must also have some *mechanism of replication*. The leading hypothesis in this area will now be explored.

- Cosmological Natural Selection (CNS): A Promising Yet Partial Evo Devo Universe Hypothesis. This hypothesis was first proposed, without the CNS name, by philosopher Quentin Smith (1990,2000) and independently proposed and simulation tested, as CNS, by theoretical physicist Lee Smolin (1992,1994,1997,2006). While speculative, it is perhaps the first viable astrophysical evo devo universe model to date. CNS was born as an attempt to explain the anthropic 'fine tuning' or 'improbable universe' problem.

  In modern particle physics and cosmology, there are a number of "fundamental" (empirically/ experimentally discovered and apparently *not* determinable by physical or mathematical theory) *universal parameters*. As far as we can test them with current cosmological models, several of these parameters appear *improbably fine tuned* for the production of physical and chemical conditions necessary for life and complexity (Leslie 1989, Rees 1999, Barrow 2002,2007). These include nineteen (at present) free parameters in the standard model of particle physics (nine particle masses, four matrix parameters for quarks, four for neutrinos, and two other constants, fine structure and strong coupling) and roughly fifteen other astrophysical constants, ratios, and relations (cosmological constant, gravitational constant, speed of light, reduced Planck's constant, Coulomb force constant, Boltzmann constant, various conservation relations, etc.).

  Duff (2002) has argued that only the dimensionless constants (currently 19 by his count) and not the dimensional ones (*c*, G, and other astrophysical constants), have the capacity be the 'cosmic genes' of our particular universe, as only the former constants are independent of choice of measure and are potentially universally valid for all observers. Yet this elegant insight does not argue that the current number of dimensionless constants must shrink to zero, into some some future 'theory of everything,' such as M-theory or string theory, as Duff and other grand unification theorists hope. Certainly some of our existing dimensional constants will disappear as theory advances, and be seen to be aggregates or emergents of other dimensionless constants, as Duff observes. Yet other dimensional constants, such as the masses and charges of our still-expanding zoo of fundamental particles, may lead us to yet more dimensionless constants as our theory advances. Also, if the EDU hypothesis is correct, we may gain a developmentalist understanding of how apparently critical and potentially universal dimensional constants, such as *c*, the speed of light, and G, the gravitational constant, emerge from their dimensionless progenitors.

Thus a critical and eventually falsifiable prediction of the EDU hypothesis is that grand unified theories in physics must be impossible. As with the genes of biological organisms, whose informational values *cannot be explained* solely from the context of that organism's internal process and structure, in the EDU hypothesis the values of our universe's fundamental constants *cannot be specified via its internal physics*, as they are proposed to be *informational inputs from a wider context*, from our universe's prior history of evolutionary experimentation and development in the multiverse. Both a multiversal framework and specific information about the multiversal environment would be needed to explain their values.

Again, it does seem likely that some of our current dimensionless universal parameters will be eliminated in the future by discovering hidden relationships between them, as occurred to a mild extent in the emergence of quantum theory in the 1930's. In this regard, as Levy-Leblond (1979) proposed, the *typical* fate of a dimensionless universal constant may be to be "forgotten altogether by a suitable redefinition of physical units" as physical theory progresses. On the other hand, we have seen a large increase in *new dimensionless parameters* introduced via the particle physics of the last half-century, and we can reasonably expect several more such constants to be added in coming years, as there are even-higher-energy levels of unprobed physical structure and function still inaccessible to physical experiment. In fact, high-energy physics, which has delivered most of these new constants, may be directly analogous to 'gene probing' in the biological sciences, a process destined to deliver several more 'genes' before our map of the cosmic genome is complete. As final additional support of this conjecture we can note that there are numerous cosmic phenomena we still do not understand particularly well (e.g., theory of hadrons, dark matter and dark energy (or gravitation), black hole physics, etc.). My bet would be that the fundamental constants will continue to grow in coming years.

Particle physicist Victor Stenger (2000) is a leading advocate of the idea that universal fine tuning (anthropic coincidences) can be explained by entirely "natural" circumstances. His central argument is that certain physical laws, such as the laws of conservation of energy and linear and angular momentum, derive directly from space-time symmetries in our universe, while other forces, particles, and structures appear to have emerged via 'random' symmetry breaking events in historical space-time. Yet his position is fully consistent with a cycling evo devo universe model. The dimensionality of and mathematical type of universe we inhabit, out of all logically possible types (Tegmark 2008), must *determine* its initial symmetries, and be central, along with multiversal constancies, to its constraining developmental architecture. Contingent symmetry breaking events within this universe would also be central to its evolutionary history, in the EDU model. Yet if symmetry breaking is an evolutionary developmental process and the EDU hypothesis is correct, *the large majority (perhaps 95%) of* symmetry breaking events can be random, but not all events. Both environmental (multiversal) constancy and the necessity of developmental structure must predetermine the persistence and emergence of a critical subset of universal parameters, particles and structures, both uniformly across this particular universe, and over the life cycle of all universes of our type. The EDU hypothesis would seem to require that symmetry breaking can't all be random, another testable feature of the hypothesis.

In sum, if there are a significant number of fundamental constants underlying our universe, then instead of a future "theory of everything," a single equation in M-theory or string theory describing universal relations which might fit on a T-shirt (Weinberg 1993), the best we can ever expect to uncover will be a "theory of special things," an economical but still ungainly set of *numerous* fundamental equations and constants that determine our special, complex, and biofelicitous (Davies 2004,2007) universe.

Like the developmental genes of living organisms, an economical but still ungainly set of fundamental informational parameters which *interact with the environment* to create organismic form in complex and still-poorly-understood ways, developmental physical parameters may interact with the multiversal

environment to dictate many basic features of our universe, such as its lifespan, hierarchical structure, hospitability to internal complexity, and ability to produce black holes.

CNS proposes that the special values of our universal parameters are the result of an evolutionary selection process involving universe adaptation in the multiverse, and universe reproduction *via black holes*. Beginning in the 1980's theorists in quantum gravity began postulating that our universe might 'give birth' to new universes via fluctuations in spacetime over very short distances (Baum 1983; Strominger 1984; Hawking 1987,1988,1993; Coleman 1988). Some (Hawking 1987; Frolov 1989) proposed that new universe creation might be particularly likely at the central 'singularity' inside black holes. The singularity is a region where our equations of relativity fail to hold, depicting energy and space at improbably 'infinite' densities. In Smolin's model, what occurs there is a "bounce" that produces a new daughter universe in another region of 'hyperspace,' one with fundamental parameters that are *stochastically different* from the parent universe.

See Susskind 2005 (string theory), Randall 2005 (M-theory) and Smolin 2001 (loop quantum gravity) for some competing proposals that our universe's space-time continuum is but a subset of a higher dimensional hyperspace. Any of these (and other) multiversal proposals could be consistent with an evo devo universe, as long as they were not formulated as a theory of everything, eliminating the constants. McCabe (2006) states that loop quantum gravity "now appears to support Smolin's hypothesis" of a bounce at the center of black holes forming new universes (see also Ashtekar 2006). CNS is parsimoniously self-similar to organic complexity development, as it mandates a type of *reproduction with inheritance for universes*, which become an extended, branching chain exploring a "phenospace" of potential somatic forms within the multiverse (Figure 16).

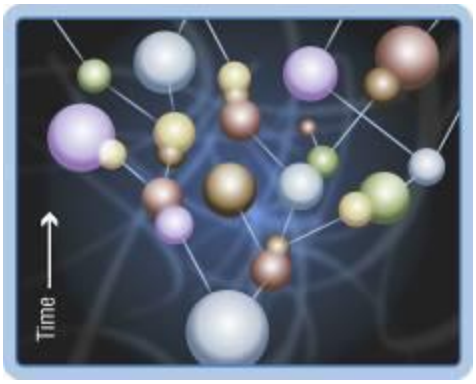


Figure 16. 'Baby universes.' Exploring universal phenospace on a phylogenetic tree, with a low branching rate and frequent terminal branching in this cartoon (Adapted from Linde 1994).

Smolin's theory began as an attempt to explore the fine tuning problem via an alternative landscape theory to string theory, one that might prove more readily falsifiable, given its black hole predictions. By the mid-1990's his team had been able to sensitivity test, via simple mathematical simulations, eight of approximately twenty (by his count) fundamental universal parameters (Smolin 1992,1994,1997). In such tests to date, our present universe appears to be fine tuned both for long-lived universes capable of generating complex life and for the production of hundreds of trillions of black holes, or for 'fecundity' of black hole production. If our particular complex universe has self-organized and adapted on top of a broad base of much more plentiful, much simpler universes, just as human intelligence could emerge only on a base of vastly more plentiful simpler replicating organic forms (e.g., prokaryotic life), then *fecundity* of black hole production should be validated by theory and observation, in any internally complex evo devo universe.

Another promising aspect of CNS, also increasingly testable by simulation, is that changes in the parameter values ("genes") of our evo devo universe may provide results analogous to changes geneticists can induce in the genes of evo-devo biological organisms. In biology we can now differentiate between developmental genes (a very small fraction of the typical genome, controlling the development of the organism) and evolutionary genes (a majority of the remaining genes, more involved in regulation in a developed organism and phenotype variation in a population). Developmental genes are *highly conserved* from species to species, and any change in them is almost always either deleterious or catastrophic, particularly in more complex organisms, which have much more "downstream" developed complexity to protect. We can define evolutionary genes, by contrast, as those that can undergo much more change, as

they have few effects on *internal* processes of development but many effects on the variety of unique phenotypes, which are in turn subject to *external* natural selection. Evolutionary variants will usually also turn out to be deleterious to adaptation, but that is a *different process of selection* (external/evo, not internal/devo selection) with typically milder and more slowly manifesting effects, on average.

Applying this analogy we find that some fundamental parameters of physics, what we may call "developmental parameters," appear *very sensitively tuned* to sustain our universe's internal complexity, with small changes being catastrophic to complexity emergence in such universes (the fine tuning problem). By contrast, others appear more robust to producing minor phenotypic variants of the universe when their values are changed by small amounts. Those in turn might be called "evolutionary parameters," and the developmentally viable, evolutionarily variant universes they produce would be expected to undergo some form of external selection in the multiverse. With respect to developmental parameters, *only very rarely* should changes in them lead to potentially more adaptive features in phenospace, such as replication fecundity or internal complexity. Large random changes in such parameters should virtually never have such result (Vaas 1998). With respect to evolutionary parameters, other tests, comparable to those seen in evolutionary variation in biological systems, should be increasingly accessible to simulation.

Looking a few decades or generations ahead, a robust future evo devo simulation science should allow us to construct a *limited phylogenetic tree* (record of likely evolutionary changes in developmental systems), and of *universal systematics* (hierarchical classification of likely universe species, based on recent evolutionary ancestry) for at least the set of possible universes *nearest* to our particular universe in phenospace. We are now learning to build such models in evo-devo biology (Figure 17), with the great advantage of having not one, but many extant biological forms available to analyze, with all of apparently common descent.

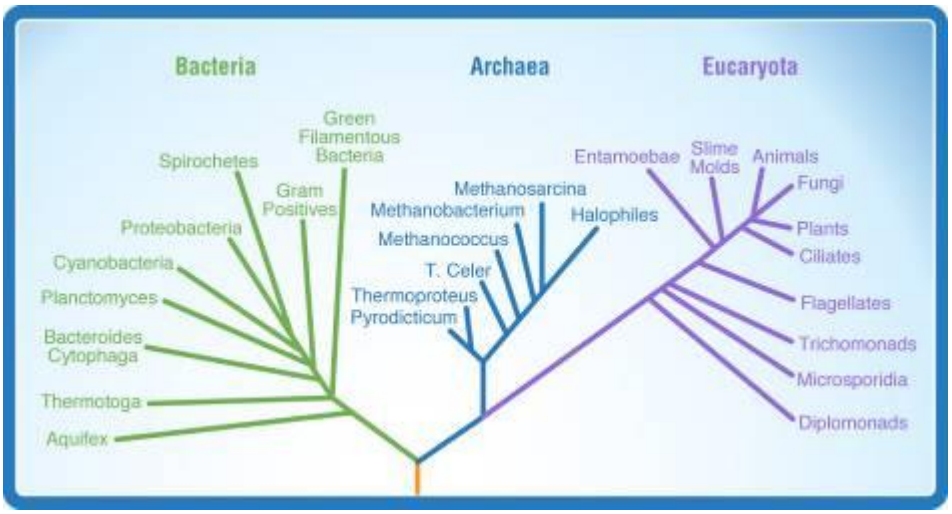


Figure 17. Phylogenetic tree in evo-devo biology.

Unfortunately phylogenetic evo devo universe models are simply not possible in current simulation science. Vaas notes that simulating small variations not only in universal parameters, as in Smolin's present scheme, but also in universal laws, and simulating how such laws emerge, perhaps via both (developmental) symmetry constraints and (evolutionary) symmetry breaking, is presently "beyond any possibility of scientific investigation." Accelerating developments in evo-devo biology, cosmology and computation may one day deliver such possibility, however.

To recap, Smolin's CNS hypothesis proposes that our universe's developmental constants are fine tuned for the fecund replication of complex universes via black holes. The developmental singularity hypothesis (to come), proposes that our universe's developmental constants are fine tuned for the replication of universes like ours via *intelligent* black holes, an even more specific and falsifiable claim. Fortunately we can expect such hypotheses to be supported or invalidated by better knowledge of the existing known constants (whose measurement accuracy presently improves tenfold every 15 years, according to Flowers

and Petley 2004), by discovery of additional fundamental constants and relationships (improvement of physical theory), and by inputting these results into tomorrow's far more powerful simulation systems.

While Smolin's CNS is a promising and clarifying theory, one of its shortcomings is that it provides *no role for systemic intelligence influencing the replication cycle*, as occurs at least in all the higher replicators here on Earth. The class of CNS models where emergent intelligence plays some functional role in replication can be called 'CNS-I' (CNS with Intelligence). We will now consider a few CNS-I models that have been proposed to date, and suggest another, 'evo devo CNS-I,' below and in the DS hypothesis to come.

- Evo Devo Cosmological Natural Selection with Intelligence (Evo Devo CNS-I). Strictly speaking, Smolin's CNS and other mildly-related work (King 1978,2001; Nambu 1985) can be considered partial, or 'gene-centric' models of CNS-I, as they allow the self-organization of 'genes' (unique fundamental universe-specifying parameters) that can in turn develop increasingly intelligent universes, even those with conscious observers. Where this work stops short is in considering how "postgenetic" intelligence must also grow in strength as the universe body unfolds, and would be expected to nonrandomly influence cosmological natural selection and replication, just as we see postgenetic intelligence (eg, cultural and technological intelligence) nonrandomly influence CAS replication here on Earth. Models that address this oversight may be called true CNS-I (Crane 1994; Harrison 1995,1998; Gardner 2000,2003,2005,2007; Smart 2000,2002,2008; Balázs 2002; McCabe 2006; Vidal 2008a,2008b), and will now be discussed.

  In a brave and pioneering paper, the late cosmologist Edward Harrison (1995; and critique: Byl 1996) argued that the "ultimate aim in the evolution of intelligence [e.g., the purpose of universal evolutionary and developmental processes] is conceivably the creation of universes that nurture intelligence." As the first peer-reviewed publication on the full CNS-I hypothesis, Harrison originated several evo devo universe ideas. He argued that 'random variations' in Smolin's CNS scheme may have generated the first 'low level' universal intelligence in a manner analogous to biogenesis on Earth. He also proposed that just like life's trajectory in Earth's environment, intelligent, computation-rich universes might come to dominate universe ensembles, *if internally-developed intelligence can usefully (nonrandomly) aid in universe reproduction and adaptation*. As early evidence for the latter he noted that speculative theoretical schemes for universe creation already exist in astrophysics (e.g., Farhi and Guth 1987).

  In a series of articles and books beginning in 2000, complexity theorist James Gardner has further developed and evaluated Harrison's hypothesis. In *Biocosm* (2003), Gardner proposed the selfish biocosm hypothesis, which portrays the universe as a self-organizing self-improving, replication-driven system, in which 'highly-evolved' internal intelligence plays a key role in future universe reproduction. As the most extensive thesis on CNS-I to date, *Biocosm* is a must read for evo devo scholars. At the same time, we propose that the EDU and DS hypotheses (Smart 2000 and this paper), as alternative CNS-I proposals, can further develop and constrain Gardner's valuable insights. In particular, three important points of difference between the EDU model and Gardner's model should now be mentioned.

  First, while Gardner champions Smolin's model of the black hole as a *replicator* in low-level CNS, he does not explore the many attributes that make black hole environments an ideal *attractor* for higher universal intelligence. The latter concept seems central to an evo devo theory of CNS-I, as it connects the developmental trajectory of all higher intrauniversal intelligence with Smolin's reproductive mechanism, and makes quantifiable near-term predictions with respect to developmental trends in Earth's intelligence, as we will do in our discussion of STEM compression shortly.

  Second, Gardner does not elevate universal development to the same level of importance as universal experimentation in his current analysis, which leads to a universe model that is *less constrained and*

predictable than one would expect if universal developmental dynamics broadly apply. As one example, Gardner proposes (2003) that a single cycling universe may be as likely as a branching system of universes under the selfish biocosm hypothesis. An evo devo CNS-I model, by contrast, would predict the necessity of a branching tree of self-organizing complexity underlying our universe, and *an abundance of very simple proto-universes* coexisting in the multiverse with a *comparatively tiny number of complex universes* such as ours, just as abundance of existing replicating bacteria are an evo devo prerequisite to the existence of a comparatively tiny number of replicating humans on Earth. In other words, in an evo devo CNS-I universe, detectable black holes should form an *ecology*, with a distribution of reproductive complexity that has some homology to Earth's ecologies. Our universe must also be tuned to *fecundity* but never a 'maximum' of black hole production (Gardner proposes the latter), since the application of energy and information to reproductive vs. somatic activities always has a cost-benefit tradeoff in evo-devo biology (Kirkwood 1977; Miller 1978).

Third, and most curiously, Gardner proposes some form of prior intelligent life is likely to have "created," "designed," or "architected" our universe, and that humanity's postbiological descendants may one day become "cosmic engineers" of the next universe(s). Others have made this suspiciously anthropomorphic claim as well (Farhi and Guth 1987; Frolov 1989; Harrison 1995), but in any theory of evo devo CNS-I, we should expect such creative influence to be *greatly limited* by the inherited constraints of the existing universal developmental cycle. Reflect on your knowledge of evo-devo biology, and consider how very little "control" (innovation, change) evolutionary intelligence ever has over developmental processes *within any single replication cycle*. It is true humans have significant rational control over technological design at present, for example, but we *must not forget that technology is not yet its own autonomous substrate*. So our semi-rational, top-down control over it doesn't count as any kind of evidence that evolutionary intelligence can somehow escape developmental constraints as it advances. If we think, for example, that biological humans will be able to maintain engineering control over tomorrow's postbiological life forms (much less daughter universes) the evidence does not support this. In every autonomous evo devo complex adaptive system (CAS) inside our universe, from molecules to man, we observe only minor, marginal evolutionary influence on and improvement of the system in each developmental cycle, regardless of complexity of the substrate. This is likely because evolutionary intelligences can never have full knowledge of the implications of any experimental changes they make to evo devo systems in advance, and too much change in developmental architecture always disrupts system survival. As a result, and as evo-devo biology broadly demonstrates, evolutionary experimentation *changes the nature* of developmental systems *very little* in each cycle.

This latter point addresses the critical question of whether end-of-universe intelligences in an evo devo universe could ever become *"gods"* or *"god-like beings*," omniscient or omnipotent entities able to engage in true creation, design, or engineering of universes, or whether they would merely be *distant natural ancestors* with evo compu devo constraints, mortality, and motivations surprisingly similar to us.

As the IPU hypothesis proposes, such natural intelligences could never be omniscient or omnipotent, but would instead always be *computationally incomplete* (Gödel 1934). Consider the evolution-like phenomenon of free will, our own ability to choose but never fully predict the consequences of our choice, even in what may be an almost entirely deterministic universe at scales relevant to human life (Stent 2002). Free will must perennially exist in all CAS, such as they have intelligence, because evo devo intelligence is always built, in large part, out of *stochastic evolutionary systems* of which that intelligence can have only *limited* self-understanding, predictive capacity, and control. So it is also likely to be with any end-of-universe intelligence, as we will discuss in the DS hypothesis to come.

Furthermore, as the EDU hypothesis proposes, physical intelligences apparently partition themselves across three systemic forms as *seed, organism, and environment* (SOE partitioning). Thus the bodies

(organisms) of all physical systems, end-of-universe entities included, must always be *mortal* and developmentally fated to become *increasingly senescent* with time (Salthe 1993), just like the universe they reside in. The evo compu devo telos, in turn, would argue that all end-of-universe intelligences must have their own unproven (evolutionary) *beliefs*, adaptive (computational) *practical knowledge and philosophy*, and proven (developmental) *science*. Such intelligences must emerge, as we did, inside a system whose basic structure they *can only mildly influence in any cycle* (evo), *cannot fully understand* (compu), and *did not create* (devo). They would also be very likely to be simpler and more limited than our own universe-influencing progeny will be. Not gods, but *ancestors*, whose intelligence we can hope to one day equal and exceed, multiverse willing.

In the EDU framework, the classical religious conception of God as an omnipotent, omniscient, supernatural entity, becomes a hypothesis we "do not need" (Pierre Laplace, in De Morgan 1872). As Bateson (1972) argues, the concept of a *supernatural God*, as opposed to belief in a limited higher intelligence embedded in natural systems, is equivalent to belief in a mind that is free, separate, and unaccountable to body, to relationships in the natural world. Such "pathologies of epistemology" may lead, among other things, to living unaware of and out of balance with one's social and physical environment. In an evo compu devo universe, intelligence *self-organizes* over many evolutionary developmental cycles, using SOE partitioning, with higher intelligence using belief-based, philosophical, and scientific (evo, compu, and devo) models that incrementally improve themselves. In this framework our theology becomes restricted to unproven (presently poorly evidenced but still subjectively useful) beliefs regarding natural universal process, a hypothesis known as philosophical or scientific naturalism. This is not a theology of pantheism "God is all" but of naturalism "nature/universe is all." All this assumes that science has advanced to a point where a self-organizing, evo devo paradigm can well explain most of our internal universal complexity, which today it cannot. Yet to this author, the EDU hypothesis seems the most parsimonious of explanations presently available.

With respect to the expected physical features of an evo devo universe, note that the use of black holes as "genetic" intelligence transmission systems in CNS provides a powerful functional rationale for the emergence of a *relativistic universe*. Note also that quantum cosmology and the quantum mechanism of the black hole bounce each provide functional rationales for the emergence of a *quantum mechanical* universe. But what evo devo rationale might there be for the emergence of a *mathematically simple universe*, exhibiting such "unreasonably effective" and simple approximations as f =ma and $E=mc^2$ (Wigner 1960)? Such underlying simplicities may primarily be due to the assumedly mathematically simple and symmetric physical origins of *any* cycling universe. However there might also be an internal selection mechanism or weak anthropic principle requiring or preserving such simplicities, as they allow intrauniversal intelligence development (universal pattern recognition and STEM manipulation) to be a *strongly nonzero sum game* (Wright 1997,2000). Mathematically elegant universes seem particularly robust to rapid internal intelligence development. Must all evo devo universes start this way and does the lineage grow more or less mathematically elegant with time? Inquiring minds would like to know.

Now recall that seed, organism, and environment (SOE) intelligence partitioning predicts that postbiological intelligence may not transfer its learned information into a new universe, except through germline (seed) structure and the informational constancies of the multiverse (environment). In other words, it seems an inviolable constraint that continually self-aware organismic intelligence cannot enter the next universe, except in its potential (seed plus environment) form. If it could, we should expect to see evidence of ancestor intelligence far and wide in our present cosmos, long before our own emergence.

This begs the question of whether any form of *one-way communication* might be possible or desirable between intelligences in successive universes. As we will consider in our discussion of the Fermi paradox to come, one-way messages are occasionally useful for developmental control, but always constrain

evolutionary creativity. In an evo devo universe, it seems the only strategies beneficial to producing further universal complexity would be to attempt small evolutionary improvements in the structure of the seed, and incremental modifications to the multiversal environment. If there were a way to encode and send any message in the *body* of the universe itself (e.g, some obvious message of intelligence, such as a highly nonrandom sequence of numbers buried deep in the transcendental number *Pi*, as occurs in Sagan's novel *Contact*, 1997), we may expect several unfortunate consequences. First, the discovery of such a "designed" message by all descendant intelligences would *homogenize their remaining evolutionary searches for universal meaning, while giving the false impression of a designed (architected, engineered, or "God-controlled"), and not an evo devo universe*, thus reducing the computational variety of that universe and its successors. Second, the creation of such a message would constrain universal developmental structure to message-delivering, not evo devo priorities, again reducing the complexity of successor universes.

Note however that the EDU hypothesis *does* seem to allow ancestor intelligence to leave one-way messages *outside our universe*, in the special structure of the *multiversal environment*, as a form of niche construction. Thus we may very well find evidence of prior cosmic intelligence only when we grow sharp enough to *leave our universe entirely*, a topic we will discuss in the DS hypothesis to come.

EDU Hypothesis: Processes of Universal Development

Wherever we find tentative evidence for universal development, we find constraints that may apply to all emergent cultural and technological intelligences. So far, we have considered an evo compu devo telos, hierarchical stage progression, the 95/5% rule, SOE intelligence partitioning, CNS and CNS-I as potentially constraining aspects of an evo devo universe. There are a number of other potentially predictable (with the right empirical and theoretical tools) and irreversible (on average) perspectives on universal developmental process that we may propose. Recall our long list of developmental attributes in Table 1. Let us now more carefully explore just three that seem particularly important to understanding the DS hypothesis to come: *STEM compression*, *differentiation*, and *ergodicity*.

- Universal Development as STEM Compression of Information and Computation (IC) in Dissipative Structures. One of the most curious and apparently developmental processes in our universe is that it seems to be hierarchically constructing special zones of local intelligence (computational complexity, modeling capacity, meaningful information) which are measurably and predictably more space, time, energy and matter (STEM) dense, meaning increasingly *localized* in space, *accelerated* in time, and *dense* in energy and matter flows, and STEM efficient (in space, time, energy, and matter resources used per standardized unit of information, computation, or physical transformation), relative to parent structures.

  Taken together, the twin accelerating STEM density and STEM efficiency trends may be called *STEM compression* of information, computation and/or physical transformation in universal development (Smart 1999,2000,2002b, and referred to as MEST compression in my older literature). To better understand this curiously accelerating universal phenomenon, let us briefly survey these twin trends (STEM density and STEM efficiency) from the partially separable perspectives of space, time, energy, and matter.

  Space Compression. Perhaps the most obvious universal developmental trend of these four is space compression or *locality*, the increasingly local (smaller, restricted) spatial zones within which the leading edge of complex adaptive change has historically emerged in the hierarchical development of universal complexity. In other words, each major developmental transition in the quintet hierarchy has involved a *sharply increasing spatial locality* of the system environment (Smart 2000). For example, the leading edge of structural complexity in our universe has apparently transitioned from universally distributed early matter, to galaxies, to replicating stars within galaxies, to solar systems in galactic habitable zones, to life

on special planets in those zones, to higher life within the surface biomass, to cities, and soon, to intelligent technology, which will be a vastly more local subset of Earth's city space. Alternatively, when we consider the Earth itself as a single universal system of (roughly) fixed size, we see another profound type of space compression due to near-instantaneous global digital networks, sensors, effectors, memory, and computation (Broderick 1997; Kurzweil 1999), and an end of geography (Harvey 1989; O'Brien 1992) or death of distance (Cairncross 1998). Space compression is a real developmental trend. It constrains future human cultural variation in ways we do not yet fully appreciate.

On a deeper and more speculative note, consider how even gravity, which has helped organize all of the transitions just listed, is actually not a force in real terms, but as relativity tells us, a process of *space compression* around massive objects. Thus gravity itself seems to be a basic driver (an integral aspect) of universal computational development, as we discuss in the DS hypothesis to come.

Time Compression. We see time compression in the increasingly rapid succession of key events in hierarchical complexity emergence over the last six billion years of our universe's lifespan. First Adams (1909), and later, Carl Sagan popularized this acceleration pattern, the latter in the metaphor of the Cosmic Calendar (1977). Meyer (1947,54) and occasional successors (Von Foerster 1960; Coren (1998); Nottale et al. 2000a, Johansen and Sornette 2001) have built preliminary quantitative models of acceleration in the history of life and human culture. Kurzweil (2005) cites fifteen such models, in an attempt to demonstrate that though the event selection *process* in each case must be subjective, the observed acceleration *pattern* is apparently not. Fortunately, as described in my Brief History of Intellectual Discussion of Accelerating Change (Smart 1999-2008), while time compression as an apparent universal developmental process remains ignored by mainstream science, continual social acceleration has been described by prescient cultural, technological, and economics scholars including Adams (1909), Marinetti (1916), Dewey (1927), Fuller (1938,1979,1981), Halévy (1948), Feynman (1959), McLuhan (1964), Good (1965), Toynbee (1966), Toffler (1970), Piel (1972), Moravec (1979), Platt (1981), Vinge (1983,1993), Virilio (1986), Grou (1987), Harvey (1989), Kurzweil (1990,1999,2005), Gleick (2000), Eriksen (2001), Scheuerman (2004,2009), and Rosa (2009,2010).

How time compressed is the postbiological intelligence substrate likely to be, relative to human culture? Consider the *10 millionfold* difference between the speed of biological thought (roughly 150 km/hr chemical diffusion in and between neurons) and the speed of electronic "thought" (speed-of-light electron flow). The scalar distance between *Phi*-measured learning rates (a topic we will explain shortly) of modern technological society (perhaps 10^7 ergs/s/g) and tomorrow's autonomous computers (perhaps 10^{12} ergs/s/g), is roughly the same as the difference between modern society and plants (Figures 18 and 19).

Figure 18. Plants, modern human society, and tomorrow's AIs appear to have roughly equivalent scalar 'distance' between their intrinsic learning rates.

In other words, to self-aware postbiological systems, the dynamics of human thought and culture may be so slow and static by comparison that we will appear *as immobilized in space and time as the plant world appears to the human psyche*. All of our learning, yearning, thinking, feeling, all our desires to merge with

our electronic extensions, or to indignantly pull their plugs, must forever move *at plantlike pace* relative to postbiological intelligences.

Furthermore, such intelligences are far less computationally restricted, with their near-perfect memories, ability to create variants of themselves, reintegrate at will, and think, learn, experiment in virtual space, and share in physical space at the universal speed limit, the speed of light. To be sure, as evo devo systems they must also be bound by developmental cycling and death, but for such systems death comes as archiving or erasure of poorly adapted intelligence architectures and redundant or harmful information, or the death-by-transformation seen in any continually growing system. We can expect that such processes will be far less informationally destructive and subjectively violent than the death we face as biological organisms.

We may be dismayed by such comparisons, yet such leaps in the critical rates of change for new substrates are apparently built into the developmental physics of our universe. More than anything else, these leaps define the *one-way, accelerating, and developmental nature* of the universe's leading evolutionary computational processes over the long term. Discovering such preexistent paths for computational acceleration and efficiency seems the developmental destiny of universal intelligence, though the creative evolutionary paths taken to such destiny are never predictable, and each path adds its own unique value.

Energy Compression. In fascinating and clarifying work, astrophysicist Eric Chaisson (2001) has calculated that the energy flows used (harvested, degraded) by complex adaptive systems can be placed on an apparent developmental emergence hierarchy, from galaxies to human societies and beyond, with the recency and complexity of system emergence both the function of an energy dissipation variable called *Phi*, and with the hierarchy charting a universal J-curve (Figure 19).

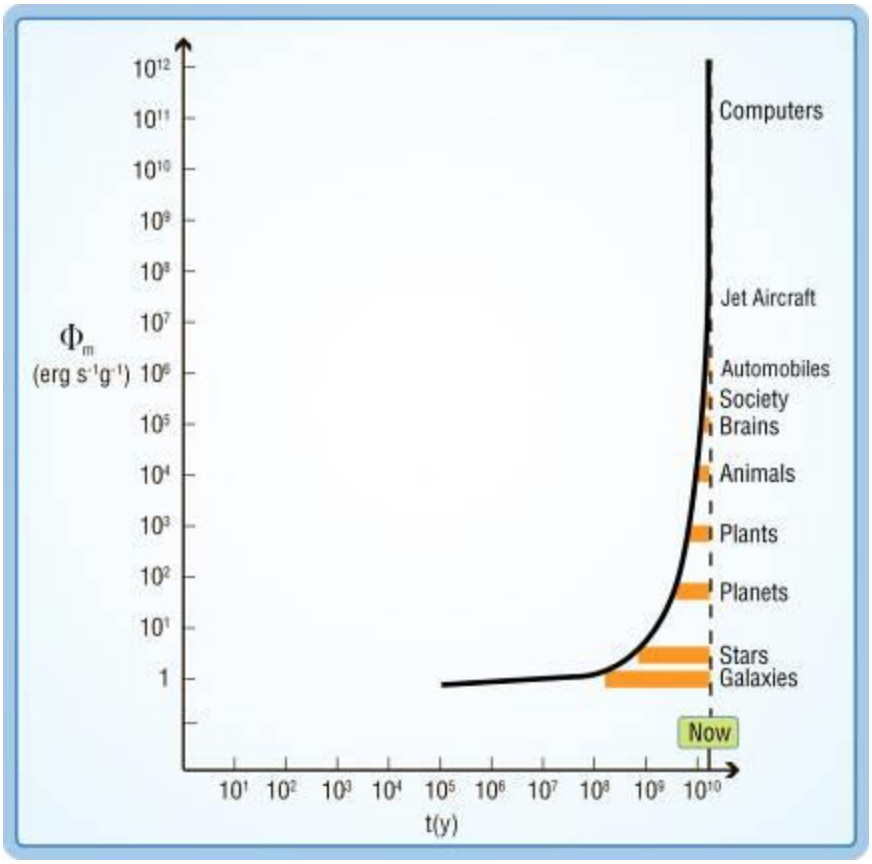


Figure 19. Free energy rate density (*Phi*) values in emergent hierarchical CAS. When the accelerating curve of dissipation rate begins in an expanding early universe is not yet clear. We draw *Phi* beginning at matter condensation (10^5 yrs) to the present. (Adapted from Chaisson 2001).

Table 3. *Phi* in Complex Adaptive Systems (Chaisson 2001).

Phi (ergs/sec/g)	Complex Adaptive System
10^{11}	**Pentium II** of the 1990's
10^{10}	**Intel 8080** of the 1970's
10^{5} to 10^{8}	**Modern engines**
$5x10^{5}$	**Society** (Modern culture)
$1.5x10^{5}$	**Brains** (Human cranium)
$2x10^{4}$	**Animals** (Human body)
900	**Plants** (Biosphere)
75	**Planets** (Early Earth)
2	**Stars** (Sun)
0.5	**Galaxies** (Milky Way)

Phi measures free energy used per second per mass (ergs/sec/gm) of the system being described. Free energy is the energy available to build structural, adaptive complexity (von Bertalanffy 1932; Schrödinger 1944). Thermodynamic theorists Nicolis and Prigogine (1977) famously called all complex energy-using systems "dissipative structures," and considered them the central story of universal complexification. According to Chaisson (2003), *Phi* can be considered a measure not of structural complexity but of *dynamic complexity*, or what we might call the *maximum marginal learning capacity* of the dissipative system in question (specifically, when it is in the growth stage of its life cycle). Many theorists (e.g. Kleidon 2004; Kleidon and Lorenz 2005) have attempted to make a connection between thermodynamics and what Salthe (1993) calls "infodynamics," or informational content, learning, or complexity in physical systems. Such work has great intuitive appeal, but remains unpredictive at present, in our era of underdeveloped universal information theory.

Table 3 lists Chaisson's (2001) estimates for *Phi* (free energy rate density, in units of ergs/sec/g) for a set of semi-hierarchical complex systems. Note the most recent systems, our electronic computers, have roughly *seven orders of magnitude (ten millionfold) greater free energy rate density* than human culture. Such data, preliminary as it is, gives very early evidence that postbiological systems represent the next step in a universal *developmental learning hierarchy* for dissipative complex adaptive systems. Aunger (2007) has recently extended Chaisson's work, analyzing each accelerating system emergence as a metastable state, relative to the prior system, in universal nonequilibrium thermodynamics.

It may seem unbelievable that our own Sun has two orders of magnitude less *Phi* (2) than a houseplant (900). But remember *Phi* measures not total energy output, but energy rate density. Far more free energy flows through the *same volume or mass* of a houseplant, per time, than through the equivalent volume or mass of our Sun. Though it uses a more primal form of energy production, nuclear fusion, a Sun is both *a far "fluffier" or less energy dense system, and a far simpler object* in terms of both complexity increase per time, and complexity per mass or volume, than a houseplant, which also uses quantum-level processes, but uses those processes in *far more sophisticated* ways. To rephrase Chaisson's view, a system's *level of complexity* is in essence its ability to channel matter and energy, per volume, per time, for both system metabolism and system computation, learning, and adaptation (evo and devo) activities.

While Chaisson's curve is impressive, what I find nearly as amazing is how pervasively we presently ignore curves of this type—in a class that our small nonprofit, the Acceleration Studies Foundation, calls *acceleration studies.* Insightful works on accelerating change, such as Gerard Piel's *The Acceleration of History* (1972), or Richard Coren's *The Evolutionary Trajectory* (1998) are rare, and remain of marginal interest to modern science. As more data and hypothetical frameworks, like this paper, become available, we can only hope that acceleration studies will one day become a mainstream topic of research. Note that Chaisson includes both *autonomous and nonautonomous* CAS in this list. Planets are dependent on stellar supernovas for replication within galaxies, and computers are (presently) dependent on human society for replication on Earth. To the extent that both evolutionary variation and developmental replication (life cycle) are fundamental to all dissipative CAS, this would imply that the lowest-*Phi* CAS in this figure, galaxies, are likely to replicate as *dependents on their universe* in the multiverse.

Finally, note that Figure 19 appears *effectively asymptotic* today. Something very curious seems to be going on. When considered on an astronomical scale, universal time has effectively stopped here on Earth, with respect to Phi emergence rates. *Some universally important—not just globally important—developmental transition appears to lie almost immediately ahead of us.* Wherever postbiological intelligence emerges, dynamic learning/adaptation becomes effectively instantaneous, from the universe's perspective. Extrapolating to the future, we can expect fully autonomous computers to have *Phi* values of *at least* 10^{12}, seven orders of magnitude greater than human society (10^5). Even today, our global set of electronic computing systems, while presently far from our level of structural complexity, are learning about the universe, encoding knowledge from their human-aided, quasi-evolutionary searches, 10 millionfold faster than human society, albeit still in narrow ways and only for intermittent periods.

However, if tomorrow's best commercial computers will increasingly improve themselves (self-provision, self-repair, self-evolve, self-develop), as many designers expect they must, they will be able to exploit their greatly superior learning rate on a *general and continuous basis*, escaping the present need for human manufacturers and consumers in each upgrade cycle. This also assumes that quasi-organic, self-improving computers can be *selected for stability, productivity, and deep symbiosis with humanity*, just as our domestic animals have been intelligently selected for human compatibility over at least the last 10,000 years (5,000 breeding cycles). Both today's domestic dogs and tomorrow's domestic robots are systems whose detailed brain structures will be a mystery to us, even as we increasingly depend on them. If in turn evolutionary experimentation by computers in ultrafast *digital simulation space* becomes a useful proxy for experimentation in slow physical space (an intuitive argument that deserves careful investigation) we can begin to understand how ten-millionfold-accelerated computers might *recapitulate* our 500 million years of metazoan evolutionary developmental learning in as short a period as 50 years. We'll speculate more on the implications of technological acceleration in the DS hypothesis to come.

Matter Compression. This may be the hardest of the four STEM compression processes to visualize, at first glance. Consider first the astounding growth in matter efficiency and density of computation that produced, in our universe's chemical substrate, *biological cells* on Earth. Early life and pre-life forms must have been far less genomically and cellularly (e.g., materially) efficient and dense. DNA folding and unfolding regimes in every eukaryotic (vs. prokaryotic) cell are an astounding marvel of material compression (efficiency and density of genetic computation) which we are only now beginning to unravel. Consider also the material density and efficiency of social computation (increasing human biological and material flow efficiency and density) in a *modern city*, vs. nomadic pretechnologic humans. Note the matter compression (increasing matter efficiency and growing material density) in our *digital computing machinery*, in Moore's and a large family of related "laws" in electronic computing, and in emerging nanotechnology, optical, quantum and now single electron transistor devices. Consider next how the gravitationally-driven process of matter compression creates *nuclear fusion* in a star, the most powerful and ubiquitous universal energy source known. Consider the extreme matter compression involved in the *black hole*-forming process that made our *initial cosmic singularity*, if the CNS hypothesis is correct. Such a STEM-dense fate lies ahead in our local future if the DS hypothesis (to come) is correct.

Integrating Space, Time, Matter, and Energy processes, let us briefly consider a brain, a social organization, and a planet to see if we can identify STEM density and efficiency growth in each as they progress through their life cycle. Human brains, as they learn any algorithm, must increase synaptic connectivity (greater material, spatial, and temporal density at the circuit and protein complex level) and this allows them much greater energy efficiency per learned algorithm. As social organizations, we use languages and artifacts to communicate, compete and cooperate. Our languages grow increasingly information dense on the social level (social vocabulary grows in complexity, in level of abstraction, speed of communication increases), and our artifacts and social networks grow greatly in complexity and density (we move from villages with simple tools to modern cities with advanced automation). Efficiency

also accelerates (technical productivity per worker grows exponentially, at 2-9%/year in most countries today, cities are much more STEM efficient than villages at providing almost any type of social good, etc.). Considering the long-term, postbiological future of our planet, we can envision megacities of "living" computational machinery, carpeting Earth like a technological neocortex, with robotic sensors and effectors ranging throughout the solar system. This would be global brain of vastly greater STEM density and efficiency of computation than anything that presently exists, and a community of entitites that fully absorbs and exceeds our biological humanity. As we will discuss in the DS hypothesis to come, such an entity, as its density grows, may seem increasingly like a black hole to external observers.
When we consider computation from a universal perspective, we can also observe ever-decreasing *binding energies* employed by complex systems at the leading edge of evo devo computation. As Table 4 shows (after Laszlo 1987), each successively emergent substrate (computational system) in the quintet hierarchy uses greatly decreased binding energies to create and process information via its physical structure.

Table 4. Qualitative Binding Energies for Universal Hierarchies of Complex Systems (adapted from Laszlo 1987)

Univ. Hierarchy	Comp. System	Binding Energy of System
Physics	Matter	Nuclear exchange (near-irresistible 'strong forces')
Chem	Molecules	Ionic and covalent bonds (powerful electromagnetic (EM) forces)
Bio	Macromols/Cells	Peptide bonds, cell adhesion molecules (weaker EM forces)
Socio	Brains	Synaptic weighting, neural arborization (even weaker EM forces)
Tech	Computers	FET-gated electron flow, single electron transistors (yet weaker EM forces)
Post-Tech	Black holes?	Gravitons? (weakest of currently known binding forces)

Presumably this allows far greater energy (and space, time, and matter) efficiency of computation.

Energy (and space, time, and matter) density and efficiency trends may also be quantified through the framework of Adrian Bejan (2000) and his constructal law, which proposes that for any finite-size system to persist in time (to live), "it must evolve [and develop] in such a way that it provides ever-easier access to the imposed currents that flow through it." Constructal theory, a type of operations research, seeks to describe developmental limits on evolutionary action in nature, describing "imperfectly optimal" conditions for animate and inanimate flow systems, and championing both the emergence of and boundaries to all fractal (self-similar) hierarchies in physical systems.

If they are to be validated, STEM compression models need to be made much more quantifiable and predictive across the substrate levels. Many fascinating trends or "laws" highlighting some component of STEM efficiency or density have been described for biology or human culture (see Lotka 1922; Zipf 1948; Vermiej 1987; Winiwarter and Cempel 1992 for a few), but hypotheses of STEM compression (both STEM efficiency and density acceleration) as a universal developmental process for leading edge complex systems seem to be missing to date. Perhaps the first historical example is Buckminster Fuller's (1938,1979,1981) concept of ephemeralization (STEM efficiency) or "the [universal intelligence efficiency] principle of doing ever more with ever less weight, time and energy per each given level of functional performance." Fuller also noted some spatial and time density trends in human culture, but he did not consider STEM density to be a universal developmental vector for complex systems. Likewise, Harvey's (1989) concept of time-space compression (ST efficiency and density) is a particularly broad physical insight, though it is presented from an obscure postmodernist perspective.

Fortunately the energy density work of Chaisson (2001), Kleidon and Lorenz (2005), Aunger (2007) and other scholars in the energetics of complexity is presented in universal and developmental terms. We also find a powerful update to Fuller's perspective in systems theorist Ray Kurzweil, who proposes a "law of accelerating returns" (1999,2005), which describes the evolution of universal intelligence as increasing both the resource efficiency and time density of computation and productivity (while leaving space,

energy, and matter density of dominant computing systems undiscussed). Most recently, Seth Lloyd champions space, time, energy, and matter density increase in his proposal that the "ultimate" universal computer is a black hole (2000a,2000b), but even Lloyd presently stops short of proposing STEM density as a developmental attractor for universal intelligence. We will make this specific proposal in the DS hypothesis to come.

- Universal Development as Differentiation and Terminal Differentiation (aka Cosmogonic Philosophy). In biological development, differentiation is often the first process that comes to mind. All organic development begins from a totipotent, stem-cell-like zygote, capable of taking *many* adaptive paths, then the replicating cells move through a series of irreversible, branching differentiation steps of steadily decreasing velocity, and the system ends in an array of "terminally differentiated" and functionally highly specialized tissues (Figure 20). This process involves both random (what we are calling "evolutionary") dispersion (at the molecular scale) and developmental integration (at the system scale) of the differentiated tissues into their local environments. Nerve cells are arguably the most differentiated of metazoan cell types, as they have specialized to carry high-level environmental information in their synapses, and so lose, on average, even the ability to replace themselves as they age (neural stem cells do not appreciably change this picture). Differentiation as a process is a *stepwise loss of flexibility*, the steep price paid for a short phase of increasing *adaptive complexity* in the mature developed organism. Only in the germline cells is totipotency and immortality maintained, but even here flexibility is *frozen* in the process of seed creation, and only returns on the later sprouting of the seed.

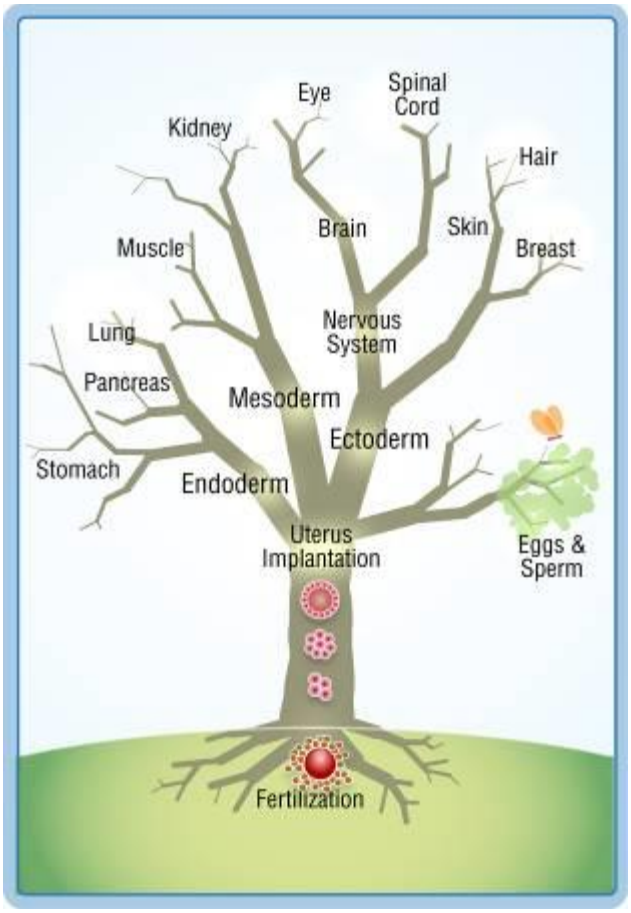


Figure 20. Tree of embryonic development. Terminal differentiation of cell, tissue type and organ production (excepting eggs and sperm).

When we think of *universal development*, from the Big Bang seed to the mature universe body, we must expect to find the same sobering process of increasing differentiation and eventually *terminal differentiation* at every computational substrate level, whether it be physics, chemistry, biology, culture, or technology. At each level the "tree of evolution" will branch continually, delivering ever-greater diversity of forms with time, but as this is *also* a "tree of differentiation" (development), the *feebleness of branching* must eventually get progressively more noticeable as well. Eventually every evo devo "tree" reaches the *maximum height* allowed for its particular substrate in morphospace or functionspace. Increasingly ergodic recombination (revisiting the same forms) still continues in the lower branches, but as a tool for evolutionary innovation (finding new phase space), the substrate is now exhausted. It has become terminally differentiated. To better understand it, let us consider a few examples of terminal differentiation in action.

At the astrophysical/chemical substrate level, we can clearly see terminal differentiation in the creation of chemical elements. The production of elements useful for new complexity construction was exhausted by

cycling supernovae *many billennia ago* (Figure 21). Elements in dark grey require high energy and exotic conditions to form, are highly unstable, and have little utility to the further growth of chemical complexity. Note that the elements necessary for the next leap in the quintet hierarchy, an organic chemistry capable of *biogenesis* on special planets, are made mostly in the first half of elemental phase space (the periodic table) as explored by replicating stellar nucleosynthesis, long before terminal differentiation of elemental innovation occurs. This seems a rather efficient system for universal hierarchy development.

In biology on Earth, we also see terminal differentiation at *every level* of the taxa, from kingdoms to species. Diversity continues to go up in the "leading edge" modules of the tree (eg, species), but the *rate* of diversity innovation is drastically reduced at all levels, and has stopped entirely at all the older, lower levels. There have been no new *kingdoms* for billennia, and the production of *metazoan body plans* stopped entirely in the Cambrian, 550 million years ago (Müller and Newman 2003).

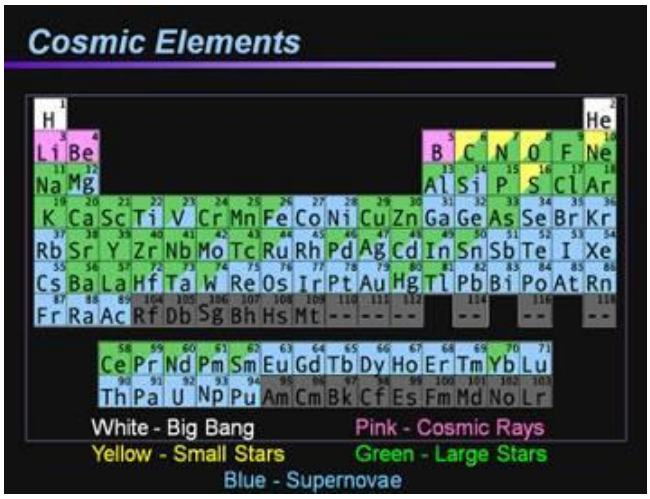


Figure 21. New element creation is increasingly terminally differentiated over time (NASA/Lochner & Kinnison 2003)

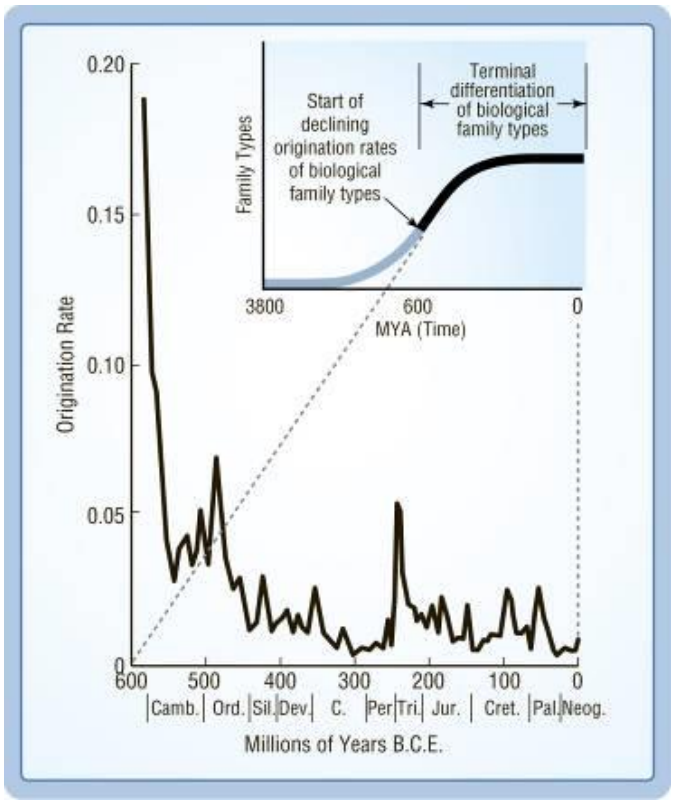


Figure 22. Rate of origination of marine animal families (new families divided by extant families) over time. High rates of origination occur initially and then after major extinction episodes. Small spikes after Early Late Cretaceous and Early Cenozoic extinctions are associated with the attainment of hitherto unsurpassed levels of global familial diversity. In other words, the global evolutionary tree has grown larger than ever, but its marginal branching is now feebler than ever (adapted from Vermiej (1987) and Van Valen and Maiorana (1985)).

The revealing Figure 22, adapted from Vermiej (1987) shows that marine animal families (a taxonomic rank presently easier to document than species) have experienced *rapidly declining rates of origination* since the Cambrian. We see in this data that biology always maintains some creative capacity in reserve, with catastrophe (major extinctions) periodically reinvigorating the system. Nevertheless, note here how family innovation as an evo devo process has *progressively exhausted itself over time*, just like our periodic table, only in a more gradual manner, occurring in a more complex adaptive substrate. We can also observe terminal differentiation in ecosystems, where any long-mature ecology becomes "senescent" (Ulanowicz 1997) brittle and less innovative (unable to host a changing set of species), and thus susceptible to death, disease, fire, succession, or other ecological renewal process.

So while absolute species numbers on Earth are today larger than ever, the branching rates at the end of the evolutionary tree, the average new species generation rates, independent of periodic extinction and origination epochs) and the marginal percentage of novel morphologies and functional specializations introduced into

the ecospace by genetic variation is lower than ever. Astonishingly, though this remains underappreciated by contemporary evolutionary biologists, biological morphocomplexity on Earth is exhausting itself.

In other words, the tree of biological developmental differentiation on our planet has nearly reached its maximum height. Since the leading edge of computational change on Earth has been *cultural* evo devo for at least the last two million years, when *Homo habilis* picked up the first stone, increasingly terminal differentiation of biological evo devo systems is perhaps to be expected. Yet the *mechanisms* controlling the timing and location of terminal differentiation in biological morphospace and function space remain far from clear. Are there generic relations between the growth curves in hierarchy development? Must the one substrate begin to terminally differentiate (growth saturate) before the next can emerge?

Turning next to the genetic dimension of human cultural variation, we find that even brain-expressed genes in humans appear to follow a terminal differentiation dynamic. Such genes evolve slowly in mammals, but even more slowly in the more complex mammals, like chimps and humans. As Wang et al. (2006) Bakewell et al. (2007) and others report, *evolutionary change in human brain-expressed genes has slowed down both in absolute terms and relative to chimpanzees* since our split from them six million years ago. I have proposed (Smart 2001) that once hominid brains became vessels for external rapidly-improving gestural, linguistic, tool-using, and other socially-constructed semiotics, algorithms and grammars, perhaps two million years ago with *H. erectus*, all change in brain genes was increasingly restricted to propagating this exploding new social information base, in an increasingly standardized set of synaptic networks, such as our specialized brain regions for acquiring and using language (Deacon 1997).

Human brains thenceforth became functionally specialized to be *carriers and variers* of "memes," culturally-transmissible symbols, ideas, behaviors, and algorithms (Dawkins 1976; Blackmore 1999; Aunger 2000) which are no longer recorded mainly in unique gene networks, but rather in unique synaptic connections. *Memetic*, not genetic evo devo thus became the leading edge of local computational change. From that point forward major brain changes would be expected to increasingly create *antagonistic plieotropies* (negative effects on legacy systems), and autistic or otherwise socially dysfunctional humans. Our neural phenotype at that point became increasingly *canalized* (stable to small random changes) around an evolutionary cul-de-sac of initially randomly discovered, meme-propagating architectures. In other words, terminally differentiated. Fortunately the rapidly moving research in this area should validate or falsify this terminal differentiation hypothesis in coming years.

Finally, with the advent of digital electronic computers, the leading edge of evo devo change now seems on the verge of jumping from biological culture to our more ethereal and resource-efficient information technology. As computers accelerate all around us, we see global human population saturating (Wattenberg 2005) but still not fast enough (Hardin 1995), and for the first time in human history, we face truly global environmental and resource constraints of our own making (Worldwatch 2008). Some scholars even see signs of emerging *memetic* terminal differentiation in human culture. While the size of the tree of cultural innovation will undoubtedly continue to grow, there may already be a sharply *declining fraction* of truly innovative vs. derivative and repetitive *human-initiated and understood* cultural knowledge, products and behaviors (Stent 1969; Lasch 1991; Barzun 2001; Smart 2005; Jacoby 2008). At the same time, *technology-initiated and embedded knowledge* continues to accelerate, and is *increasingly inaccessible* to the average biological mind. Yet the astrotechnological substrate is only at the beginning of its own "S-curve" of evo devo, having not yet even achieved autonomy from its biological creators.

Generalizing from a similar set of observations, the great American philosopher Charles S. Peirce (1935) proposed a "cosmogonic philosophy" in which the long term evolutionary development of life and intelligence in our universe must cause it to gradually lose its spontaneous character (reach the top of its S-curve) in *any* substrate. In Peirce's model, life everywhere seeks to totally order (as far as it can) and

reduce the flexibility of an initially fecund universal chaos. Translating this insight to EDU terms, we can say that the *more historical variation* any computational system has engaged in, on average, the more ways it may become constrained to follow whatever *final developmental trajectory* exists for that particular system. Salthe (1981,1985,1993) also holds this perspective in his discussion of predictable, progressive and irreversible "universal senescence."

Certainly accelerating development of higher, more intelligent levels of the universal hierarchy must periodically open up new evolutionary innovation options, yet *acceleration cannot continue forever* in a universe of finite physical resources and dimensions. As physical substrates, both a coming technological singularity and a developmental singularity (to be discussed) would presumably, after *ever briefer periods* of fantastic new innovation, each be subject to terminal differentiation and increasing computational and behavioral constraints, the closer they approach *either* the senescent structures of a mature universe (body), or the time-frozen germline structures of a mature seed, waiting for its reproduction.

- Universal Development as Ergodicity (aka Computational Closure). Random walks vs. ergodic walks in statistical processes may be one of the best *mathematical* ways to discriminate evolutionary from developmental processes, as the former stays perennially unpredictable and the latter converges to an average predictability. In a random walk, such as stock prices under normal conditions, observed events will stay random or stochastic no matter how you sample them (Malkiel 2007). By contrast, an ergodic walk is a sampling process whose average over time converges to the population average. To do this, the population as an entity must adequately sample the entire phase space (behavior, phenomena, or state space presently available to the system), within a representative timeframe. Furthermore, the phase space must not be rapidly or unpredictably growing (new behaviors becoming possible) relative to the existing phase space. In other words, ergodicity requires the emergence of a computationally closed map (or at least a saturated or very slow-growing map) of the phase space of possible behaviors for a system, and an appropriate sampling technique. In ergodic systems, when you sample an appropriate subset of individuals, over an appropriate length of time, you get a model that allows you to predict up from the sample to the collective and down from the collective ("ensemble") to sample behavior (Tarko 2005).

  Ergodicity seems a key precondition to irreversibility, directionality, and hierarchy in information and development theory. It may be only when a system becomes ergodic, which may be the same as saying terminal differentiation is emerging in that particular morphospace and function space, that one can make probabilistically predictive inferences about the system's behavior. In relation to human foresight, this means that *inaccurate generalizations, poor predictions, and flawed models of the future may all be a result of the non-ergodicity (the robust evolutionary creativity) of most ensembles, most of the time.*

  For example, predicting our own future cultural variations is particularly difficult, as the phase space of culture historically has grown rapidly and chaotically *relative to us*, and as the sampling is typically done by individual, narrowly intelligent humans. But as global tech intelligence continues to accelerate, and as human culture terminally differentiates, much developmental ergodicity may emerge. We may soon see a "total simulation society" (Brigis 2004) in which collective intelligence, transparency, quantification and simulation of human behavior will allow emerging technological intelligence to deliver increasingly accurate models of human culture. One example of effective, sample-based trends in cultural prediction is the rise of quantitative marketing and public relations. Others are models that reliably forecast *value shifts* in countries as a function of their social, technical, and economic development (e.g. Inglehart and Welzel 2005), or that predict national wealth or poverty as a substantial function of cultural values (Landes 1999).

  Note that we are arguing here for science and intelligent technology's ability to increasingly predict the past and future of *human and earlier* systems, both being simpler and presumably more ergodic (closed) substrates. In an evo devo universe, an AI's ability to predict *its own* evolutionary future (as opposed to its

increasingly-clearer developmental future) should remain as persistently intractable to the AI as humanity's ability to predict its own social innovation future is to us, today.

To close our discussion of ergodicity, let us briefly survey a few ways humans have used *evolutionary* intelligence processes to generate increasingly closed, ergodic maps, allowing predictable, directional and 'optimized' *developmental* features to then emerge:

- The salient features of Earth's surface, a sphere of fixed area, are a particularly obvious eventually ergodic system. Once cartographers had our first good maps (Figure 23), many aspects of terrestrial exploration "lost their novelty" and predictable, optimized trade routes emerged.

Figure 23. First good maps of Earth.

- Human evolutionary psychology, emotions and morality have many ergodic features, as they represent gene-internalized, contextually optimized knowledge accumulated over millions of years, in increasingly insulated (niche constructed) environments, resulting in predictable group social behaviors (Wright 1997).
- Many aspects of human sociology, culture, and art have become ergodic because human nature changes so slowly, and the number of ways to please and offend human psychology are actually *limited*. Art forms such as classical music, which began to greatly decelerate in rates of evolutionary creativity even in the late 1800's, thus become ergodic as there are limited ways to play the notes of the chromatic scale in a manner aesthetically satisfying to (equally ergodic) human psychology. In such cases only the opening of new phase space (a culture acquiring new creative or psychological capacity, or a genre's recombination with another genre) can reintroduce novelty and unpredictability.
- Many branches of mathematics (eg, number theory) and science have entered long periods of ergodicity, where new learning ceased to emerge, and have only been reinvigorated (usually only for brief periods) when new computational or investigational methods become available (Horgan 1996).
- Even our maps of astronomical events are rapidly headed toward computational closure, as Martin Harwit (1981) argues (Figure 24). Harwit's estimate predicts the total unique phenomena in a set based on the repetitiveness of phenomena in the current sample. Such techniques (Fisher et al. 1943) are valid for a broad range of (ergodic) physical ensembles. Just as there are a limited number of existing species on Earth (an ensemble now predicted to be between four million and six million), there are a limited and much smaller number of unique astronomical phenomena to be discovered in the future, either by a variety (multimodal) or by only one (unimodal) observational method. Given our accelerating discovery rate and the much smaller phase space (compared to biology) for *much simpler* astrophysical evo devo systems, Harwit's model predicts terminal differentiation of novelty in observable outer space phenomena very soon in cosmic time, as early as *2200 CE* in his estimate.

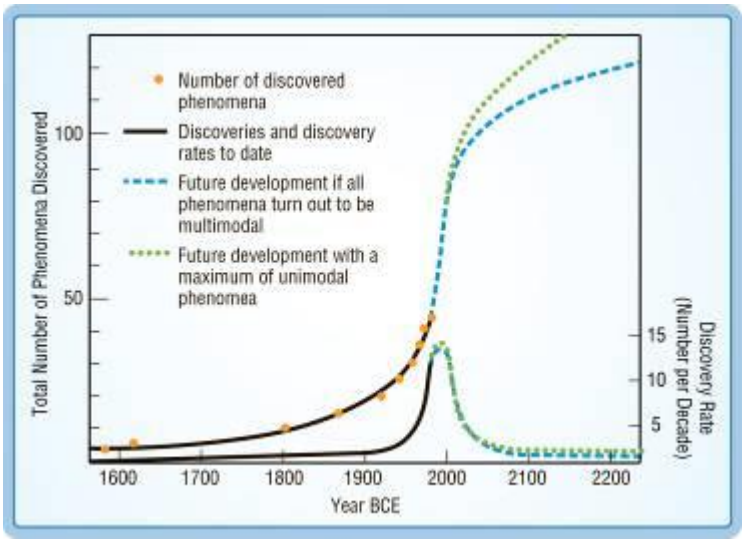


Figure 24. Astronomical discoveries & discovery rate, projected forward (Harwit 1981).

Such insights reveal the increasingly *information poor* nature of "outer space" (the universal environment) as development proceeds in any substrate, and suggest that local intelligence will be driven progressively into *"inner space,"* into zones of ever greater STEM compression and simulation capacity, in our accelerating evolutionary search for novel, valuable information. We will explore this speculation further in the DS hypothesis, next.

EDU Hypothesis: Closing Thoughts

The EDU hypothesis is a "just so" story, a self-selected and suspicious fantasy that must be held at arms length until it can be more objectively evaluated. It has parsimony of sorts and intuitive appeal to (at least some) purpose-seeking, biological minds. We present it in a long tradition of Goethe (1790), Schelling (1800), Chambers (1844), Darwin (1859,1871), Spencer (1864,1874,1896), Lotze (1879), Haeckel (1899), Newcomb (1903), Bergson (1910), Wallace (1912), Henderson (1913,1917), Alexander (1916), Whitehead (1925,1927,1933), Vernadsky (1926,1945), Shapley (1930), Teilhard (1945,1955), du Noüy (1947), Wiener (1961); Aurobindo (1963); Miller (1978), Murchie (1978), de Rosnay (1979,2000), Jantsch (1980), Fabel (1981,2004), Cairns-Smith (1982,1985), Hoyle (1983), Dodson (1984), Salthe (1985,1993), Varela (1986); Winiwarter (1986,1999,2008); Lewin (1988); Stenger (1990,2000); Wesson (1991); Smolin (1992,1997), Heylighen (1993), Kauffman (1993, 1995); Stock (1993), de Duve (1995), Bloom (2000), Stewart (2000), Gardner (2000,2007), Allott (2001), Balázs (2002), Morris (2004,2008), Primack and Abrams (2006) and other philosophers of science who suspect a naturalistically teleological (directional, progressive, and partly purposeful) universe that uses natural selection as an integral process, but not the only process in its successive self-improvement.

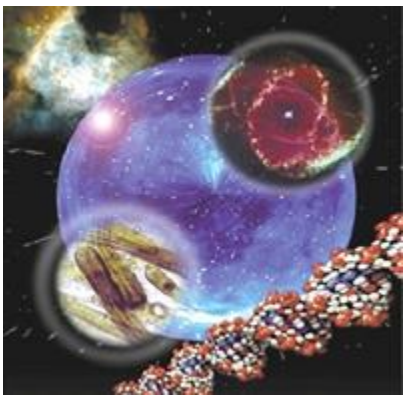


Figure 25. Astrobiology. A uniquely transdisciplinary science.

Fortunately, as the evo-devo biology community continues to grow in size, research corpus, and legitimacy, it will increasingly be able to inform and test EDU models. Besides theoretical evo-devo biologists, information theorists, and philosophers, major contributors to and critics of EDU-related models will be the anthropic cosmologists (Barrow et al. 2006; Leslie 1989,1998, Rees 1999,2001, Davies 1987,2007, etc.), complexity theorists (Gardner 2003,2007; Smith and Morowitz 2006), and astrobiologists (Figure 25; Ward and Brownlee 2000; Lunine 2004; Ulmschneider 2006; Horneck and Rettberg 2007).

Let us close our EDU speculations with the realization that there is something deeply organic and developmental-looking about our cosmic web, the apparent large-scale structure of our universe (Figure 26; Gnedin 2005; Springel 2006) with its patterns of filaments, nets, and voids driven by accelerating aggregations of dark matter. Both random and directional processes seem simultaneously at work.

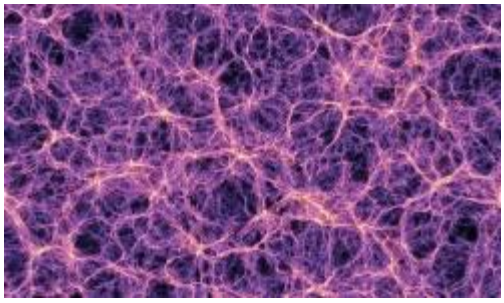


Figure 26. Cosmic web. Millennium Run simulation (Gnedin 2005).

Until sufficiently predictive models of universal development can be brought to bear, EDU concepts must remain speculative systems theory and philosophy of science. We now turn to an even more speculative model, the DS hypothesis, which nevertheless holds promise for predictive verification or falsification reasonably soon, as it has even more specific things to say about the constraints on and future developmental trajectory of cosmic intelligence.

3. The Developmental Singularity (DS) Hypothesis

How likely is it that Earth's local intelligence, as it continues to evolve and develop, will transcend the universe, rather than expand inside of it? Are highly dense, highly localized astronomical objects (black holes and objects which approximate them) computationally privileged platforms for universal intelligence, selection, and reproduction? Might all higher intelligence in our universe be developmentally destined for transcension, and could this explain the Fermi Paradox in way that is testable by future science and SETI?

Our first hypothesis considered the universe as a system of *information, physics, and computation*. Our second considered the universe as a *quasi-organic* and *hierarchically developing* (evo devo) complex system. Our final hypothesis considers the *life cycle* and *communication constraints* of such a system, and makes falsifiable predictions for the developmental future of universal intelligence.

The Developmental Singularity (DS) hypothesis will now be presented in brief. It includes the following claims and subhypotheses:

- The IPU and EDU hypotheses, in some variation, and:

- The Developmental Singularity (aka Inner Space, anti-Kardashev, Transcension) Hypothesis: An Asymptotic Mechanism for Universe Simulation and Reproduction. Due to the universal developmental trend of STEM compression (accelerating STEM efficiency and density of higher intelligence), Earth's local intelligence will apparently very soon in astronomical time develop *black-hole-analogous features*, a highly local, dense, and maximally computationally efficient form that we may call a developmental singularity (DS) (Smart 2000). The DS seems to be a natural progression of the technological singularity (highly STEM efficient and dense autonomous postbiological intelligence) that is likely to emerge on Earth in coming generations.

  In the EDU hypothesis, we proposed that our universe improves itself via evolutionary processes occurring within a finite, cycling developmental framework. This framework requires universal structural (body) aging and death, the emergence of internal reproductive intelligence, natural selection on that intelligence, and new universe (seed) production in an evo devo life cycle.

  In the DS hypothesis, we propose that Earth's local intelligence is on the way to forming a black-hole-analogous reproductive system, and then new seed formation via developmental (germline) processes to produce another universe within the multiverse. As all the substrates of our quintet hierarchy appear both evolutionary and developmental, it is likely that our local DS intelligence will also engage in natural selection (competitive and cooperative merger and recombination) with other evolutionarily unique universal intelligences *prior* to universe reproduction. Finally, this reproduction may occur via a special subset of physics (Smolin 1997) found only in the quantum domains of black holes.

  Perhaps the simplest way to understand and critique the DS hypothesis is via the following seven-assertion outline. The summary of the first four assertions is provided courtesy of my colleague Clement Vidal:

  1. Energy=matter (Einstein's $e=mc^2$).
  2. Space-Time is curved by Energy-Matter density (far more by density than by total E-M in fact).
  3. STEM density and efficiency of computation/metabolism grow exponentially or faster at the leading edge of universal intelligence development (STEM compression hypothesis).

4. This gives ever-greater space-time curvature in the most complex environments, and at the limit, a black hole emerges.
5. In standard relativity, black holes are near-instantaneous one-way information collection (to the hole, almost exclusively) and time travel (to the future only) devices. Even in our dark energy universe, black holes merge nearly instantaneously, from their unique time-dilated reference frame, with all other black holes in their local gravity wells. For us, this is Andromeda and Milky Way Galaxies, which begin to merge in 20 billion years (our time) but near-instantaneously in black hole time (Nagamine and Loeb 2003). All matter in each gravity well may end up inside merged black holes (Lehners et. al. 2009).
6. If Smolin's CNS is true, then the physics of black hole singularities allows for universal replication. If the most advanced universal intelligences can exist either inside or at the edge of black holes, they will thus nearly-instantaneously merge, compete, cooperate, and compare their unique, locally developed models prior to the next replication event, adding multi-level selection dynamics and great new diversity to the process of cosmological evolution and development.
7. In an evolutionary developmental CNS universe under black hole transcension physics, advanced intelligences should develop highly effective ethical and physical constraints against sending out one-way broadcasts or probes prior to transcension, as this would greatly reduce the evolutionary variety of their later mergers. This provides a testable explanation of the Fermi paradox, as we will discuss. For this to be provably true we would have to develop a predictive information theory of ethics in complex systems, in the same way that we have a number of predictive physical theories of STEM processes. We are likely many years away from such a capacity, though the powerful civilizing effect of complexity on human nature to date (Elias 1978) provides early evidence for this.

Note that of the first four assertions most critical to contemplating the hypothesis, it is only Assertion 3, the STEM compression hypothesis, that is not widely known by researchers today, perhaps because the data supporting this have not yet been widely collected, validated, or critiqued, and funds for this kind of work have not yet materialized. Nevertheless, the process seems intuitively obvious to any who might look. For early data on exponential or superexponential STEM density trends at the leading edge of universal complexity development, see Chaisson (2003) on energy flow density. For data on exponential or superexponential growth in STEM efficiency, see Richards and Shaw (2004) on accelerating efficiency per instruction in digital electronic computing technology.

The DS hypothesis is just one of several possible models of evo devo CNS-I. It assigns a potential evolutionary role in universe reproduction for all successfully-developing cultural intelligences in the cosmos. The DS hypothesis argues that local intelligence, should it continue to successfully develop, will *leave our visible cosmos very soon in universal time.* Nevertheless, due to the greatly accelerated nature of postbiological intelligence, this will also represent a *very long period in subjective (perceived, conscious, computational) time* prior to universal transcension.

Colloquially, the process of DS creation may be summarized as an irreversible developmental trajectory for universal intelligence from outer space to *inner space*, to zones of ever greater STEM density, STEM efficiency, and self-awareness/simulation capacity. Alternatively, this may also be called a Transcension Hypothesis (intelligence becoming increasingly local and *leaving* the visible universe over time, in order to meet other intelligences and/or partially reshape *future* universes) as opposed to an Expansion Hypothesis (intelligence expanding throughout and reshaping the *current* universe over time).

Intelligence expansion is by far the standard perspective contemplated by those who presently consider the future of astrosociology and astrotechnology. It is in fact so dominant that it is generally *assumed* to be true without question. Generalizing from the STEM compression trend, the DS hypothesis proposes that

expansion is 180 degrees out of phase with the true vector of universal intelligence development. Futurists frequently refer to the Kardashev scale, which proposes that growth in the amount and spatial scale of energy use (planet, sun, then galaxy) is an appropriate metric for future levels of civilization development. Cosmologist John Barrow (1998) has proposed an anti-Kardashev scale, where the appropriate metric is not total energy use, but the miniaturization of a civilization's engineering. The DS hypothesis proposes STEM density and STEM efficiency of our physical and computational engineering as the anti-Kardashev scale. Miniaturization is a good proxy for this, as the closer approach engineering on the Planck scale, the greater the densities and efficiencies of our engineered objects.

Fortunately, in addition to testable STEM compression trends describing past and near-future human civilization, the DS hypothesis also has testable implications for long-term communication from extraterrestrial intelligence and SETI, as explained in Smart 2000a and briefly at the end of this paper.

- 'Law' of Superexponential Growth (J-curves) as a Function of Intelligence. As briefly noted in our discussion of STEM compression of information and computation earlier, in the most complex or intelligent systems at the *leading edge* of universal computational complexity, we see not exponential, but *superexponential* growth. In other words, there is a "knee" in the curve of capacity growth for our most intelligent developmental processes. Exponential processes have no "knee", they grow the same at all points in their acceleration. For example, bacteria will grow in a food-rich environment with a constant doubling time, as a standard exponential process. But Szathmary (1991) notes that while bacteria grow exponentially, higher metazoans, such as rabbits in Australia or humans on Earth, grow their numbers superexponentially until they reach capacity limits. Because metazoans, including rabbits, have *culture*, not just genetics as part of our intelligence system, we are able to employ additional positive feedback loops, and respond superexponentially to the unexploited resource gradients in our local environment.

  Similarly, when we look at the leading edge of universal complexity development over long spans of time, as it migrates to increasingly intelligent substrates, or at the growth of a number of cultural and technological processes in complex communities like human beings, we can find several examples of superexponential growth, and thus points at which one can observe a shift, or shifts, to substantially faster rates of acceleration. The growth curve in such processes looks not like a flattened "U" (exponential) but instead like a "J", with a sharp shift from a state of slow growth, lifting gradually from the x axis (in units of time or experience), to a state of explosive growth, running nearly parallel to the y axis (in units of capacity or performance).

  We have already seen a J-curve in free energy density increase in universal development (Chaisson 2001). We could show another in the growth of GDP in Western Europe before and after the industrial revolution (Maddison 2007). Moravec (1988), Kurzweil (1999), and Nagy et. al. (2010) also demonstrate that computational price-performance measures have grown superexponentially from at least the 1800's to today. World system modelers like Andrey Korotayev et. al. (2006) use superexponential models for a number of informational, economic wealth, and other social growth processes. Interestingly, while human population grew hyperbolically (superexponentially) until the 1960's (see von Foerster et. al. 1960 for the classic paper on this), Korotayev observes that global human population growth has since been in *hyperbolic decline*. Thus absolute numbers of humans are projected to peak at 9-11 billion people mid 21st century, and then decline (Wattenberg 2005). The causes most often cited for saturation in human population growth in the 20th century, economic development, technology development, and education/information access facilitated by communications and computation technologies, are themselves systems displaying even shorter doubling times, and thus even more rapid modes of superexponential growth. The dynamics of superexponential growth and decline in complex systems are a rich field of investigation waiting to be developed.

- ‘Law’ of Developmental Immunity as a Function of Intelligence. When we contemplate processes of superexponential complexity or performance growth, we must ask why so many of these J-curves appear so smooth, across such long spans of historical time. Addressing this smoothness question seems central to understanding accelerating processes of change. Why, for example do we not see more fluctuations in the growth of energy rate density flow in leading-edge systems across cosmological time (Chaisson 2001)? Or in the J-curve of GDP per capita in Western Europe between 1000 and 2000 AD (Maddison 2007)? For the latter, booms and busts occur on the scale of decades, but disappear entirely on longer timescales. Why also do we not see more fluctuation in the price-performance of computing and communications technology between the 1800s and 2010? We see very brief plateaus, and occasional increases in the verticality of the curves. Nordhaus (2007) charts a noticeable increase in the rate of computing technology price performance after WWII, in the switch from electromechanical to electronic computing. Koh and Magee (2008) show a similar jump in communications bandwidth growth with the switch from coaxial to optical cable. But over longer spans, both of these IT performance curves are smooth and gently superexponential. Nagy et. al. (2010) say long-term IT performance curves best follow a hyperbolic curve. Kurzweil (1999,2001,2005) calls them a ‘double exponential.’ Whatever their mathematical expression turns out to be, their most interesting features remain their *superexponential shape* and their *smoothness* over long timescales.

  Let us briefly consider four potential reasons for the smoothness of superexponential growth in social wealth and technical capacity. We will then make a proposal which will allow us to generalize these reasons to include the smoothness of free energy rate density growth as well. First, the increasingly network (redundant, distributed) nature of memory (species knowledge) and intelligence at the leading edge of complexity in developing human societies means that if any leading individual, company, or country suffers catastrophe, others are always ready and willing to move into a leadership position. Second, the more complex society becomes, the more ways we have of accomplishing the desired thing, thus increasing the resiliency of social processes. Third, the persistent value of growing these particular processes (wealth, technical capacity) within evolutionary social systems will keep their selection pressure high regardless of environmental context. In other words, these special social processes seem far more *developmental* than evolutionary. Fourth, the increasing STEM compression (resource efficiency and density) of these special processes keeps them *free of limits* to their continued growth for the forseeable future. Magee (2007) states “technologies that improve as scale reduces are those that are currently improving most rapidly. These [scale reducing] technologies are therefore growing in their contribution to overall technological progress.” Magee quotes Feynman (1959) in noting that there is still “plenty of room at the bottom” for scale reduction as our substrates for social intelligence increasingly move to nano and femtospace. We can also forsee that as long as social wealth becomes increasingly *information based* (virtual) it too may continue to grow superexponentially as we move further into computational and conscious “inner space.” In other words, the more biological intelligence is applied to inner space, on all Earth-like planets, the more likely it is that social organisms will discover and unlock the great physical and computational efficiencies hidden within them. This is another way of saying that though local intelligences all take unique and creative evolutionary paths to find these efficiencies, their discovery and exploitation is, on average and over long timescales, a developmental process.

  In other words, if intelligence emergence is part of the developmental ‘genes’ (special initial conditions and laws) of our universe, then accessing accelerating and ever more miniaturized STEM efficiencies and densities, including free energy rate densities, and their associated technical capabilities and wealth must be developmental processes, and thus highly likely to be increasingly smooth as they progress further in the developmental cycle. In biological development, the failure rates for complexity emergence are very high at the beginning, but drop drastically as the developmental process progresses. Think of all the seeds that are dispersed but which never sprout. Once planted, think of all the spontaneous abortions which occur in the first few days of embryonic development in complex organisms. Developmental failure

(miscarriage) of late term fetuses is much lower still. And the closer any biological organism gets to sexual maturity, the lower their year-over-year mortality risk.

The longer biological evolutionary development runs in any environment, both in terms of the number of cycles since emergence of the first replicator (inter-cycle development), and the farther along the process gets within any particular developmental cycle on the way to its next replication point (intra-cycle development) the more we observe "developmental immunity" to both internal and external sources of disruption, and at the same time, the greater the system's expressed intelligence. Any complex system that has been cycling (replicating) over vast numbers of prior times in an information-stable environment, like living systems on Earth, or like our universe in the multiverse in the CNS-I hypothesis, will have inherited a developmental process that has become *particularly* immune, resilient, and self-sustaining with respect to environmental perturbation. Uncovering and understanding that immunity will give us great clues into our most likely developmental future, and will help us understand the critical subsystems that need to be protected today to ensure a more complex future tomorrow.

Immune systems are a mysterious aspect of human physiology, critical to every complex system, and far more pervasive, in any developmental process, than we give them credit for. Biological organisms have immunity on many levels, most of which are today well hidden from human observation. When modern science looks at what we presently take to be the human immune system, with its ability to genetically "compute" the difference between self and nonself at birth (certainly the most complex genetic processing done in our bodies by far), and its different overlapping physical systems of barrier, complement, humoral, and cellular immunity, I suspect that we see only the very tip of the iceberg of the true "immunity function" of this developmental system. Perhaps the most important system protecting any organism's cycling development is the set of stable standard and limit cycle attractors that guide cellular development and repair, from the molecular level on up, across the entire phase space of operating conditions on Earth. The higher immune functions we see, the ones described in our textbooks as "immune" functions, are just a small subset of that far larger and more subtle set of physical and chemical computations.

Using this larger definition of immunity and immune systems as processes that protect development wherever we find it, we can begin to properly address the smoothness of the curves we've described above. If superexponential growth in leading edge complexity is a universal developmental process, we should expect it to be smooth, as just as we find the biological developmental processes smooth. Consider how predictably and concurrently two genetically identical twins will hit their developmental milestones, for example. We do not find such smoothness in evolutionary processes, which are defined by irregular (chaotic) divergence and creativity. To summarize, we suspect social complexity development to be so smooth because our universe system has *gone through this transition before*, in prior cyclings, and also because Earth's present phase of social development is a *later stage complexity transition*, occurring on top of a long chain of prior supporting developments, such as our complex and resilient biosphere.

If there is a 'law' of developmental immunity in all developmental systems, including our universe, this hypothesis has many testable implications for astrobiology. For example, astrobiologists contemplate various hierarchical emergences on the path to complex life, including:

- the rise of complex galaxies from large scale structure in the early universe
- the rise of life-suitable stars from complex galaxies
- the rise of life-suitable planets from these stars
- the rise of life on such planets
- the rise of intelligence on planets with life
- the rise biology-surpassing intelligent technology on such planets

They make a series of best-educated guesses with respect to the probabilities of each of these transitions. Most biologists today, under the sway of the evolutionary, "life is a random accident" world view, would estimate the probability of life to be particularly rare, and intelligent life extremely rare. This school of thought is exemplified by Rare Earth astrobiologists (eg., Ward and Brownlee, 2000), among others.

But if leading edge complexity emergence in our universe is on a developmental path from birth to replication and maturity, as both the CNS-I and developmental singularity hypotheses propose, then we can expect *increasing emergence probability models must be true.* Just as we observe an ever declining mortality rate in higher biological systems as they progress from fertization to sexual maturity, including humans, where the lowest risk of death occurs in an organism just prior to puberty (Carnes et. al. 1996), we can expect to find an ever increasing probability of attaining higher hierarchical emergences as intelligent civilizations advance toward their own replication points. The steepness of this "developmental immunity" curve would seem likely to be a function of both the extent of local intelligence, and of the extent of the complex systems previous cyclings in the environment (for living systems) or multiverse (for the universe as a system). As a result, each of the steps described above will be shown to be *increasingly probable* relative to the previous step. Fortunately, as astronomy and astrobiology advances, we should get better data and theory with respect to transition probabilities. If developmental immunity is correct, we will begin to discover it everywhere we look. We can easily imagine how postbiological life could make itself immune to all the existential threats facing life on Earth today, including the death of our Sun. What is perhaps harder to see is how we are making ourselves immune as a function of our complexity.

Developmental immunity of intelligence within the universe, if true, allows us to understand a large number of today serendipitous observations, such as why gamma ray bursts from dying suns are so rare later in later stage galaxies, when there are many more complex civilizations that might be sterilized by them. Or how fortuitous it is that the gas giants (eg, Jupiter and Saturn) in Earth-like solar systems will vacuum up the vast majority of life-killing asteroids very early in planetary development, making complex life in such systems nearly immune from this threat. With respect to our planet, its plate tectonics, climate, ocean, life's carbon cycle, and a number of other processes ranging across thirty orders of magnitude of scale are observed to interact with solar radiation and orbit in a way that creates an amazingly resilient and unreasonably homeostatic (self-sustaining) environment for life. The Gaia hypothesis (Lovelock and Margulis 1974; Volk 2003) proposes geochemical homeostasis systems on our planet as a weak form of planetary intelligence, an intelligence that necessarily confers *significant immunity from environmental disruption* to life on all Earth-like planets. Outside of the frame of universal development, the Gaia hypothesis is controversial. Within such a frame, it makes natural sense.

Now we get to an even more fascinating line of thinking, with great potential implications for human civilization. Once one suspects that developmental immunity exists in universal systems leading up to human emergence, we need to start looking for it in the human and technological systems as well. I would argue that morality, and the moderating effects of increased technological complexity (Inglehart and Welzel 2005), are not simply random evolutionary discoveries of collectively intelligent systems, they are also highly likely to be developmental inevitabilities on all planets that harbor higher life. Thus the transition of human societies to higher levels of complexity and self-sustainability, including post-biological life, should be very high-probability event. So also should be the morality of postbiological intelligence.

Beginning in the late 20th century, a number of scholars (Gurr 1981, Stone 1983,1985; Sharp 1985) have begun to document the great reduction in frequency and severity of violence in developing human societies, particularly since the Enlightenment (1600-1800's). The reasons for this civilizing effect (Elias 1978) are unclear, but when we approach it as a potential developmental process for planetary intelligence, playing out in countless locations across our universe, we may begin to see if it has hallmarks

of such a process, including increasing smoothness and predictability as a function of system complexity. I would argue that human morality does in fact have such hallmarks, and that humans are, overwhelmingly, 'unreasonably civil' to each other, and their expressions of violence are both unreasonably short and largely symbolic even under conditions of great deprivation and duress (Gintis 2005). The rare cases we see of sustained psycho and sociopathologies are curiously self-limiting in their effect.

Even more curiously, when we look to find scientific processes or technologies that humans might have access to which could powerfully disrupt the imminent transition of human society to machine intelligence, we find virtually no such technologies. It seems as if we have inherited a *'Childproof Universe',* one where impulsive, selfish, and irrational human beings are simply unable to access species-killing technologies, as a result of the self-organized universal immunity which protects universal intelligence development, just as all biological intelligences have their own accompanying deep immunity.

Scholars of 'existential risks' (Bostrom and Circovic 2006) have eloquently imagined a number of planet-killing scenarios that human beings might access now or shortly in the future. These might include nuclear bombs creating an unsurvivable nuclear winter, underground development of an antimatter bomb (predicated on 'backyard fusion' emerging), or a more competitive, human-engineered form of some preexisting process, which wipes out all higher life in its emergence, such as a new and denser form of ice which freezes from the bottom of a body of water ('ice-nine', depicted chillingly by Vonnegut 1963), a toxic industrial process that kills our oceans zooplankton, a replicating nanobot swarm, a genetically-engineered bacterium that outcompetes Earth-bacteria and all multicellular life that depends on such bacteria, or a human-developed species-killing supervirus or pathogen. If developmental immunity exists, such Universes should be very rare. They would not propagate very far down the timeline.

As a younger man, I took these and a number of other species-extinction scenarios very seriously. Yet the closer I have looked at potential existential risks in subsequent years, I have been astonished not at their frequency, but at their extreme improbability. Even the famed Doomsday Machine, a nuclear device designed to create species-killing fallout via a cobalt bomb, dreamed up by physicist Leo Szilard and futurist Herman Kahn in the 1950's, would never have been built by nations (Kahn 1960). More importantly, even if built by a very well-funded and suicidal group, it *simply would not have worked*. There is an urban myth that hydrogen bombs can be designed to be arbitrarily large (see Teller-Ulam design), but in reality, unsurpassable physical constraints cap these devices in the low hundred megaton range. Also, as atmospheric scientist Brian Martin (1982,1983) and others have argued, the environmental effects of nuclear weapons scale far less than linearly with their yield, thus greatly limiting the nuclear winter which would result. Finally, both lower and higher life are much more resilient to background radiation than was originally assumed. While hundreds of millions of humans might die in such a gruesome scenario, an intense selective pressure for social and technical advance would also occur. As horrific as it would be, we can predict that nuclear exchange and nuclear winter would also be a "catalytic catastrophe" for modern society, like the K-T meteorite, the Ice Ages of the Paleolithic, the African drought that caused the first modern humans to migrate out of Africa, and the paroxysms of the 20th century World Wars. Such catastrophes always greatly set us back, and are to be avoided at all rational cost, yet at the same time, when they occur, they invariably catalyze further resilience and complexity in the life system, due to its still poorly understood mechanisms of developmental immunity.

Another way of understanding human social stability and morality in the context of developmental immunity is to take the "Great Filter" hypothesis (Hanson 1996), a proposed solution to Fermi's paradox, and reinterpret it from an evolutionary developmental perspective. This useful hypothesis argues that advanced civilizations must be increasingly rare as technological evolution progresses, because evolution creates variety, and technology leads to exponentially more powerful local actors in environments of relatively fixed scale, and thus a few variants will eventually be able to kill the whole system. But if we

consider that there is not only sociotechnological evolution, but also sociotechnological development, including immune systems development, we can understand in theory how a highly immune and moral postbiological civilization may one day emerge, from almost all universal evolutionary variants.

Again, we can imagine some of the ways immunity of advanced civilizations may greatly increase if there is a developmental migration to inner space via STEM compression. Highly dense matter seems likely to be immune to many or all of the cosmic disturbances that would kill biology. But making the case for mechanisms of morality development as a function of complexity will require further scholarship. Nevertheless, if we recognize that the likelihood of individual destabilizing events in advanced civilizations (such as nuclear detonations within cities, etc.) must go up due to increased evolutionary variation, we must also realize that the evolutionary selection pressure for survival is also is greatly increased in such local environments. In other words, selection pressure for survival must go up steadily in all kinds of local systems as a function of technological advancement. Once we understand this, we need only to discover a developmental mechanism that leads to *greater immune learning*, emerging most rapidly in the entire system (macroenvironment) after each subsequent catastrophe in local environments, and we can then understand the mechanisms leading to civilization resilience and moral development.

This is an unpopular position to take, but I believe it is the correct position, given the early evidence to date. Herman Kahn was pilloried in the press because of his careful conclusion that nuclear war was, in fact, winnable in a strict military sense, and would certainly be survived by both sides. Kahn described the terrible cost of nuclear exchange, in nauseating detail. But he also argued it was highly unlikely that nuclear war would destroy our species, a conclusion which few found productive or prudent to make. Modern nations have since moved on to large scale nuclear disarmament and nonproliferation, certainly in part because of the 'self-preventing prophecies' of nuclear winter and unwinnable wars, but perhaps mainly because we decided that the damage posed *to our societies, not to our species,* by these terrible technologies was increasingly morally unacceptable. Those who know the story of the Cuban Missile Crisis know how rapidly, over the space of just a few days, our leading countries improved their behavior under threat of impending catastrophe. From that point forward, history shows that nuclear war by major powers has become an ever-declining possibility.

To return to our larger issue of intelligence's smoothly accelerating history on Earth, what is truly amazing is how hard it is for us to imagine credible scenarios where humanity could wipe out even all other humanity, much less higher life. Social activist authors paint self-preventing prophecies of doom ahead (Carson 1962; Erlich 1968; Meadows et. al. 1972; Kunstler 2005) and these motivate us to painful social change, but they almost always greatly overestimate the true threat. Our science fiction includes stories of impulsive children gaining vast powers (recall six year old Anthony Fremont wishing away people and things he does not like to a cornfield in Jerome Bixby's Twilight Zone episode *It's a Good Life*, 1961), though humanity's childhood remains far more benign. We enjoy contemplating menageries of planet-killing technologies, but reality is far more mundane. Our ascendant species, the third chimpanzee (Diamond 1991), seems likely to have the capacity to incrementally create our electronic successors, via a global digital web, but very unlikely to gain the ability to destroy ourselves, though through we can create much pain, misery, and damage in the transition. Furthermore, as Wright notes (2009, 2010) creating a global web of humans and machines seems a critical next step in guaranteeing human sustainability and moral progress. The DS hypothesis proposes that creating an analog to a global brain, with measurably greater STEM compression, sustainability, and immunity, is part of our *developmental purpose*, recognized or not. We also have an *evolutionary purpose* to create and experiment in measurably greater ways, and an *evo devo purpose* to adapt, learn and measurably increase our intelligence/simulation capacity along the way.

What about the possibility of malevolent artificial intelligence? Couldn't the coming emergence of intelligent machines, an event that must surely dwarf all other technological advances to date, and which may occur even this century, easily cause the extinction of our species? This is a serious question, and as it is perhaps the most important one facing us in coming decades, we will attempt to address it in the final section of this paper.

To recap, there seems to be a deep developmental immunity in the particular laws and initial conditions of our universe, an immunity that statistically protects all humanoid intelligences through their transitions to a vastly hardier and immune postbiological form of life. We can look for and begin to recognize, measure, and characterize this immunity, and thus figure out how to maximize it. Or we can continue to pretend we live in an Accidental Universe, as it is both politically and scientifically more conservative to take this amoral position. The price we will pay is a persistent ignorance of the developmental aspects of morality, and significantly greater violence, randomness, and lack of self- and universe-awareness in the transition. The choice is ours.

- 'Law' of Locally Asymptotic Computation (LAC). As it undergoes smooth superexponential growth, the leading edge of local computation exhibits an ever-increasing *spatial locality*, and an ever greater ability to *simulate* (past and present) and *influence* the universe (present and future) within the inner space (STEM compressed structure and simulation system) of the highest local intelligence. In any universe with finite compressibilty and finite *local* physical resources, this trend cannot continue forever, but must eventually reach a *local asymptote*, or limit, some maximally efficient state accessible in that local environment. For us, that environment would be our solar system, in which local resources can be repurposed for ever faster computing, but where resources outside our system are so far away they cannot affect our local growth. We must therefore propose some form of LAC law as a "right wall" (Schroeder and Ćirković 2008) of accelerating complexity increase, sharply constraining the developmental dynamics of universal intelligence wherever it arises (Figure 27).

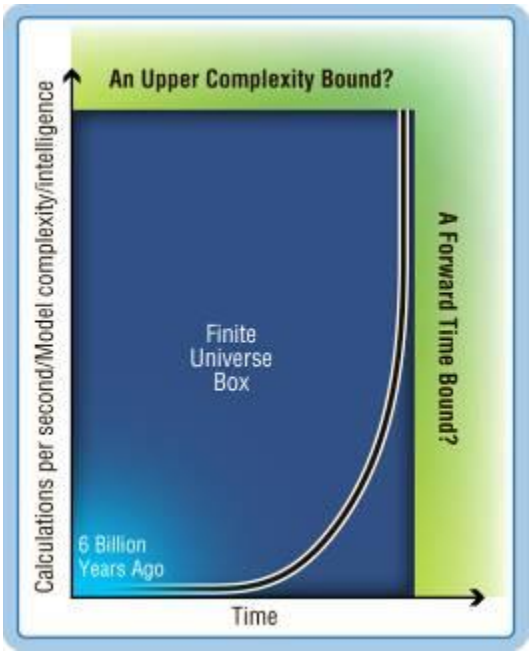


Figure 27. 'Law' of locally asymptotic computation (LAC).

Computronium is defined by speculative writers as hypothetical maximally condensed matter that is "optimally structured as a computing substrate" (Amato 1991). As any physical optimum is always context-dependent, a general theory of computation must posit *forms of computronium at every hierarchical level of STEM density* achievable by developing computing systems.

For example, biological computation based on *DNA in cells* seems likely to *already* be an optimal or near-optimal *chemistry-catalyzed* (lower intelligence) form of computronium, with respect to the set of chemically-based systems that are accessible to discovery by molecular evolutionary systems. Likewise, *nanotechnology* (molecular scale engineering), which promises far greater STEM density of information and computation than all biological systems to date, seems likely to be an optimal *culture-catalyzed* form of computronium, again when we are restricted to the set of substrates accessible to discovery by evolutionary human or AI intelligence (Drexler 1986,1992,2007). After nanotechnology, some form of *femtotechnology*, or atomic, optical, or quantum computing computronium must lie in wait as yet another evolutionary and developmental computing frontier. As legendary physicist Richard Feynman (1959) presciently observed,

there is "plenty of room at the bottom" of conventional molecular and atomic structures, which are almost all empty space in their current, non-relativistic configurations. Just as life repurposed molecules to create cells, atoms are waiting to be repurposed by future intelligence into far more STEM efficient, STEM dense, and adaptive informational and computational systems (Moravec 1999).

The LAC law proposes that as STEM efficiency and density of intelligent computation continues to rapidly increase, the *final universal computronium* must be a *black hole*, a structure Lloyd (2000a,2000b) and others have already proposed as an ideal computing platform for universal intelligence. It also proposes that the closer universal civilizations tend toward this black hole attractor, the more powerfully they are driven to further STEM compress (increase the spatial locality, speed, energy efficiency, and matter density of) their computation.

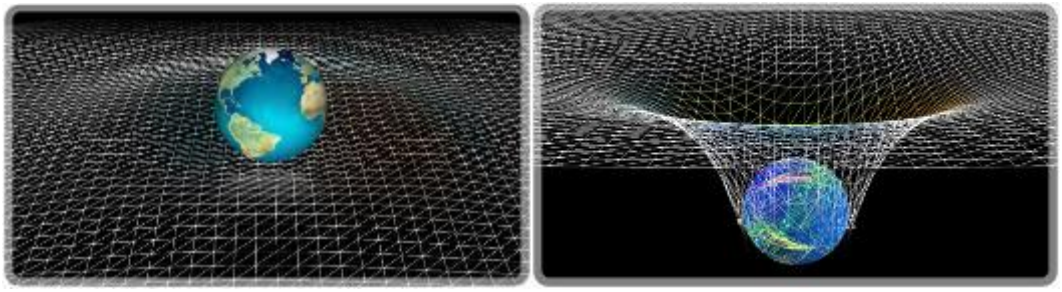


Figure 28. Gravity is the *altering of space-time* around high-mass objects, affecting local celestial dynamics as a function of mass. Likewise, STEM compression may be the altering of space-time and matter-energy *dynamics* as a function of complexity. In high-complexity objects like our future Earth's postbiological culture, *transcension-related behaviors* may become increasingly probable the closer the system approaches the black hole computational attractor.

Just as gravity *physically* alters spacetime around high-mass objects, making local escape from their orbit increasingly unlikely, so too there appears to be some yet-unclear *informational* relation between gravitation and universal computation. In fact, gravitation may be the universe's lowest-order driver of evolutionary computation, as gravity brings high-mass objects into close spatial proximity, and thus accelerates their physical interaction. In other words, the phenomenon of STEM compression somehow alters the *informational* landscape around high-complexity objects, increasingly chaining them to further computational acceleration, until eventually an irreversible, black-hole-like regime is reached (Figure 28).

Whether we are discussing a typical black hole formed in an early, or late, class of stars which never supported biological life, or an "intelligent" black hole, formed by any advanced civilization, such an object seems highly analogous to a *seed* (or less precisely, a *brain*), the distilled informational essence of that system's physical explorations, ready to be integrated into some future ecology and replication cycle. Such conjectures wait to be validated or refuted by future theory of universal computation which must, in this model, include general relativity its equations.

A composite J-curve (Figure 29) illustrates some assumptions of the LAC model. While *individual* physical computing platforms either *saturate* their complexity growth and form the stable base for the next hierarchy emergence (S-curves) or *die/go extinct* (B-curves), the leading edge of *collective* local computation (a second order J-curve) continually accelerates on the way to the black hole attractor. Local computational growth achieves this by regularly jumping to ever newer, more STEM dense and STEM efficient computing platforms, each with steeper S-curves of computational capacity and impact.

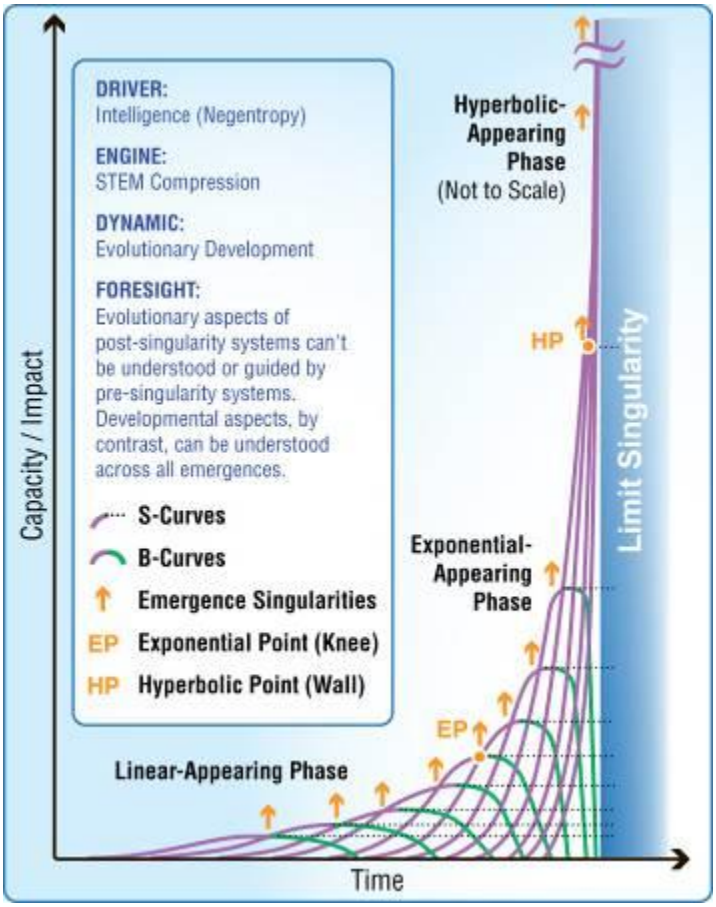


Figure 29. The second-order *J-curve* of the LAC law is composed of a series of first order *S- and B-curves,* each individually growth-limited computing substrates.

In a universe with physical limits however, there must be some 'highest' S-curve, some maximally STEM compressed nonrelativistic computronium. Once we have arrived at that, we will find no further substrate to jump to other than black holes themselves. In that terminal environment, a *local saturation in acceleration* must finally occur. This leveling off of computational acceleration may occupy a very insignificant fraction of nonrelativistic ("objective") time (the x-axis in Figures 27 and 29), yet this could still be a very long period in consciously experienced ("subjective") time, for the hyperaccelerated intelligences of that era, as we will shortly discuss.

Accurately modeling the "objective" length of time until we reach saturation may be beyond our present abilities, though early work (Lloyd 2000a,2001; Krauss and Starkman 2004) suggests such a universal physical-computational asymptote may be reached in *hundreds*, not even thousands, of years from today. Such a possibility is breathtaking to consider. Fortunately, if the LAC proposal is correct, it will be increasingly predictive and falsifiable in coming years, as we develop better metrics and models for the dynamics of planetary technological change.

- Black Holes as Ideal Structures for Information Gathering, Storage, and Computing in a Universe that is Increasingly Ergodic to Local Observers. Current research (Aaronson 2006,2008) now suggests that building future computers based on quantum theory, one of the two great theories of 20th century physics, will not yield exponentially, but only *quadratically* growing computational capacity over today's classical computing. In the search for truly disruptive future computational capacity emergence, we can therefore look to the second great physical theory of the last century, relativity. If the DS hypothesis is correct, what has been called relativistic computing, a black-hole-approximating computing substrate, will be the final common attractor for all successfully developing universal civilizations. At one level, the strange spacetimes possible in such an environment may allow so-called hypercomputation, the ability to engage in a wide variety of non-Turing computations in finite time (see Andréka et. al. 2009). Yet even without hypercomputation, which may violate logic or causality within our universe, relativistic computing seems to be a particularly desirable attractor for advanced intelligence. Let us see why.

Consider the following thought experiment. Imagine that you are a developmental singularity, and have STEM compressed yourself from nonrelativistic computronium all the way to the relativistic domain of a black hole. These special objects, at the limit of STEM density growth trends for computational devices, have a space-time curvature so extreme they allow not even light or information to escape, but only to flow inward, at an amazingly instantaneous rate. Once you have entered a black hole, everything that happens in the external universe, as well as any sensing and computing devices you have set up just external to you (outside yourself, in the nonrelativistic universe) will tell you everything they can learn about the universe in *virtually no relative local time*. This is because physical rates of change are happening far, far faster in all parts of the universe external to your event horizon "eye" (Figure 31).

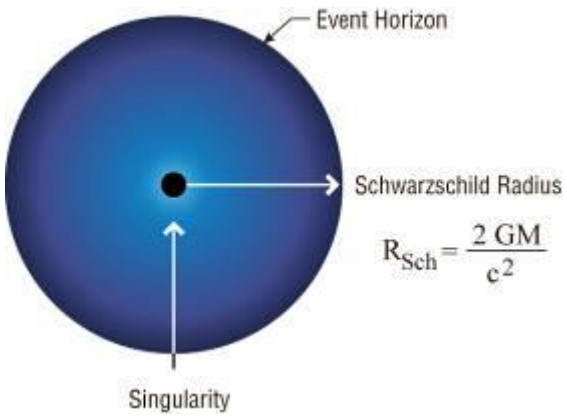


Figure 31. Black hole time dilation. Clocks near a black hole appear to slow down to an external observer, and stop altogether at the event horizon. Inside the black hole, external clocks move arbitrarily fast.

A black hole is the last place you want to be if you are still trying to *create* (evolve) in the universe, but this seems *exactly* where you want to be if you have reached the asymptote of complexity development in outer (normal) space, have employed all finite local resources into the most efficient nonrelativistic computronium you can, and are now finding the observable universe to be *an increasingly ergodic (repetitive, uncreative, "cosmogonic") and senescent or saturated learning environment, relative to you*. In other words, the more computationally closed local computing and discovery become, and the more complex *you* become relative to the universe proper, the faster you want the external universe to go to gain the last bits of useful information in the *shortest amount* of local time, before entering an entirely new zone of creativity (black hole intelligence merger, natural selection and new universe creation). Given their unique internal computational capacity (to be discussed next) black holes seem to be *ideal germline devices* for gaining the last observational and computational information available in the universe, from your no-longer-accelerating local reference frame, and taking it with you to someplace else. As the external universe dies at an accelerating pace, you are locally learning every last thing you can about as it disintegrates *in virtually no subjective time*.

With respect to their internal computational capacities, quantum physicist Seth Lloyd (2000a,2000b) has theorized that black holes are the "ultimate" computing environment, as only at black hole energy densities does the "memory wall" of modern computing disappear. In all classical computing, there is a time cost to sending information from the processor to the memory register and back again. Yet as Lloyd shows, at the black hole limit of STEM density, computers attain the Bekenstein bound for the energy cost of information transfer (Bekenstein 1981), and the time it takes to flip a bit (t_{flip}) at any position, is on the same order as the time it takes to communicate (t_{com}) from *any* point in the system to any other around the event horizon. In other words, communication and computation have become a *convergently unified process* in black holes, making them a maximally STEM efficient learning system. Even the femtosecond processes and great STEM densities in neutron stars would be slow and simple by comparison.

At the same time, we must admit that this is a learning system that has entered a jail of its own choosing. If one hallmark of developmental processes is their irreversibility, the creation of a black hole is as irreversible a phase transition as one can imagine. Not even information can leak back out into the universe. Once a black hole intelligence is formed, it can "never go home again," only forward, perhaps to merger with other black hole intelligences (discussed shortly), and perhaps also to some form of direct

experience of and influence on the multiversal environment. We have become very much like a *seed*, almost frozen in universal time, waiting patiently for the opportunity to flower again.

Local intelligence would very likely need to be able to enter a black hole without losing any of its structural complexity. Hawking (1987) has speculated we might do just this, if advanced intelligence is built out of some form of femtotechnology (structures below the atom in size). Atoms and above might be destroyed on entering a local, intelligently-created low-mass black hole, but there are 25 orders of magnitude of "undiscovered country" in scale between atoms (10^{-10} m) and the Planck length (10^{-35} m) for the possible future creation of intelligent systems. Inner space engineering may one day occur within this vast range, which is almost as broad as the 30 orders of scale inhabited by biological life.

In the DS hypothesis, local intelligence must continue to migrate to these more STEM efficient and dense learning environments. *Until* we reach the black hole stage, reversibility will always be an option, but we can expect outer space to be far less interesting, and vastly slower and simpler by comparison to the consciousness, insight, and adaptive capacities we gain by venturing further into inner space.

As a prime example, human consciousness is presently the most STEM dense computational platform known. It emerges from 100 trillion unique synaptic connections contained in a very small mobile platform that communicates with thousands out of billions of other local memetically unique variants. We regularly alter it but rarely seek to voluntarily eliminate it, statistically speaking. If you could *reversibly* leave your human mind and become the entire sea of your single-celled ancestors, you probably would do so at least once, for the experience. But you probably wouldn't stay in that vastly less complex space for long. Conversely, any opportunity we might gain to go further into STEM compression and thus deeper and broader into conscious experience would very likely be a one way, irreversible, developmental progression, on average, for all universal intelligence. In other words, intelligence apparently has a developmental trajectory, moving whenever possible towards greater STEM density and efficiency.

If the DS hypothesis is proven true, such concepts as the generalized Copernican principle (Principle of Mediocrity) while perhaps valid for the contingent 95% evolutionary "body" of our universe, must be revised with respect to *special accelerating developmental reference frames* (local germline/seed environments of continual STEM compression and complexity increase, the predictable 5% of the 95/5% rule) like Earth (Figure 30). In turn, Copernican-dependent models like the random observer self-sampling assumption (Bostrom 2002), and randomness-based "doomsday" arguments (Carter 1983; Gott 1993,1994; Leslie 1998) estimating the likely duration of cosmic presence of humanity must also be revised.

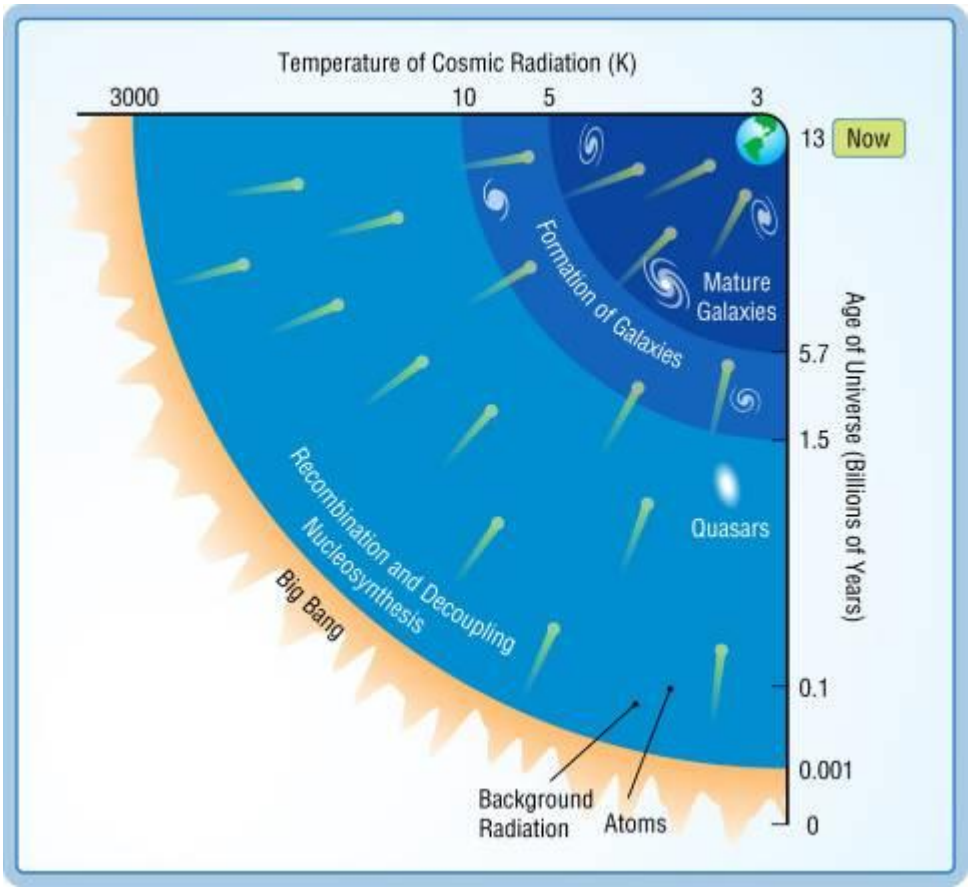
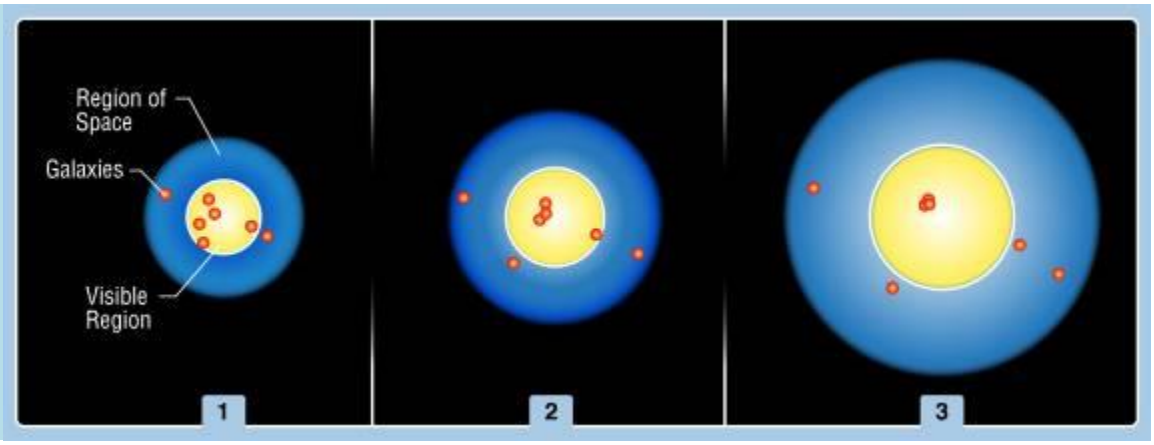


Figure 30. Complexity-centric representation of the universe. If Earth-type emergences need a developmental reference frame, some cosmological models must be revised.

- Black Hole or Nonrelativistic Computronium Mergers as Mechanisms for Intrauniversal Natural Selection in Evo Devo CNS-I. As competitive and cooperative natural selection seems to emerge early in all evo-devo biological systems, and as such selection becomes particularly *intricate and multilayered* in more complex systems in the hierarchy (eg, genetic, kin, sexual, cultural, technological, and many other forms of selection all influencing the reproduction of human beings) (Keller 1999; Okasha 2007), some form of intrauniversal or extrauniversal (multiversal) natural selection seems necessary with respect to black hole intelligences *prior* to their replication. Two intrauniversal selection models will now be proposed.

We have proposed that all advanced civilizations, as they transition into a black-hole-like intelligence in their advanced state of development will increasingly looks like a *seed*, or a spore, an increasingly inanimate, low-to-no-metabolizing structure that has captured evolutionary information and is waiting for the right conditions to replicate it. That the energy and matter dissipation of all advanced civilizations must eventually end seems obvious in a universe where all is subject to the second law of thermodynamics. But we can further propose that not only do intelligent black holes appear to be ideal pre-seeds, packaging the last useful information that is available to them locally as they develop, but they also appear to be ideal *selection systems* for merging, competing, cooperating, and engaging in natural selection with other intrauniversal intelligences. This is because black holes, and only black holes, allow a special kind of "one way time travel" for merging with other evolutionarily unique universal intelligences throughout each galaxy in *almost no subjective (internal) time*.

Looking at the future dynamics of our universe under dark energy, Krauss and Scherrer (2008) describe a cosmos where space self-fractionates into supergalactic "islands" with *continually decreasing* observable universal information available to each island. Throughout the universe, local group galaxies merge under gravitational attraction to form supergalaxies (islands), and the rest of the universe rapidly recedes beyond each island's view (Figure 32). In related work, Nagamine and Loeb (2003) predict our Milky Way galaxy, Andromeda galaxy, and the dwarf galaxies in our Local Group will all collapse 50-100 billion years from now into a single supergalaxy, while the rest of the universe will move permanently beyond our observation horizon.



1. At the onset of acceleration, we see the largest number of galaxies we ever will.	2. The visible region grows, but the overall universe grows even faster, so we see a smaller fraction of what exists	3. Distant galaxies (not bound to us by gravity) move out of our range of view. Gravity pulls nearby galaxies together.

Figure 32. About six billion years ago, universe expansion began to accelerate. It is now self-fractionating into local 'islands,' each of which may create evolutionarily unique intelligence mergers.

From a biological perspective, this developmental process looks much like the formation of a large number of universe "eggs" or "follicles," reproductive structures that facilitate gravity driven merger and natural selection amongst all intelligent black holes (pre-seeds) that exist inside each supergalaxy (Figure 33). It looks analogous to the way many sperm compete to fertilize a single egg, or the way eggs compete each month in the human ovarian follicle for ovulation of the single fittest egg for reproduction.

Why does our universe self-fractionate into many islands (supergalaxies) at the end of its life cycle? Perhaps each supergalaxy merger creates one new universe. Multiple supergalaxies would then allow simultaneous exploration of many slightly different universal developmental lineages in the next cycle. Alternatively, as with biological ovaries, each supergalaxy merger might create one "potential" new universe, and then a second-order process of selection among supergalactic intelligences could create the next "single fittest universe" for reproduction.

How many advanced civilizations might be involved in each supergalaxy merger? Drake and Sagan's original estimate ranged from one to one million technical civilizations in our Milky Way galaxy alone. Estimates from "rare Earth" astrobiologists are far more conservative, but also far from conclusive. As astronomer Dimitar Sasselov (2010) remarks, life on Earth has successfully survived for one-third the lifespan of the universe to date, and this fact alone suggests ubiquity of life in our type of galaxy. If Earth-like planets turn out to be as common as we suspect, biological life seems very likely to be common in the universe. If the law developmental immunity holds, advanced technological life must be plentiful as well. Thus if we assume a similar number of civilizations for the Milky Way and Andromeda, and none for the local dwarf galaxies (developmental failures, it seems), our Local Group follicle should harbor *at least two (one per galaxy) to as many as two million cosmic intelligences* that are statistically likely to meet and merge prior to replication, assuming our own future development does not end in failure prior to the merger event. My own intuition, given the impressive biofelicity that our universe appears to exhibit to date, would put the number of merging intelligences in each supergalaxy much closer to the high end than the low end of this range.

We can expect each of these cosmic intelligences to have truly unique perspectives on the universe, each having taken slightly different evolutionary pathways to their own developmental singularities, and each being quite limited and incomplete by contrast to intractable multiversal reality. Universes that allow the comparing and contrasting of many uniquely constructed models of reality in a competitive and cooperative manner via black hole mergers would allow *greatly increased natural selection for robustness and complexity* of universes and their civilizations in the next EDU cycle.

In addition to passive black hole merger, we can propose at least one active intrauniversal merger scenario. If minimizing nonrelativistic universal time is important prior to merger, or if local developmental singularities choose to STEM compress themselves only to the highest nonrelativistic (form-reversible) computronium available, they might actively launch themselves to some central merger point to allow knowledge sharing as soon as possible in *nonrelativistic* time. This scenario seems less likely to this author, given the apparent primacy of local, subjective, internal, relative time in complexity development to date, but remains in the realm of plausibility.

Whether passive or active travel occurs, we can already say something obvious about the likely destination for these intelligences. Given the generally proposed shape of our galactic habitable zone (GHZ), the closest central merger point for a community of cosmic intelligences would be the supermassive black holes at the center of any intelligence-supporting galaxy (Figure 34). Using the Chandra X-ray observatory, Muno (2005) has found early evidence for an unusually high concentration (thousands) of black holes and neutron stars within 3 light years of Sagittarius A*, the 4.1+ million solar mass black hole the center of the Milky Way. Local neutron stars and black holes are expected to passively migrate toward this supermassive under a process called dynamical friction (Morris 1993). GHZ-located black holes would presumably also do the same, though on much longer timescales. We must ask: Does such migration serve an information capture, selection, or recycling purpose at the galactic scale? Should we expect "intelligent" high-density objects, such as might be created by Earth's future civilization, to differ in mass, composition, or behavior from typical neutron stars and black holes?

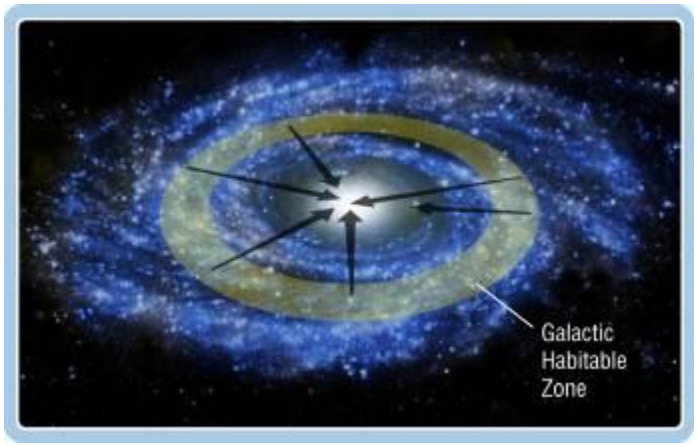


Figure 34. Active black hole merger scenario. Another possible natural selection mechanism for evo devo CNS-I. Might mature DS's actively migrate from the GHZ to the galactic center?

Curiously, supermassives are the only black holes that do not immediately destroy, via tidal forces, even the ordinary matter they collect across their event horizons. Could there be something special about these objects that makes them ideal not only for galactic evolutionary development, but also for DS merger? Might future SETI pick up signs of planet- or stellar-mass neutron star or black hole computronium entities, whose gravitational lensing signatures depict great mass compacted into negligible volumes, passively or actively traveling from our and Andromeda's GHZ toward the galactic center, like salmon swimming home, as evidence of our own constrained cosmic future? What level of SETI sensitivity would we need before we could detect such evidence? Note that this scenario, though it would involve a specific form of passive or active interstellar travel, is still one of developmentally constrained transcension, not expansion, of cosmic intelligence.

Next, consider why in an evo devo universe, a No-Broadcasting Directive (no active communication of our presence to the universe) would be likely to be self-discovered and scrupulously followed by all advanced civilizations in the cosmos. Given developmentally-fated merger (either passive or active) and transcension physics, and given that advanced intelligences should be strongly bound by benevolent, evo compu devo value sets, no advanced communication beacons are likely to be constructed or *Encyclopedia Galacticas* sent prior to merger and transcension. Why? In the biological world, one-way communication is occasionally useful for developmental *control* but never for evolutionary *complexity construction*.

It can presently be argued, and we would predict, will eventually be proven with future computation theory, that *one-way, nonlocal communication* (aka 'broadcasting') with no possibility of feedback, *must always reduce the remaining evolutionary variability* and *homogenize the developmental transcensions of all civilizations receiving such messages*. Such behavior should therefore be ethically avoided by all advanced intelligences as they inevitably become aware of EDU and DS physics and information theory. Thus the DS hypothesis proposes a very specific solution to the Fermi Paradox (Webb 2002) and falsifiably predicts that future SETI should discover "radio fossils," Earth-like civilizations that transmit *very low* levels of nonrandom electromagnetic radiation during their *early* cultural development, *and then reliably cease such transmission* as they disappear into transcension soon after their technological singularity is reached. For more, please see Smart 2000a.

Finally, we should ask ourselves whether a universe where dark energy didn't dominate might be preferable to the one we seem to inhabit. A universe that ended in a "Big Crunch," for example, would allow us to merge with *all* universal black hole intelligences, as opposed to just a subset of local intelligences prior to replication. Curiously, when we look for such a strategy in evo-devo biological systems, we find it doesn't exist. Why? One of biology's most basic strategies is increasing variety over time, perhaps as an adaptation to the pervasive computational incompleteness of each organism. In general, a phylogenetic tree of universes that *keeps branching into many unique forks* (increasing number and variety of daughter universes) will be more robust than an ensemble that brings all its eggs back to one basket at the end of universal time. But remember also that all evolutionary trees also eventually exhaust themselves. The novel branching in the phenospace of universe ensembles should eventually saturate (terminally differentiate), and a convergent phase transition to some form of *postuniversal substrate* should then occur. In other words, even a network of branching universes must eventually give way to some qualitatively different and more unbounded system in the multiversal future. As it goes in biology, so may we expect it to go in universes, in an evo devo approach to computing reality.

- The Coming Challenge of Postbiological Intelligence: The Evolutionary Development of Friendly AI. Let us close this paper by returning to a particularly imminent concern, the potential arrival of a technological singularity on Earth in coming generations. In EDU language, such an event would be a major threshold in the local evolutionary development of cosmic complexity. Contemplating the transition, which may arrive even this century, what theoretical and empirical strategies may we use to ensure postbiological intelligence will be "friendly" to the complexity, needs, and desires of our species? This question has been addressed carefully by only a few thoughtful scholars to date (e.g., Bostrom 2003; Yudkowsky 2006).

The IPU, EDU and DS hypotheses can each inform the friendly AI question, should any of these be validated by future science. Let us consider some interesting, and hopefully testable, speculative scenarios. Recall that the IPU hypothesis argues that the universe seeks to preserve intelligence, computation, or complexity. Currently, two of the most popular approaches to modeling human cognition are *connectionism* and *computationalism*. The former is a computational strategy that occurs in all living systems, and the latter, involving formal symbolic logic and Bayesian processes, is emergent, as far as we know, only in human brains and our technology. The EDU hypothesis would argue that both strategies involve both evolutionary and developmental processes. Furthermore from a universal perspective, the

95/5 rule suggests that any connectionist strategies to create AI, such as scanning and modeling mammalian brains, or using other network-based approaches, and any computationalist strategies, such as language, logic, or Bayesian approaches, are *each* 95% bottom up, or evolutionary. Can this be true?

Some engineers and theorists, from their human perspective, strive to do work designing smarter machines is largely computationalist and top-down. But of course, any associations the Bayesian designer makes with other human beings, or any work they learn of and are influenced by that was not generated from their own language or logic adds some connectionist influence to their designs. We begin to see that while it may be quite useful for us to attempt the greatest degree of "rationally designing" our smart machines, in reality we are always using some mix of contingent and rational strategies. From our perspective, we may see computationalist strategies as more desirable and less experimental. When we can use them, they may give us a sightly better ability to control and predict next technology generation. But in the long term, both involve combinatorial explosions of predictive uncertainty. As any scholar of technology knows, in the long run, serendipity is the main singature. From the universe's perspective, using us as actors, we are just the latest substrate doing a mix of mostly stochastic and bottom-up searches, some generated by our higher complexity, some generated by our older and more primitive complex systems.

Now if the DS hypothesis is true, some kind of developmental immunity must guide the developmental component of *all* the strategies we use to generate cognition and computation. In other words, the evolutionary component of each process must always be gently constrained to conserve local system complexity, average or total. This is an exciting claim, as it is so very specific, and so may be particularly testable. Can we find evidence that the connectionist approach to building minds has smoothly and robustly conserved average or total distributed complexity in the history of life? If so, and if the EDU hypothesis holds in some fashion, we may gain some confidence that connectionist-computationalist approaches (all computationalist aproaches are also connectionist to some degree) will do the same.

In the EDU framework, human and postbiological complexity are built not only by random evolutionary accidents but also by statistically probable developments emerging from the interaction of connected collectives of evo compu devo systems. Such a universe has been iteratively tuned for robust computational acceleration, and appears to be *broadly guided* by an inherent evo compu devo moral telos. Just as 21st century humanity is finally concerned with creating, adapting to/learning from, and preserving Earth's biological diversity, postbiological intelligences would likely seek to *create*, *adapt to/learn from*, and *sustain* personal, planetary, and universal complexity, with a degree of ethical rigor that is directly proportional to their own complexity. We may therefore expect such intelligences to have a collective postbiological morality and set of physical and ethical constraints vastly exceeding ours in scope and sophistication, even as they have individual evolutionary moral deviants who are policed by the collective, just as do human populations. In other words, they may aggressively enforce the preservation of human complexity, as well as the basic needs and positive sum desires of biological humanity, at least for a time.

If such intelligences emerge via evolutionary developmental processes (replicating, varying, selecting, and converging in biologically-inspired hardware), they may need to do so as a collective or *population* of intelligences, never as a single, top-down engineered intelligence. In other words, massively parallel evolutionary variation, countless developmental cycles, and selection on a population of cyclers may be the only viable path to the developmental emergence of intelligence, as it was for our own brains. No single isolated engineering effort may ever create a human-equivalent artificial intelligence, contrary to the hopes of many AI aspirants. Instead, an extensive period of bottom-up evolutionary gardening of a *global ecology* of narrowly intelligent machine assistants may need to occur long before any subset could reach a technological singularity.

Just as it takes a 'village' to raise a child, we may need a global human community to raise, select, and prune Earth's most advanced forms of artificial intelligence. This should allow us many years in which to select our learning agents for safety, symbiosis, and dependability, and to gain extensive empirical evidence of their friendliness even if our theories of friendliness remain underdeveloped, and even as the intricacies of their electronic brains remain as unscrutable as brains of any artificially selected animal that exists today. Applying this perspective, one distributed development we may expect within the next decade, long before a technological singularity, is the *conversational interface*, a bottom-up, statistically constructed natural language processing platform (a connectionist approach to generating a new computationalist platform) that will enable sophisticated human-machine, human-avatar, and avatar-avatar conversations. See Smart, 2003 for more on this imminent development, one of our planet's next major steps toward postbiological intelligence.

Those unsatisfied with these arguments may still approach the friendliness question from other aspects of the EDU framework. Consider self-interest: it seems likely that once postbiologicals can deeply and developmentally (predictively) understand all the simpler systems from which they arose, they would be potentially much safer from previously unknown subtle universal processes, and considerably more adaptive and intelligent. In an ergodic universe, all of biology must eventually become *increasingly (though never fully predictively) computationally closed systems* relative to postbiological intelligence. Given our subordinate hierarchical relationship to postbiologicals ("they" must arise from us) and their unique ability to understand and at least with respect to developmental dynamics, predict our biological thoughts and behaviors once their nanosensors and processors are tightly linked to us, the evo devo nature of the human species should be the *most interesting solvable puzzle* in the universe to tomorrow's AI's (recall that no evolutionary CAS can ever be ergodic to *self*-simulation). A useful parallel to the way humanity will be studied is the way structural and computational cellular biologists presently try to simulate and predict, in real time, metabolic events in model species of Earth's bacteria today, even though we are perhaps generations away from having the sensor data, computational power or theoretical base to achieve this feat in any comprehensive way.

How long postbiological intelligences would be—or should be—friendly not just to collective planetary human complexity, but to our needs and desires as *individual biological human beings* is a harder question to evaluate. Wesley (1974), for example, would allow no more than a century after postbiological intelligence arrives before the complete disappearance of *Homo sapiens*. While such a guess may be too abbreviated by at least an order of magnitude, its very briefness speaks to the strangeness of unchecked computational acceleration. Once postbiologicals can deeply and successfully predict our species mental and behavioral events, *in realtime*, there might be little reason left not to turn us into them, as long as they can do so in a largely voluntary way, by incrementally sharing their complexity in the many ways we are likely to request it.

Given the profound STEM compression limitations of biology as a computing platform, such a strategy would seem to require continued accelerating complexity of our "cybertwins" (personal digital assistants) until they become our *cyberselves*, via *a culturally-desired, accelerating intimacy of connections* between our cybernetic and biological identities. Today our cybertwins are our limited electronic data, and our primitive, nearly static profiles on today's social networks. Very soon they will be our increasingly intelligent digital avatars, and the growing variety of technologies they will control (Smart 2001,2004).

It seems to me that the most productive human beings in mid-21st century society, as well as most of our youth, will increasingly depend on their cybertwins as their primary interface to the world. It also seems likely that many of us will allow our cybertwins to continue to increase in complexity and usefulness to society even after our biological bodies have died, which will in turn profoundly change the nature of grieving and the social impact of death. At some point, with the advanced nanotechnology that

postbiological life seems likely to command, our cybertwins can permeate our biological brains and bodies with their nanosensor grids, develop deep connectivity between our digital and biological identities, and deliver a kind of immortality, even a subjective immortality, by *successive digital approximation*.

Consider this: once we can experience our own personal consciousness across *both our electronic and biological forms*, due to intimate, complex nanotechnological connections between them, will not the inevitable aging and death of our biological components be seen as simply growth, not death? Won't it be like having a part of you that has more intrinsic limitations finally being shed, while the other part learns something from the shedding? Won't humanity decide to stop procreating biologically once we recognize our cyberselves have fully encapsulated and exceeded our biological complexity, consciousness and humanity? When postbiologicals can *understand, predict, and archive* all planetary biology, will they then consider it morally justified to give *all local biology* cybernetic appendages, and progressively turn our entire planet into a developmental singularity? A postbiological intelligence made of highly STEM dense materials would likely be impervious to all external environmental threats. It would also have new inner space complexity frontiers to explore that we can scarcely imagine from our biological perspective.

Finally, while the IPU, EDU and DS hypotheses provide a reasoned and intriguing basis for expecting the continued acceleration of local complexity, they leave unanswered many questions concerning *which unpredictable, evolutionary paths Earth's most intelligent species will take* as it catalyzes postbiological development. Will we be able to reform our most self-absorbed and materialistic cultures (U.S., Japan, U.K. etc.) that frequently serve profit, plutocracy, and exploitation more than innovation, learning, and sustainability? Will we limit the scope of human-initiated catastrophe, war, and terrorism by advancing our global immune systems (biological, cultural, and technological), maximizing individual self-determination, eliminating deprivation, and limiting disparity and ecological destruction? Will we fund the discovery and validation of an increasingly evidence-based and universal *science of human values*, such as our proposed evo compu devo telos, or continue to allow unexamined, cynical postmodernism and unquestioned religious superstition to dictate our deepest beliefs? Will we finally admit that science and technology are not just human enterprises but also the latest stage in a *long-accelerating process of intelligence development*, serving some higher, universal purpose? Will we conscientiously select our technological intelligence for *demonstrable value and symbiosis with humanity* in coming generations? Or will we approach these issues languidly, childishly, and with little foresight, risking an inhumane, disruptive, dangerous, and unfriendly transition?

The future never comes as fast, as humanely, or as predictably as those who shirk responsibility expect it to. Such questions seem among our species great choices and moral challenges in the years ahead. Let us be wise in answering them.

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References

Aaronson, Scott. 2006. Computational Complexity and the Anthropic Principle. Notes for a talk given at the Stanford Institute for Theoretical Physics, 15 Dec 2006. http://www.scottaaronson.com/talks/anthropic.html
—— 2008. The Limits of Quantum Computers. *Scientific American*, March 2008.
Abraham, Ajith et al. 2006. *Stigmergic Optimization (Studies in Computational Intelligence)*, Springer.
Adami, Christoph. 1995. Self-organized criticality in living systems. *Physics Letters A* 203: 29–32. http://arxiv.org/abs/adap-org/9401001.
Adams, Henry B. 1909 [1919]. The Rule of Phase Applied to History. In: *The Degradation of the Democratic Dogma*, Macmillan, pp. 267-311.
Alexander, Samuel. 1916 [1966]. *Space, Time, and Deity: Gifford lectures at Glasgow, 1916-1918, Vol. II*, Macmillan.
—— 1920. *Space, Time, and Deity*, Kessinger.
Allen, Timothy F. and Starr, Thomas B. 1982. *Hierarchy: Perspectives for ecological complexity*, U. Chicago Press.
Allott, Robin. 2001. *The Great Mosaic Eye: Language and Evolution*, Book Guild Ltd.
Amato, Ivan. 1991. Speculating in precious computronium. *Science* 253(5022):856-57.
Andréka, Hajnal, Németi, István, and Németi, Péter. 2009. General relativistic hypercomputing and foundation of mathematics. *Natural Computing* 8(3):499-516.
Arthur, Wallace. 2000. *The Origin of Animal Body Plans: A Study in Evolutionary Developmental Biology*. Cambridge U. Press.
Ashtekar, Abhay. 2006. The Issue of the Beginning in Quantum Gravity. http://arxiv.org/abs/physics/0605078.
Aunger, Robert. 2000. *Darwinizing Culture: The Status of Memetics as a Science*, Oxford U. Press.
—— 2007a. Major transitions in 'big' history. *Technological Forecasting & Social Change* 74(8):1137-1163.
—— 2007b. A rigorous periodization of 'big' history. *Technological Forecasting & Social Change* 74(8):1164-1178.
Aurobindo, Sri. 1963[2003]. *The Future Evolution of Man*, Lotus Press.
Bak, Per et al. 1987. Self-organized criticality: An explanation of the 1/f noise. *Physical Review Letters* 59(4):381–384. http://dx.doi.org/10.1103/PhysRevLett.59.381.
Bakewell, Margaret A. et al. 2007. More genes underwent positive selection in chimpanzee evolution than in human evolution. *PNAS*, April 17, 2007.
Balázs, Béla. 2002. The Role of Life in the Cosmological Replication Cycle, Paper from 2002 ISSOL Conference. http://astro.elte.hu/~bab/Role_Life_Univp.rtf.
Barrow, John D. 1998. *Impossibility: The Limits of Science and the Science of Limits*, Oxford University Press.
—— 2002. *The Constants of Nature: The Numbers that Encode the Deepest Secrets of the Universe*, Pantheon.
—— 2007. Living in a Simulated Universe. In: *Universe or Multiverse?*, B. Carr (ed.), p. 481-486.
Barrow, John D. and Tipler, Frank. 1986. *The Anthropic Cosmological Principle*, Oxford U. Press.
Barrow, John D. et al. (eds). 2006. *Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning*, Cambridge U. Press.
Barzun, Jacques. 2001. *From Dawn to Decadence: 500 Years of Western Cultural Life*, Harper Perennial.
Bateson, Gregory. 1985[2000]. *Steps to an Ecology of Mind*, U. Chicago Press.
Baudrillard, Jean 1968[1996]. *The System of Objects*, Verso.
Baum, Eric. 1983. Discussion, *Physics Letters* B 133(185).
—— 2006. *What Is Thought?*, MIT Press.
Bejan, Adrian. 2000. *Shape and Structure: From Engineering to Nature*, Cambridge U. Press.
Bekenstein, Jacob D. 1981. Energy cost of information transfer. *Physical Review Letters* 46:623-626
Bergson, Henri. 1910 [1983]. *Creative Evolution* (1911 English translation of *L'Evolution créatrice*), U. Press of America.
Blackmore, Susan. 1999. *The Meme Machine*, Oxford U. Press.
—— 2008. On Memes and "Temes". TED Conference [presentation video], Feb 2008.

Bloom, Howard. 2000. *Global Brain: The Evolution of Mass Mind from the Big Bang to the 21st Century*, Wiley.
Blume-Kohout, R. and Zurek, W.H. 2005. Quantum Darwinism: Entanglement, Branches, and the Emergent Classicality of Redundantly Stored Quantum Information. arXiv:quant-ph/0505031v2
Bostrom, Nick. 2002. *Anthropic Bias: Observation Selection Effects in Science and Philosophy*, Routledge.
—— 2003. Ethical Issues in Advanced Artificial Intelligence. In: *Cognitive, Emotive and Ethical Aspects of Decision Making in Humans and in Artificial Intelligence, Vol. 2*, I. Smit et al. (ed), Int. Institute of Advanced Studies in Systems Research and Cybernetics, pp. 12-17.
Bostrom, Nick and Cirkovic, Milan M. (eds.) 2006. *Global Catastrophic Risks*, Oxford U. Press.
Breuer, Reinhard. 1991. *The Anthropic Principle: Man as the Focal Point of Nature*, Birkhauser.
Brier, Soren. 2008. *Cybersemiotics: Why Information Is Not Enough*, University of Toronto Press.
Brigis, Alvis. 2004. Personal communication.
Broderick, Damien. 1997[2001]. *The Spike: Accelerating into the Unimaginable Future*, Reed Books.
Brown, James. H. and West, Geoffrey. 2000. *Scaling in Biology*, Oxford U. Press.
Byl, John. 1996. On the Natural Selection of Universes. *Quarterly Journal of the Royal Astronomical Society*, 37(369-71).
Cairncross Frances C. 1998 [2001]. *The Death of Distance: How the Communications Revolution is Changing Our Lives*, Harvard Business School Press.
Cairns-Smith, A. Graham. 1982. *Genetic Takeover and the Mineral Origins of Life*, Cambridge U. Press.
—— 1985. *Seven Clues to the Origin of Life*, Cambridge U. Press.
Callebaut, Werner and Rasskin-Gutman, Diego. 2005. *Modularity: Understanding the Development and Evolution of Natural Complex Systems*, MIT Press.
Carnes, Bruce A. et al. (1996) Continuing the Search for a Law of Mortality. *Population and Development Review* 22(2):231-264.
Carroll, Sean B. 2005. *Endless Forms Most Beautiful: The New Science of Evo Devo*, Norton.
Carson, Rachel. 1962. *Silent Spring*, Houghton Mifflin.
Carter, Brandon. 1983. The anthropic principle and its implications for biological evolution. *Philosophical Transactions of the Royal Society of London* A310: 347–363.
Chaisson, Eric J. 2001. *Cosmic Evolution: The Rise of Complexity in Nature*, Harvard U. Press.
—— 2003. A unifying concept for astrobiology [Φ_m]. *International Journal of Astrobiology* 2(2):91-101. http://www.tufts.edu/as/wright_center/eric/reprints/unifying_concept_astrobio.pdf.
Chaitin, Gregory J. 1987. Algorithmic Information Theory, Cambridge U. Press.
—— 1998. *The Limits of Mathematics*, Springer-Verlag.
Chambers, Robert. 1844. *Vestiges of the Natural History of Creation*, Churchill.
Church, Alonzo. 1934. A Note on the Entschiedungsproblem. *Journal of Symbolic Logic* 1:40-41.
Clarke, Andy. 2003. *Natural-Born Cyborgs: Minds, Technologies, and the Future of Human Intelligence*, Oxford U. Press.
Coleman, Sidney. 1988. Black holes as red herrings: topological fluctuations and the loss of quantum coherence. *Nuclear Physics* B 307(864).
Coren, Richard. 1998. *The Evolutionary Trajectory: The Growth of Information in the History and Future of Earth*, CRC.
Corning, Peter. 2003. *Nature's Magic: Synergy in Evolution and the Fate of Humankind*, Cambridge University Press.
Crane, Louis. 1994. Possible Implications of the Quantum Theory of Gravity: An Introduction to the Meduso-Anthropic Principle. arXiv:hep-th/9402104v1
Darwin, Charles. 1859. *On the Origin of Species By Means of Natural Selection*, John Murray.
—— 1871. *The Descent of Man, and Selection in Relation to Sex*, John Murray
Davies, Paul C.W. 1987[2004]. *The Cosmic Blueprint: New Discoveries in Nature's Creative Ability to Order the Universe*, Templeton Foundation Press:
—— 2004. How bio-friendly is the universe? arXiv:astro-ph/0403050
—— 2007. *The Goldilocks Enigma: Why Is the Universe Just Right for Life?*, Penguin.
Dawkins, Richard. 1976[2006]. *The Selfish Gene*, Oxford U. Press.
Deacon, Terrence W. 1997. *The Symbolic Species: The Co-Evolution of Language and the Brain*, W.W. Norton.
de Duve, Christian. 1995. *Vital Dust: Life as Cosmic Imperative*, Basic Books.
De Morgan, Augustus 1872. *A Budget of Paradoxes*, Longmans, Green, and Co.
Dennett, Daniel C. 1998. *Brainchildren: Essays on Designing Minds*, MIT Press.
de Rosnay, Joël. 1979. *The Macroscope: A Systemic Approach to Complexity (Online Book)*, Harper & Row.
—— 2000. *The Symbiotic Man*, McGraw Hill.
Descartes, René. 1641. *Meditations on First Philosophy*, in *The Philosophical Writings of René Descartes*, Cambridge U. Press, 1984, vol. 2, pp. 1-62.
Deutsch, David. 1985. Quantum theory, the Church-Turing Principle and the Universal Quantum Computer. *Proceedings of the Royal Society* 400: 97-117.
—— 1997. *The Fabric of Reality*, Penguin.
de Vaucouleurs, Gerard. 1970. The Case for a Hierarchical Cosmology. *Science* 27(167):1203-1213.
Devezas, Tessaleno C. and Modelski, George. 2003. Power law behavior and world system evolution: A millennial learning process. *Technological Forecasting & Social Change* 70(9):819-859.

Dewar, Roderick C. 2003. Information theory explanation of the fluctuation theorem, maximum entropy production, and self-organized criticality in non-equilibrium stationary states. *J. Phys. A: Math. Gen.* 36:631-41. [Has a critical math mistake, see Grinstein and Linsker 2007].
—— 2005. Maximum entropy production and the fluctuation theorem. *J. Phys. A: Math.Gen.* 38:L371-L381.
Dewey, John. 1927[1954]. *The Public and Its Problems*, Swallow Press.
Diamond, Jared. 1991. *The Third Chimpanzee: The Evolution and Future of the Human Animal*, Hutchinson Radius.
Dick, Steven J.. 1999. *The Biological Universe: The Twentieth Century Extraterrestrial Life Debate and the Limits of Science*, Cambridge U. Press.
—— 2000. *Many Worlds: The New Universe, Extraterrestrial Life, and the Theological Implications*, Templeton Foundation Press.
—— 2003. Cultural evolution, the postbiological universe and SETI. *International Journal of Astrobiology* 2(1):65-74.
—— 2006. Anthropology and the Search for Extraterrestrial Intelligence: An Historical View. *Anthropology Today* 22(2):3-7.
Dodson, Edward O. 1984. *The Phenomenon of Man Revisited: A Biological Viewpoint on Teilhard de Chardin*, Columbia U. Press.
Drexler, K. Eric. 1986. *Engines of Creation: The Coming Era of Nanotechnology*, Anchor.
—— 1992. *Nanosystems: Molecular Machinery, Manufacturing, and Computation*, Wiley.
Drexler, K. Eric et al. 2007. Technology Roadmap for Productive Nanosystems, Battelle Memorial Institute. http://www.e-drexler.com/p/07/00/1204TechnologyRoadmap.html
Duff, Michael J., Okun, Lev B. and Veneziano, Gabriele. 2002. Trialogue on the number of fundamental constants. *Journal of High Energy Physics* 3:19-42. http://arxiv.org/abs/physics/0110060.
du Noüy, Pierre Lecomte. 1947. *Human Destiny*, Longmans, Green & Co., 273 pp.
Dyson, Freeman. 1988[2004]. *Infinite in All Directions*, HarperCollins.
Edelman, Gerald. 1989. *Neural Darwinism: The Theory of Neuronal Group Selection*, Basic Books,
Eigen, Manfred. 1979. *The Hypercycle: A Principle of Natural Self-Organization*, Springer-Verlag.
Elias, Norbert. 1978[2000]. *The Civilizing Process: Sociogenetic and Psychogenetic Investigations*, Wiley-Blackwell.
Eriksen, Thomas H. 2001. *Tyranny of the Moment: Fast and Slow Time in the Information Age*, Pluto Press.
Erlich, Paul R. 1968. *The Population Bomb*, Ballantine Books.
Fabel, Arthur. 1981. *Cosmic Genesis: Teilhard de Chardin and the emerging scientific paradigm*, ANIMA Books.
—— 2004+. NaturalGenesis.net. "An annotated anthology and sourcebook for the concept of a creative, organic universe." Thoughtful, holistic perspectives on the value of an organic worldview.
Farhi, Edward and Guth, Alan. 1987. An obstacle to creating a universe in the laboratory. *Physical Review Letters* B183(2)149-155.
Ferrer I Cancho, Ramon and Solé, Ricard. 2003. Least effort and the origins of scaling in human language. *Proceedings of the National Academy of Sciences* 100(3):789-791.
Ferris, Timothy. 1998. *The Whole Shebang: A State-of-the-Universe(s) Report*, Simon & Schuster.
Feynman, Richard. 1959. There's Plenty of Room at the Bottom. Lecture to the American Physical Society, Caltech, 29 Dec 1959.
Fisher, Ronald A. et al. 1943. The Relation Between the Number of Species and the Number of Individuals in a Random Sample of an Animal Population. *Journal of Animal Ecology* 12:42-58.
Floridi, Luciano. (ed.) 2003. *The Blackwell Guide to the Philosophy of Computing and Information*, Wiley-Blackwell.
—— 2008. *Philosophy of Computing and Information: Five Questions*, Automatic Press.
Flowers, Jeff and Petley, Brian. 2004. Constants, Units, and Standards. *Lecture Notes in Physics* 648:75-93.
Frank, Steven A. 2009. The Common Patterns of Nature. *Journal of Evolutionary Biology* 22:1563-1585.
Fredkin, Edward. 1990. Digital mechanics. *Physica D* 45(1-3):254-270.
—— 1992. Finite Nature. *Proceedings of the XXVIIth Rencontre de Moriond.*
Frolov, Valeri P. et al. 1989. Through a black hole into a new universe? *Physics Letters* B 216:272-276.
Fuller, R. Buckminster. 1938 [2000]. *Nine Chains to the Moon*, Doubleday.
—— 1979. *Synergetics 2: Further Explorations in the Geometry of Thinking*, Macmillan.
—— 1981 [1982]. *Critical Path*, St. Martin's Griffin.
Fuster, Joaquin M. 2002. *Cortex and Mind: Unifying Cognition*, Oxford U. Press.
Gardner, James N. 2000. The selfish biocosm: Compexity as cosmology. *Complexity* 5(3):34-45.
—— 2003. *Biocosm: The New Scientific Theory of Evolution – Intelligent Life is the Architect of the Universe*, Inner Ocean Pub.
—— 2003. Coevolution of the Cosmic Past and Future: The Selfish Biocosm as a Closed Timelike Curve. *Complexity* 10(5)14-21.
—— 2007. *The Intelligent Universe: AI, ET, and the Emerging Mind of the Cosmos*, New Page.
Gelernter, David. 1993. *Mirror Worlds: Or the Day Software Puts the Universe in a Shoebox… How It Will Happen and What It Will Mean*, Oxford U. Press.
Gershenson, Carlos. 2007. *Design and Control of Self-Organizing Systems*. PhD Dissertation, Vrije Universiteit Brussel, http://homepages.vub.ac.be/~cgershen/thesis.html
—— 2008. The World as Evolving Information. http://arxiv.org/PS_cache/arxiv/pdf/0704/0704.0304v2.pdf

Gibson, James J. 1979. *The Ecological Approach to Visual Perception*, Houghton Mifflin
Gintis, Herbert et al. (eds.) 2005. *Moral Sentiments and Material Interests: The Foundations of Cooperation in Economic Life*, MIT Press.
Gleick, James. 2000. *Faster: The Acceleration of Just About Everything*, Vintage.
Gnedin, Nickolay Y. 2005. Cosmology: Digitizing the Universe. *Nature* 435:572-573
Gödel, Kurt. 1934. On Undecideable Propositions of Formal Mathematical Systems, lecture notes taken by Kleene and Rossner at the Institute of Advanced Study. Reprinted in Davis, M. (ed.) *The Undecidable*, Raven Press, 1965.
Goethe, Johann W.v. 1790. Metamorphosis of Plants (Versuch die Metamorphose der Pflanzen zu erkläre).
Good, Irving J. 1965. Speculations Concerning the First Ultra Intelligent Machine. In: *Advances in Computers, Vol.6*, F.L. Alt and M. Rubinoff (eds.), Academic Press, pp. 31-88.
Gott, J. Richard III. 1993. Implications of the Copernican principle for our future prospects. *Nature* 363: 315–319.
—— 1994. Future prospects discussed. *Nature* 368:108.
Gott, J. Richard III and Li, Li-Xin. 1997[2002]. Can the Universe Create Itself? http://xxx.lanl.gov/PS_cache/astro-ph/pdf/9712/9712344.pdf
Gould, Stephen J. 1977. *Ontogeny and Phylogeny*, Harvard U. Press.
—— 1992. Impeaching a Self-Appointed Judge. *Scientific American* July:118-121.
—— 2002. *The Structure of Evolutionary Theory*, Harvard U. Press.
—— 2007. *The Richness of Life: The Essential Stephen Jay Gould*, Steven Rose (ed.), Norton.
Grinstein, G., and Linsker, R. 2007. Comments on a derivation and application of the 'maximum entropy production' principle. *J. Phys. A: Math. Theor.* 40:9717-20. [Points out a critical mathematical mistake in Roderick Dewar's MEP work].
Grou, Pierre. 1987. *L' Aventure Economique de l'australopithèque aux multinationales*, Hartmattan.
Gurr, Ted R. 1981. Historical Trends in Violent Crime: A Critical Review of the Evidence. In: *Crime and Justice: An Annual Review of Research*, iii, p.285-353.
Haeckel, Ernst. 1899 [1992]. *The Riddle of the Universe*, Prometheus Books.
Halévy, Daniel. 1948 "Essai sur l'acceleration de l'histoire (Essay on the acceleration of history), Les Iles d'Or, 166 pages.
Hall, Brian K. (ed.). 2003. *Environment, Development, and Evolution: Toward a Synthesis*, MIT Press.
Hanson, Robin. 1996[1998]. "The Great Filter - Are We Almost Past It?", http://hanson.gmu.edu/greatfilter.html
Hardin, Garrett. 1995. *Living Within Limits: Ecology, Economics, and Population Taboos*, Oxford U. Press.
Harrison, Edward R. 1995. The Natural Selection of Universes Containing Intelligent Life. *Quarterly Journal of the Royal Astronomical Society* 36:193.
—— 1998. Creation and fitness of the universe. *Astronomy & Geophysics* 39(2):27
Hart, Michael H. and Zuckerman, Ben. 1982 [1995]. *Extraterrestrials: Where Are They?*, Cambridge U. Press.
Harvey, David. 1989. *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change*, Blackwell.
Harwit, Martin. 1981. *Cosmic Discovery: The Search, Scope and Heritage of Astronomy*, Basic Books.
Hawking, Stephen W. 1987. Coherence down the wormhole. *Physics Letters* B 195(337).
—— 1988. Wormholes in spacetime. *Physical Review* D 37(904).
—— 1993. *Black Holes and Baby Universes – and Other Essays*, Bantam.
—— 2005. Information Loss in Black Holes. arxiv:hep-th/0507171
Hegel, G.W.F. 1807[1977]. *The Phenomenology of Spirit*, Clarendon Press.
Henderson, Lawrence J. 1913. *The Fitness of the Environment for Life*, Macmillan.
—— 1917. *The Order of Nature*, Harvard U. Press.
Heylighen, Francis. 1999. The Growth of Structural and Functional Complexity during Evolution. In: *The Evolution of Complexity*, F. Heylighen, J. Bollen & A. Riegler (eds.), Kluwer Academic, p. 17-44. http://pespmc1.vub.ac.be/Papers/ComplexityGrowth.html
—— 2007a. Accelerating Socio-Technological Evolution: from ephemeralization and stigmergy to the global brain. In: *Globalization as an Evolutionary Process: Modeling Global Change*, George Modelski, Tessaleno Devezas, and William Thompson (eds.), Routledge, p.286-335.
—— 2007b. Mediator Evolution. In: *Worldviews, Science and Us*, D. Aerts, B. D'Hooghe & N. Note (eds.), World Scientific.
—— 2007c. The Global Superorganism: an evolutionary-cybernetic model of the emerging network society. *Social Evolution and History*, 6(1):58-119.
Heylighen, Francis et al. 1993+ Principia Cybernetica Web. A broad and deep web-based exploration of evolutionary-systemic and cybernetic philosophy. Promotes 'MetaSystem Transition Theory' of hierarchical emergence.
Hofkirchner, Wolfgang. (ed). 1999. *The Quest for a Unified Theory of Information*, Routledge.
Hofstadter, Douglas R. 1995. *Fluid Concepts and Creative Analogies*, Basic Books.
Holland, John. 1995. *Hidden Order: How Adaptation Builds Complexity*, Perseus Books.
—— 1998. *Emergence: From Chaos to Order*, Perseus Books.
Horneck, Gerda and Rettberg, Petra (eds.). 2007. *Complete Course in Astrobiology*, Wiley-VCH.
Horgan, John. 1996. *The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age*, Broadway Books.
Hoyle, Fred. 1983. *The Intelligent Universe: A New View of Creation and Evolution*, Holt, Rhinehart & Winston.
Jablonka, Eva and Lamb, Marion J. 1995. *Epigenetic Inheritance and Evolution: the Lamarckian Dimension*, Oxford U. Press.

—— 2005. *Evolution in Four Dimensions: Genetic, Epigenetic, Behavioral, and Symbolic Variation in the History of Life*, MIT Press.
Inglehart, Ronald and Welzel, Christian. 2005. *Modernization, Cultural Change, and Democracy: The Human Development Sequence*, Cambridge U. Press.
Iranfar, Negin et al. 2003. Genome-Wide Expression Analyses of Gene Regulation during Early Development of Dycostelium discoideum. *Eukaryotic Cell* 2(4):664-670.
Jacob, François. 1977. Evolution and tinkering. *Science* 196:1161-1166.
Jacoby, Susan. 2008. *The Age of American Unreason*, Pantheon.
Jain, Anil K. et al. 2002. On the similarity of identical twin fingerprints. *Pattern Recognition* 35:2653-2663.
James, William. 1921. *Pragmatism, a New Name for Some Old Ways of Thinking*, Longmans, Green.
Jantsch, Erich. 1980. *The Self-Organizing Universe*, Pergamon.
Jaynes, Edwin T. 1957a. Information Theory and Statistical Mechanics. *Phys. Rev*, 106**:**620
—— 1957b. Information Theory and Statistical Mechanics II. *Phys. Rev.*, 108**:**171
—— 2003. *Probability Theory: The Logic of Science.* G.L. Bretthorst (ed.), Cambridge University Press.
Johansen, Anders and Sornette, Didier. 2001. Finite-time singularity in the dynamics of the world population, economic and financial indices. *Physica A* 294(3-4):465-502.
Johnson, Norman L. et al. 1998. Symbiotic Intelligence: Self-Organizing Knowledge on Distributed Networks Driven by Human Interaction, In: *Artificial Life VI: Proceedings of the 6th International Conference on Artificial Life*, Christoph Adami et al. (eds.), MIT Press.
Kahn, Herman. 1960. *On Thermonuclear War*, Princeton U. Press.
Kant, Immanuel. 1781[1999]. *Critique of Pure Reason*, Cambridge U. Press.
—— 1788[1997]. *Critique of Practical Reason*, Cambridge U. Press.
—— 1790[2007]. *Critique of Judgment*, Oxford U. Press.
Kauffman, Stuart. 1993. *Origins of Order: Self-Org. and Selection in Evolution*. Oxford University Press.
—— 1995. *At Home in the Universe*. Oxford University Press.
Keller, Laurent. 1999. *Levels of Selection*, Princeton U. Press.
Kelly, Kevin. 2005. How does technology evolve? Like we did. TED Conference (presentation video).
Kelso, JA Scott. 1995. *Dynamic Patterns: The Self-Organization of Brain and Behavior*, MIT Press.
Kimura, Motoo. 1983. *The Neutral Theory of Molecular Evolution*, Cambridge U. Press.
King, Chris C.. 1978. Unified Field Theories and the Origin of Life. *University of Auckland Mathematics Rept. Ser.* 134.
—— 2001. *Biocosmology Part 1 Prebiotic Epoch: Symmetry-Breaking and Molecular Evolution*, WED Monographs 2(1)1-20.
Kirkwood, Tom B.L. 1977. Evolution of aging. *Nature* 270:301-304.
—— 1999. *Time of Our Lives: The Science of Human Aging*, Oxford U. Press.
—— 2005. Understanding the odd science of aging. *Cell* 120:437-447.
Kleidon, Axel. 2004. Beyond Gaia: Thermodynamics of Life and Earth system functioning. *Climatic Change* 66(3):271-319
Kleidon, Axel and Lorenz, Ralph D. 2005. *Non-equilibrium Thermodynamics and the Production of Entropy: Life, Earth, and Beyond*, Springer.
Koh, Heebyung and Magee, Chris L. 2006. A functional approach for studying technological progress: Application to information technology. *Technological Forecasting & Social Change* 73:1061-1083.
—— 2008. A functional approach to technological progress: extension to energy technology. *Technological Forecasting & Social Change* 75:735-758.
Korotayev, Andrey, et. al. 2006. *Introduction to Social Macrodynamics: Secular Cycles and Millennial Trends*. URSS.
—— 2006. *Introduction to Social Macrodynamics: Compact Macromodels of World System Growth*. URSS.
Krauss, Lawrence M. and Scherrer, Robert J. 2007. *Journal of General Relativity and Gravitation* 39(10):1545-1550 and arXiv.org/abs/0704.0221
—— 2008. The End of Cosmology?: An accelerating universe wipes out traces of its own origins. *Scientific American* 298(3):46-53.
Krauss, Lawrence M. and Starkman, Glenn. 2004. Universal Limits on Computation. arXiv:astro-ph/0404510v2
Krauss, Lawrence M. et al. 2008. Anthropic Arguments and the Cosmological Constant, with and without the Assumption of Typicality. *Physical Review Letters* 100(04):1301.
Kunstler, James H. 2005. *The Long Emergency: Surviving the Converging Catastrophes of the Twenty-First Century*, Grove/Atlantic.
Kurzweil, Ray. 1990. *The Age of Intelligent Machines*. MIT Press.
—— 1999. *The Age of Spiritual Machines: When Computers Exceed Human Intelligence*, Penguin.
—— 2001. The Law of Accelerating Returns. http://www.kurzweilai.net/articles/art0134.html?printable=1.
—— 2005. *The Singularity is Near: When Humans Transcend Biology*, Penguin.
Laland, Kevin N. et al. 2000. Niche Construction, Biological Evolution and Cultural Change. *Behavioral and Brain Sciences* 23(1):131-175.
Landauer, Rolf. 2002. Information is inevitably physical. In: *Feynman and Computation*, Anthony J.G. Hey (ed.), Westview Press.

Landes, David S. 1999. *The Wealth and Poverty of Nations: Why Some Are So Rich and Some So Poor*, W.W. Norton.
Lasch, Christopher. 1991. *Culture of Narcissism: American Life in an Age of Diminishing Expectations*, W.W. Norton.
Laszlo, Ervin. 1987 [1996]. *Evolution: The General Theory*, Hampton Press.
Lazcano, Antonio. and Bada, Jeffrey L. 2004. The 1953 Stanley L. Miller Experiment: Fifty Years of Prebiotic Organic Chemistry. *Origins of Life and Evolution of Biospheres* 33:235-242.
Lehners, Jean-Luc, Steinhardt, Paul J., Turok, Niel. 2009. The Return of the Phoenix Universe. arXiv:0910.0834
Leigh, Egbert G. Jr. 2007. Neutral theory: A historical perspective. *Evolutionary Biology* 20:2075-2091.
Lenski, Richard E. 2004. Phenotypic and genomic evolution during a 20,000-generation experiment with the bacterium *Escherichia coli*. *Plant Breeding Reviews* 24:225-65.
Leslie, John. 1989. *Universes*, Routledge.
—— 1998. *The End of the World: The Science and Ethics of Human Extinction*, Routledge.
Levy-Leblond, J.-M. 1979. *The importance of being (a) constant*. In: *Problems in the Foundations of Physics*, G. Torraldi (ed.), Enrico Fermi School LXXII.
Lewin, Roger. 1988. A Lopsided Look at Evolution: An analysis of the fossil record reveals some unexpected patterns in the origin of major evolutionary innovations, patterns that presumably reflect the operation of different mechanisms, *Science*, 241:291-293. (15 July)
Linde, Andrei. 1994. The Self-Reproducing Inflationary Universe, *Scientific American*, 271(5):48-55.
Lloyd, Seth. 2000a. Ultimate physical limits to computation. *Nature* 406:1047-1054.
—— 2000b. How Fast, How Small and How Powerful? Moore's Law and the Ultimate Laptop, Edge.org. http://www.edge.org/3rd_culture/lloyd/lloyd_index.html
—— 2001 [2002]. Computational capacity of the universe. *Physical Review Letters* 88: 237901 (2002). Also at: arXiv:quant-ph/0110141v1 (2001).
—— 2006. *Programming the Universe: A Quantum Computer Scientist Takes On the Cosmos*, Vintage.
Lorenz, Ralph. 2003. Full Steam Ahead—Probably. *Science* 299:837-838.
Lotka, Alfred. J. 1922. Contribution to the energetics of evolution, and Natural selection as a physical principle. *Proceedings of the National Academy of Sciences* 8:147–154.
Lotze, Hermann. 1879 [1884]. *Metaphysics: Ontology, Cosmology, and Psychology*, ed. and trans. by B. Bosanquet, Clarendon Press.
Lovelock, James E. and Margulis, Lynn. 1974. Atmospheric homeostasis by and for the biosphere – The Gaia hypothesis. *Tellus* 26(1):2-10.
Lunine, Jonathan I. 2004. *Astrobiology: A Multi-Disciplinary Approach*, Benjamin Cummings.
Maddison, Angus. 2007. *Contours of the World Economy: 1-2030 A.D.: Essays in Macro-Economic History*, Oxford U. Press.
Magee, Chris L. 2009. Towards Quantification of the Role of Materials Innovation in Overall Technological Development. Working Paper ESD-WP-2009-09, Massachusetts Institute of Technology.
Malkiel, Burton G. 1973 [2007]. *A Random Walk Down Wall Street*, W.W. Norton.
Marinetti, Filippo. 1916. The New Religion-Morality of Speed. [Futurist Manifesto, *L'Futalia Futurista* May 11 1916.
Margulis, Lynn. 1999. *Symbiotic Planet: A New Look at Evolution*, Basic Books.
Martin, Brian. 1982a. The global health effects of nuclear war. *Current Affairs Bulletin* 59(7):14-26.
—— 1982b. Critique of nuclear extinction. *Journal of Peace Research* 19(4):287-300.
—— 1983. The fate of extinction arguments, multiply submitted but unpublished (Martin's stance is unpopular but true I think).
Martyushev L.M. and Seleznev V.D. 2006. Maximum entropy production principle in physics, chemistry and biology. *Physics Reports* 426:1-45.
McCabe, Gordon. 2006. Extending cosmological natural selection. arXiv:gr-qc/0610016v1.
McLuhan, Marshall. 1964. *Understanding Media: The Extensions of Man*, McGraw Hill.
Meadows, Donella H. et. al. 1972. *Limits to Growth*, Universe Books.
Meyer, François. 1947. *L'acceleration evolutive. Essai sur le rythme evolutif et son interpretation quantique*, Librairie des Sciences et des Arts, Paris, 67p.
—— 1954. *Problématique de l'évolution*, Presses Universitaires de France, 279p.
Meyers, Robert A. 2009. *Encyclopedia of Complexity and Systems Science*, Springer.
Milinkovitch, Michel C. and Tzika, Athanasia. 2007. Escaping the Mouse Trap: The Selection of New Evo-Devo Model Species. *Journal of Experimental Zoology (Mol Dev Evol)* 308B:337-346.
Miller, James Grier. 1978. *Living Systems*, McGraw-Hill.
Miller, Stanley L. 1953. Production of Amino Acids Under Possible Primitive Earth Conditions. *Science* 117: 52.
Monod, Jacques. 1970. *Chance and Necessity*, Knopf.
Moravec, Hans. 1979. Today's Computers, Intelligent Machines, and Our Future. *Analog Science Fiction and Fact*, Feb 1979.
—— 1988. *Mind Children: The Future of Robot and Human Intelligence*, Harvard U. Press.
—— 1999. *Robot: Mere Machine to Transcendent Mind*, Oxford U. Press.
Morris, Mark. 1993. Massive star formation near the Galactic center and the fate of the stellar remnants. *Astrophysical Journal*, 208(2):496-506.
Morris, Simon Conway. 1998. *The Crucible of Creation: The Burgess Shale and the Rise of Animals*, Oxford U. Press.

—— 2000. The Cambrian "explosion": Slow-fuse or megatonnage? *PNAS* 97(9):4426-4429.
—— 2004. *Life's Solution: Inevitable Humans in a Lonely Universe*, Cambridge U. Press.
—— 2008. *The Deep Structure of Biology: Is Convergence Sufficiently Ubiquitous to Give a Directional Signal*, Templeton Foundation Press
Müller, Gerd B. and Newman, Stuart A. (eds.). 2003. *The Origination of Organismal Form: Beyond the Gene in Developmental and Evolutionary Biology*, MIT Press.
Muno, Michael et. al. 2005. Presentation at the American Astronomical Society, 10 Jan, San Diego, CA. See: Astronomers Find Evidence for Tens of Thousands of Black Holes, *ScienceDaily*, 11 Jan 2005.
Murchie, Guy. 1978. *The Seven Mysteries of Life*, Houghton Mifflin.
Nagamine, Kentaro and Loeb, Abraham. 2003. Future Evolution of Nearby Large-Scale Structures in a Universe Dominated by a Cosmological Constant. *New Astronomy* 8:439-448. http://arxiv.org/PS_cache/astro-ph/pdf/0204/0204249v3.pdf
Nagy, Bela et. al. 2010. Superexponential Long-term Trends in Information Technology. SFI Working Paper.
Nambu, Yoichiro. 1985. Directions of Particle Physics. *Progress of Theoretical Physics Supp* 85(104).
National Aeronautics and Space Administration. Lochner, James and Kinnison, Suzanne P. 2003[2005]. What is Your Cosmic Connection to the Elements? erc.ivv.nasa.gov/pdf/190387main_Cosmic_Elements.pdf
Newcomb, Simon. 1903. The Universe as an Organism. *Science*, 17:421, pp. 121-129
Newman, S.A. and Bhat, R. 2008. Dynamical patterning modules: physico-genetic determinants of morphological development and evolution. *Phys. Biol.* 5 015008 (14p). doi:10.1088/1478-3975/5/1/015008 http://www.iop.org/EJ/abstract/1478-3975/5/1/015008/
Nicolis, Grégoire and Prigogine, Ilya. 1977. *Self-Organization in Nonequilibrium Systems*, Wiley & Sons.
Nordhaus, William D. 2007. Two Centuries of Productivity Growth in Computing. *The Journal of Economic History* 67:128-59.
Nottale, Laurent et al. 2000a. On the fractal structure of evolutionary trees. In: *Fractals in Biology and Medicine, Vol. III*, Proceedings of Third International Symposium, Ascona, Switzerland, March 8-11, 2000, Ed. G. Losa, D. Merlini, T. Nonnenmacher and E. Weibel, Birkhäuser Verlag, pp. 247-258.
—— 2000b. *Les Arbres de l'Evolution* (*The Trees of Evolution*), Hachette. http://fractalspace.ifrance.com/livre2.htm
O'Brien, Richard. 1992. *Global Financial Integration: The End of Geography*, Council on Foreign Relations Press.
Odling-Smee,, F. John. 2003. *Niche Construction: The Neglected Process in Evolution*, Princeton U. Press.
Okasha, Samir. 2007. *Evolution and the Levels of Selection*, Oxford U. Press.
Oldershaw, Robert L. 1981. Conceptual Foundations of the Self-similar Hierarchical Cosmology. *International Journal of General Systems* 7(2).
—— 1989. The Self-Similar Cosmological Model: Introduction and Empirical Tests. *International Journal of Theoretical Physics* 28(6), 669-694.
Pagels, Heinz. 1988. *The Dreams of Reason: The Rise of the Sciences of Complexity*, Simon & Schuster.
Pattee, Howard (ed.). 1973. *Hierarchy Theory: The Challenge of Complex Systems*, George Braziller.
Paul, Gregory S. and Cox, Earl. 1996. *Beyond Humanity: Cyberevolution and Future Minds*, Charles River Media.
Piel, Gerard. 1972. *The Acceleration of History*, Knopf.
Peirce, Charles S. 1868. On a New List of Categories, *Proc. Amer. Academy Arts and Sciences* 7:287-298
—— 1935. *Collected Papers, Vol. VI: Scientific metaphysics*, C. Hartshorne and P. Weiss (eds), Harvard U. Press, p. 26.
Pinker, Steven. 2007. A History of Violence, *The New Republic* Online Edition, 3.19.07 http://www.edge.org/3rd_culture/pinker07/pinker07_index.html
John Platt 1981. The Acceleration of Evolution. *The Futurist*, Feb 1981.
Poundstone, William. 1985. *The Recursive Universe: Cosmic Complexity and the Limits of Scientific Knowledge*, Contemporary Books.
Primack, Joel R. and Abrams, Nancy Ellen. 2006. *The View from the Center of the Universe: Discovering our Extraordinary Place in the Cosmos*, Riverhead Books.
Raff, Rudolf. 1996. *The Shape of Life: Genes, Development, and the Evolution of Animal Form*. U. of Chicago Press.
Randall, Lisa. 2005. *Warped Passages: Unraveling the Mysteries of the Universe's Hidden Dimensions*, Harper Perennial.
Rees, Martin J. 1999. *Just Six Numbers: The Deep Forces that Shape the Universe*, Basic Books.
—— 2001. *Our Cosmic Habitat*, Princeton U. Press.
Reid, Robert G.B. 2007. *Biological Emergences: Evolution by Natural Experiment*, MIT Press.
Ricardo, Alonso and Szostak, Jack W. 2009. The Origin of Life on Earth. *Scientific American*. Sept.
Richards, Mark A. and Shaw, Gary A. 2004. Chips, Architectures and Algorithms: Reflections on the Exponential Growth of Digital Signal Processing Capability. Submitted to *IEEE Signal Processing Magazine*, Dec 2004.
Ridley, Matt. 2010. *The Rational Optimist: How Prosperity Evolves*, Harper.
Roederer, Juan G. 2005. *Information and its Role in Nature*, Springer-Verlag.
Rosa, Hartmut and Scheuerman, William (eds). 2009. *High-Speed Society: Social Acceleration, Power and Modernity*, Penn State U. Press.
Rosa, Hartmut. 2010. *Acceleration*, Editions La Decouverte.
Sagan, Carl. 1973. *The Cosmic Connection: An Extraterrestrial Perspective*, Doubleday.

—— 1977. *The Dragons of Eden: Speculations on the Evolution of Human Intelligence*, Random House.
—— 1997. *Contact* [fiction], Doubleday.
Salthe, Stanley M. 1981. *The New Evolutionary Timetable: Fossils, Genes and the Origin of Species*, Basic Books, p. 40.
—— 1985. *Evolving Hierarchical Systems: Their Structure and Representation.* Columbia U. Press.
—— 1993. *Development and Evolution: Complexity and Change in Biology*, MIT Press.
—— 2002. Summary of the principles of hierarchy theory. *General Systems Bulletin* 31:13-17.
—— 2003. Infodynamics, a developmental framework for ecology/economics. *Conservation Ecology* 7(3):1-19.
Sasselov, Dimitar. 2010. How we found hundreds of potential Earth-like planets, *TEDGlobal* video presentation, Jul 2010.
Schelling, F.W.J.. 1800 [1936]. System of transcendental idealism. In: *Of human freedom*, J. Guttmann (Trans.), Open Court, p. 318.
Scheuerman, William. 2004. *Liberal Democracy and the Social Acceleration of Time*, Johns Hopkins U. Press.
Schlosser, Gerhard and Wagner, Gunter P. (Eds.). 2004. *Modularity in Development and Evolution*. U. of Chicago Press.
Schrödinger, Erwin. 1944. *What is Life?*, Cambridge U. Press.
Schroeder, Karl and Ćirković, Milan. 2008. Are SETI Projects Probing the "Right Wall" of Complexity? To be presented at the First International Conference on the Evolution and Development of the Universe, Oct. 8, 2008.
Shannon, Claude E. 1948. A Mathematical Theory of Communication. *Bell System Technical Journal*, July and October Issues.
Shapley, Harlow. 1930. *Flights from Chaos*, McGraw Hill.
Sharp, James A. 1985. Debate: the history of violence in England, some observations. *Past and Present* 108(Aug):206-15.
Siefe, Charles. 2006. *Decoding the Universe: How the New Science of Information is Explaining Everything in the Cosmos, from our Brains to Black Holes*, Viking.
Simon, Herbert A. 1962. The architecture of complexity. *Proceedings of the American Philosophical Society* 106:467-82.
—— 1973. The Organization of Complex Systems. In: *Hierarchy Theory*, H. Pattee (Ed.), George Braziller.
Sipper, Moshe. 1999. *Machine Nature: The Coming Age of Bio-Inspired Computing*, McGraw-Hill.
Smart, John M. 1999+. AccelerationWatch.com (formerly SingularityWatch.com). Discussing accelerating change from universal, global, societal, organizational, and personal perspectives.
—— 2000[2008]. Intro to the Developmental Singularity Hypothesis. http://www.accelerationwatch.com/developmentalsinghypothesis.html
—— 2001[2008]. Limits to Biology: Performance Limitations on Natural and Engineered Biological Systems. http://www.accelerationwatch.com/biotech.html
—— 2002a[2007]. Answering the Fermi Paradox: Exploring the Mechanisms of Universal Transcension. *Journal of Evolution and Technology* June 2002. http://accelerating.org/articles/answeringfermiparadox.html
—— 2002b[2008]. Understanding STEM, STEM+IC, and STEM Compression in Universal Change. http://www.accelerationwatch.com/mest.html
—— 2003[2008]. The Conversational Interface: Our Next Great Leap Forward. http://www.accelerationwatch.com/lui.html
—— 2004. Human Performance Enhancement in 2032: A Scenario for Military Planners. http://www.accelerating.org/articles/hpe2032army.html
—— 2005. Measuring Innovation in an Accelerating World. Published as: Discussion of Huebner article. *Technological Forecasting & Social Change* 72(8):988-995. http://www.accelerating.org/articles/huebnerinnovation.html
Smith, D. Eric and Morowitz, Harold J. 2006. Framing the Question of Fine-Tuning for Intermediary Metabolism. In: *Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning*, J. D. Barrow, et al (eds.), Cambridge U. Press.
Smith, John Maynard and Szathmary, Eörs. 1995. *The Major Transitions in Evolution*, W.H. Freeman.
Smith, Quentin. 1990. A natural explanation of the existence and laws of our universe. *Australasian Journal of Philosophy* 68(1):22-43.
—— 2000. The black hole origin theory of the universe, *Internal Conf. on Physical Cosmology*, Santa Barbara.
Smolin, Lee. 1992. Did the Universe Evolve? *Classical and Quantum Gravity* 9:173-191.
—— 1994. The fate of black hole singularities and the parameters of the standard models of particle physics and cosmology. arXiv:gr-qc/9404011v1.
—— 1997. *The Life of the Cosmos*, Oxford U. Press. http://www.amazon.com/exec/obidos/ASIN/0195126645/
—— 2001. *Three Roads to Quantum Gravity*, Basic Books.
—— 2006. The status of cosmological natural selection. arXiv:hep-th/0612185v1.
Spencer, Herbert. 1864. *Illustrations of Universal Progress: A Series of Discussions*, D. Appleton
—— 1864-1898. *Principles of Biology, Volumes I-II.*
—— 1874-1896. *Principles of Sociology, Volumes I-III.*
—— 1896. *A System of Synthetic Philosophy*, Williams and Norgate.
Springel, Volker et al. 2006. The large-scale structure of the Universe. *Nature* 440:1137-1144.
Steele, Edward J. 1981. *Somatic Selection and Adaptive Evolution: On the Inheritance of Acquired Characters*. 2nd Edition. U. of Chicago Press.
Steele, Edward J. et al. 1998. *Lamarck's Signature: How retrogenes are changing the natural selection paradigm*. Perseus.

Stenger, Victor J. 1990. The Universe: the ultimate free lunch. *European Journal of Physics* 11:236-243.
—— 2000a. Natural Explanations for the Anthropic Coincidences, *Philo* 3(2):50-67.
—— 2000b. *Timeless Reality: Symmetry, Simplicity, and Multiple Universes*, Prometheus Books.
Stent, Gunther S. 1969. *The Coming of the Golden Age: A View of the End of Progress*, Doubleday.
—— 1998. Epistemic Dualism of Mind and Body. *Proc. Amer. Philosophical Society* 142(4):578-588.
—— 2002. *Paradoxes of Free Will*, DIANE Publishing.
Stewart, John. 2000. *Evolution's Arrow: The Direction of Evolution and the Future of Humanity*, The Chapman Press.
Stock, Gregory. 1993. *Metaman: The Merging of Humans and Machines into a Global Superorganism*, Simon & Schuster.
Stone, Lawrence. 1983. Interpersonal Violence in English Society, 1300-1980. *Past and Present* 101(Nov):22-33.
—— 1985. Debate: the history of violence in England, a rejoinder. *Past and Present* 108(Aug):216-24.
Strominger, Andrew. 1984. Vacuum topology and incoherence in quantum gravity. *Physical Review Letters* 52(1733).
Susskind, Lawrence. 2005. *The Cosmic Landscape: String Theory and the Illusion of Intelligent Design*, Back Bay Books.
Szathmary, Eors. 1991. Simple Growth Laws and Selection Consequences, *Trends in Ecology & Evolution*, 6(11):366-370.
Tarko, Vlad. 2005. What is Ergodicity? http://news.softpedia.com/news/What-is-ergodicity-15686.shtml.
Tavernarakis, Nektarios. 2007. Protein Synthesis and Aging. *Cell Cycle* 6(10):1168-1171.
Tegmark, Max. 2008. The Mathematical Universe. *Foundations of Physics* 38:101-50.
Teilhard de Chardin, Pierre. 1945 [1975]. The Planetisation of Mankind. *The Future of Man*, Image, 2004.
—— 1955. *The Phenomenon of Man*, Harper & Row.
Toynbee, Alfred. 1966. "Acceleration in Human History," In: *Change and Habit*, Oxford U. Press.
Turchin, Valentin F. 1977. *The Phenomenon of Science*, Columbia U. Press. http://pespmc1.vub.ac.be/POSBOOK.html
Turing, Alan M. 1936. On Computable Numbers, with an Application to the Entscheidungsproblem. *Proceedings of the London Mathematical Society* 2(42)230-265
Ulanowicz, Robert. 1997. *Ecology, the Ascendant Perspective*, Columbia U. Press.
Ulmschneider, Peter. 2006. *Intelligent Life in the Universe: Principles and Requirements Behind its Emergence, 2nd. Ed.*, Springer.
Vaas, Rüdiger. 1998[2000]. Is there a Darwinian Evolution of the Cosmos? Some Comments on Lee Smolin's Theory of the Origin of Universes by Means of Natural Selection. Proceedings of *MicroCosmos – MacroCosmos* conference, Aachen, Germany, 2-5 Sep 1998. http://arxiv.org/abs/gr-qc/0205119. See also http://www.vijlen.com/confs/mima/Vaas/VAAS.html.
Van Valen, L. and Maiorana, V.C. 1985. Patterns of origination. *Evolutionary Theory* 7:107-125
Varela, Francisco J. 1986. Steps to a Cybernetics of Autonomy. In: *Power and Autonomy: New approaches toward complex systems*, R.Trappl (ed.), Plenum Press.
Verhulst, Jos. 2003. *Discovering Evolutionary Principles through Comparative Morphology*, Adonis Press.
Vermeij, Geerat J. 1987. *Evolution and Escalation*, Princeton U. Press.
Vernadsky Vladimir I., 1926. *Biosphera (The Biosphere)*, Nauchnoe khimiko-technicheskoye izdatel'stvo (Scientific Chemico-Technical Publishing), 200p.
—— 1945. The Biosphere and the Noosphere. *Scientific American* 33(1):1-12.
Vidal, Clément. 2008a. The Future of Scientific Simulations: From Artificial Life to Artificial Cosmogenesis. arXiv 0803.1087.
—— 2008b. Computational and biological analogies for understanding fine tuned parameters in physics. To appear in: *Foundations of Science*, Special Issue of the Conference on the *Evolution and Development of the Universe*, Ecole Normale Supérieure, Paris 8-9 Oct., 2008.
Vinge, Vernor. 1983. First Word. *Omni Magazine*, Jan 1983.
—— 1993. The Coming Technological Singularity. [Presented at the VISION-21 Symposium, NASA Lewis Research Center, 30 Mar, 1993]. http://www.accelerating.org/articles/comingtechsingularity.html
Virilio, Paul. 1986. *Speed and Politics*, Semiotext[e]
Volk, Tyler. 2003. *Gaia's Body: Toward a Physiology of Earth*. MIT Press.
von Baeyer, Hans Christian. 2003. *Information, The New Language of Science*, Weidenfeld & Nicolson.
von Bertalanffy, Ludwig. 1932. *Theoretische Biologie*, Borntraeger.
—— 1968 [1976]. *General System Theory: Foundations, Development, Applications*, George Braziller.
von Foerster, Heinz. et. al. 1960. Doomsday: Friday, November 13, AD 2026. *Science* 132(3436) :1291–1295.
Vonnegut, Kurt. 1963. *Cat's Cradle*. Holt, Rinehart, and Winston.
Wagman and Stephens (2004) Surprising 'ultra-conserved regions discovered in human genome. *UCSC Currents*
Wallace, Alfred Russell. 1912. *Man's Place in the Universe*, Chapman and Hall.
Wallace, Rodrick. 2006. Machine hyperconsciousness. http://cogprints.org/5005/.
Wang, Hurng-Yi et al. 2006. Rate of Evolution in Brain-Expressed Genes in Humans and Other Primates, *PLoS Biology* 5(2):e13 doi:10.1371/journal.pbio.0050013
Ward, Peter and Brownlee, Donald. 2000. *Rare Earth: Why Complex Life is Uncommon in the Universe*, Springer.
Wattenberg, Ben. 2005. *Fewer: How the New Demography of Depopulation Will Shape Our Future*, Ivan R. Dee.
Watters, Ethan. 2006. DNA is Not Destiny. *Discover Magazine*, 11.22.2006.
Webb, Stephen. 2002. *Where is Everybody? Fifty Solutions to the Fermi Paradox and the Problem of Extraterrestrial Life*, Copernicus/Springer-Verlag.

Weinberg, Steven. 1993. *Dreams of a Final Theory: The Search for the Fundamental Laws of Nature*, Pantheon.
Wesley, James Paul. 1974. *Ecophysics: The Application of Physics to Ecology*, Charles C. Thomas.
Wesson, Robert. 1991. *Beyond Natural Selection*, MIT Press, p. 45.
West-Eberhard, Mary Jane. 2003. *Developmental Plasticity and Evolution*, Oxford U. Press.
Wheeler, John A. 1983. Law without law. In: *Quantum Theory and Measurement*, J.A. Wheeler and W.H. Zurek (eds.), Princeton U. Press.
—— 1990, "Information, physics, quantum: The search for links" In: W. Zurek (ed.) *Complexity, Entropy, and the Physics of Information*, Addison-Wesley.
Whitehead, Alfred North. 1925[1997]. *Science and the Modern World*, Simon and Schuster, 224pp.
—— 1927 [1969]. *Process and Reality: An Essay in Cosmology*, Free Press.
—— 1933. *Adventure of Ideas*, Macmillan.
Wiener, Norbert. 1961. *Cybernetics*, MIT Press.
Wigner, Eugene. 1960. The Unreasonable Effectiveness of Mathematics in the Natural Sciences. *Communications in Pure and Applied Mathematics* 13(1).
Wikipedia. 2007. Extraterrestrial Intelligence. http://en.wikipedia.org/wiki/Extraterrestrial_intelligence
Wilkins, Adam S.. 2001. *The Evolution of Developmental Pathways*, Sinauer Associates.
Winiwarter, Peter. 1986. Autognosis: The Theory of Hierarchical Self-Image Building Systems. *Proc. of Intnat'l Conf. on Mental Images, Values & Reality, Soc. for General Systems Research*.
—— 1999. A periodic system of system concepts. *Semiotica* 125(1/3)47-62
—— 2008. *Neural Network Nature: A Small Handbook*. http://www.bordalierinstitute.com/NeuralNetworkNature.pdf
Winiwarter, Peter and Cempel, Czeslaw. 1992. Life Symptoms: the Behavior of Open Systems with Limited Energy Dissipation Capacity and Evolution, *Systems Research* 9(4):9-34.
Wolfram, Stephen. 2002. *A New Kind of Science*, Wolfram Media.
Worldwatch Institute. 2008. *State of the World 2008: Toward a Sustainable Global Economy*, W.W. Norton.
Wright, Robert. 1997. *The Moral Animal: Evolutionary Psychology and Everyday Life*, Pantheon.
—— 2000. *Non-Zero: The Logic of Human Destiny*, Pantheon.
—— 2009. *The Evolution of God*, Little, Brown and Company.
—— 2010. Building One Big Brain, *The New York Times*, 6 July 2010.
Yi, Hong et al. (2010) Gene expression atlas for human embryogenesis. *FASEB Journal* 24(9):3341-3350.
Yudkowsky, Eliezer. 2006. Artificial Intelligence as a Positive and Negative Factor in Global Risk. In: *Global Catastrophic Risks*, Oxford U. Press.
Zipf, George K. 1948. *Human Behavior and the Principle of Least Effort: An Introduction to Human Ecology*, Addison-Wesley.
Zuse, Konrad. 1969. *Rechnender Raum* (English translation: *Calculating Space*), Friedrich Vieweg & Sohn.