Answering the Fermi Paradox: Exploring the Mechanisms of Universal Transcension

Cite as:
Smart, John M. (2005, May 26). Answering the Fermi Paradox. Acceleration Studies Foundation. https://accelerating.org/articles/answeringfermiparadox.html

[**Note:** This paper was accepted for publication by the editors of the *Journal of Evolution and Technology* for their September 2002 issue, intended to accompany a paper by astronomer Milan M. Ćirković. In an unfortunate oversight, it was never web published. This mistake was discovered by the author in May 2025. The original paper (written 6.05.2002) appears below. A slightly expanded version was first published on the website of the Acceleration Studies Foundation in May 2005 (Internet Archive copy, 5.26.2005)

Abstract: I propose that humanity's descendants will not be colonizing outer space. Complex systems rapidly transition to inner space, and apparently soon thereafter to universal transcension. For sixty years answers have been attempted for the Fermi Paradox, yet the vast majority I have read neglect what may be the most parsimonious explanation—constrained universal transcension. I propose that any species or von Neumann probe complex enough to replicate itself through interstellar space would transcend shortly after beginning its journey, for information theoretic reasons. The discrete universe that creates multi-local computational complexity rapidly becomes an informational desert to the leading edge of that local complexity, a constrained and finite developmental soma that is deeply simulated within that organism's inner space, and rapidly outgrown. Fortunately, seed-recreation by such systems starts the cycle over again, in what I term a "developmental singularity." Intelligent life on our planet appears engaged in the creation of one of these developmental singularity seeds, a process that will be rapidly accelerated by the coming technological singularity in this century. This trend is elucidated by the phenomenon of matter-energy and space-time (MEST) efficiency and "compression" in all known universal computation. Emergent complex systems consistently use less, not more, of these fundamental resources (MEST) to encode standardized amounts of environmental information, and they become dramatically more materially, energetically, spatially, and temporally dense over time, rapidly approximating black hole-equivalent energy densities. Systems of emergent local complexity thus lead rapidly to "intelligent" cosmological developmental singularities, highly compressed structures, censored from our observation. This paper will briefly explore apparent universal drivers of accelerating change, MEST compression in computational substrates, evolutionary development in the universe, cosmological natural selection, and the technological and developmental singularity hypotheses.

Introduction to the Transcension Scenario

Once hyperexponentiating computation has permeated virtually all the local matter and energy in its vicinity, what must it do next? There are **at least two competing options** that have been proposed by those presently forecasting the future of cosmic intelligence, **expansion or transcendence**. In expansion, the current perspective of the vast majority of thinkers on this subject, intelligence will inevitably move outward at close to the maximum speed that information can travel. Even with the quantum strangeness and

black hole physics that are currently generally accepted, this speed is apparently some large but very finite fraction of the **speed of light**.

In transcension, once intelligence saturates its local environment, it is constrained to **leave local spacetime**. It learns how to enter hyperspace, that suspected multidimensional environment hinted at in our string and supersymmetry theory, and within which cosmologists tell us new universes may be born and other yet-uncertain events may happen. In transcension, advanced intelligence moves out of our restrictive spacetime, multi-locally, once it reaches a certain point in its development. The developmental singularity hypothesis is one of several possible versions of the transcension scenario, but it need not be proven correct for constrained transcension to remain the destiny of local intelligence.

Cosmologist Lee Smolin, first in a 1992 paper ("Did the Universe Evolve?" *Classical and Quantum Gravity* 9, 173-191) and later in his 1997 book (*The Life of the Cosmos*) has presented early quantitative evidence that universes may perpetuate themselves via "bounces" at black holes to create new universes. This process of "cosmological natural selection", if it exists (or more accurately, developmental "*self-selection*" a distinction best elucidated in another discourse), would explain, by a mechanism of cyclic "self-tuning" through a succession of prior universes, many of the apparently carefully selected "anthropic parameters" of our present universe. That is fascinating, but **Smolin stops short of suggesting a role for intelligence in this line of universal descent.**

The developmental singularity hypothesis, taking up where Smolin leaves off, proposes that all local intelligence tends toward ever-greater matter-, energy-, space-, and time-compressed ("MEST-compressed") computational substrates, ultimately ending in something analogous to a black hole, something with both universe-simulating and universe-recreating capacity. All of our universe's black holes might therefore exist on a continuum of replicative complexity, ranging from **quasar** to **galactic-core** to **stellar** black holes, and each would be expected to create stable lineages of much simpler (and lifeless) universes within the multiverse, right on up to the **"intelligent black holes"** that must also exist in our universe, transcension remnants of universal civilizations, each going on to develop even more complex intelligence-filled universes in the next timeline.

Transcension is a suspiciously elegant solution to the problem of the Fermi Paradox. As Timothy Ferris (*The Mind's Sky*, 1992) points out, any single emergent intelligent civilization, if it wished, could colonize the Milky Way with a "galactic internet" of self-replicating robot probes in only tens of thousands to tens of millions of years. Even our nearest neighboring galaxy, Andromeda, is only two million light years away, a small hop by comparison to the *three to five billion year developmental lead time* that some civilizations must have had over us in our local galactic neighborhood.

Parsing the Drake Equation

This brings us to SETI as a transcension verification tool, but before we can consider that we need to refresh ourselves on **the Drake Equation**, formulated by Frank Drake in 1961, a useful way to package all these issues into a discrete set of probabilities. Drake proposed that the number of signals we might expect will be based on the following terms:

1. The number and rate of formation of suitable stars.
2. The fraction of such stars with planets.
3. The number of life-possible planets per solar system.
4. The fraction of such planets where life actually develops.
5. The fraction of life-bearing planets where intelligence develops.
6. The fraction of intelligence-bearing planets where technology develops.
7. The lifetime of communicating technological civilizations.
8. The desire for such civilizations to actually communicate.

This eighth term is often inexplicably dropped from SETI formulations, but note that for transcension advocates, this is the most important and most overlooked factor in the bunch. It speaks to the question of whether we are seeking **"by-products"** of intelligence when we look at a star and its planets (such as escaped television signals, or simply signs of a life-supporting atmosphere) or are instead looking for some powerful **beacon**, one specifically *designed* for interstellar communication. If we are seeking the former, our job is going to be much harder, and we may not even have the sensitivity to detect such signals until we have detection programs in space, such as the station SETI has proposed we build in Saha crater, on the far side of the moon, isolated from Earth's electromagnetic pollution.

There are two groups of opinion on the first six of the Drake terms. Most **astrophysicists**, citing the large numbers (over a hundred billion stars our galaxy alone) known to be involved in the first term, believe life must also be ubiquitous. This is called an argument from **"the law of large numbers."** Successful planet hunters like Geoff Marcy have recently given us reason to suspect that the second term is also very large.

Astrobiologists, citing the ubiquity of Earth-like, life-supporting chemistry including water, small metallic planets, spectral signatures for the critical elements (e.g., "CHNOPS," sounds like "Schnapps"), and a cosmochemistry that is now known to spontaneously create complex organic molecules, including amino acids, lipids, and even pre-nucleotides (purines and pyrimidines), make increasingly convincing arguments that the third and fourth terms are also quite large.

But when we get to the fourth term, the probability of biogenesis, we run into the second camp, the **biologists**. The majority of this group don't think about universal change developmentally, but rather *evolutionarily*, using the overly simplistic "random and contingent" **neo-Darwinian** view of evolution ("life does not progress, except in rare circumstances, and then only by chance"). Because of this outlook, biologists such as Francisco Ayala think that life, and particularly intelligent life, must be extremely rare and contingent in the universe. Thus Ayala has used estimated low probabilities in these terms (particularly terms five and six), derived from his "randomness" perspective, to argue that our biological intelligence is likely to be alone in this galaxy.

On the other hand, there is an increasing minority of "**developmentalist**" biologists, as cited earlier, who argue that in addition to evolution, developmental or self-organization processes are at work, significantly increasing the probabilities of the emergence of certain forms over time. In other words, the universe is not only evolving, but may be tuned, in its initial parameters, in the same way that genes are tuned over successive

cycles in a developing organism, to engage in an accelerating developmental emergence of multi-local complexity, *including life and intelligence*. Many of these individuals would therefore argue that terms four through six are quite large. Most would further argue that once you have one property (such as life), the next in the series becomes *increasingly* likely to emerge, in percentage terms, and thus intelligence and technology must also be plentiful in the cosmos. This is because **developmental failures (e.g., spontaneous abortions in biological development) become steadily less frequent the further advanced any developmental process, in time or complexity.**

Like Sagan's cosmic calendar, it does seem likely that at least the universal conditions for generating each of these first six situations in the Drake Equation will emerge in an accelerating manner. And specifically with regard to the sixth term, we can use our single data point, technology development on Earth, to observe that it has continued in this hyper-accelerating process.

This brings us to the seventh and eight terms, perhaps the least clearly understood of the lot, at present. Again, there are at least two distinct camps for these terms, our old friends expecting either the expansion or transcension scenarios for intelligent life in the cosmos. There are of course other potential outcomes, such as the possibility of extinction in the process, which we must also carefully consider.

If you expect expansion, then you expect intelligent civilizations to move out as rapidly as they can, shortly after they develop. In that situation, you'd expect both of the last two terms to be very large. Unless you also expect that extinction is a frequent occurrence for intelligent civilizations, in which case you would expect the seventh term, on average to be small. **But while extinction of individual species is quite frequent, the extinction, *or even the slowing down*, of the accelerating emergence of *intelligence* when defined as the *average distributed complexity* of the most complex local evolutionary developmental systems, has so far not been observed in *any* known epochs in our own evolutionary developmental record.** (I'll discuss this fascinating phenomenon at greater length in my forthcoming book). So while the extinction scenario for intelligence is possible and must be continually guarded against, it does not seem likely, at least in our present analysis.

If on the other hand you expect transcension, then you expect intelligent civilizations to leave the observable universe soon after they emerge, and you'd expect both the seventh and eighth terms to be very small.

The ever more rapid development of each successive "stage", paradigm, or substrate of complexity in the universe argues that the lifetime of intelligent civilization (the seventh term) will be surprisingly short (even as the probability of its emergence increases over previous substrates), before it proceeds to create something different, something presumably even more complex. On a surface level, this dramatically progressive time compression of substrate lifespans argues for transcension via the Drake terms.

But those backing that perspective still have a difficult challenge explaining why the eighth term would be so small. Don't we presently desire to communicate with the rest of the universe? Certainly the Voyager and Pioneer probes which we initially expected

would leave our solar system (but later discovered are still trapped in a very elongated solar orbit) are, on one level, examples of that desire. If we believe that intelligence in coming years will become much more of all those benevolent and capable attributes that I've discussed earlier, **why wouldn't all advanced civilizations automatically desire to communicate?**

Communication-Censored Transcension

The developmental singularity hypothesis suggests several possible reasons. First, in the transcension scenario, all intelligent civilizations, almost immediately after they emerge (e.g., over only a few thousand years in cosmic time) rapidly desire transcension. Perhaps their science (and ours) soon discovers (e.g., Einstein of information theory, appearing circa 2040) that *all* multi-local intelligence is developmentally tuned, physically predetermined, to rapidly transcend as well, based on the nature of the structural parameters of *this* universe. If so, it would be quite rare to find two civilizations of comparable complexity both around long enough and close enough together to want to communicate before they transcended. In such circumstances, it is likely that the only kind of "communication" we'd be interested in and able to do, if our universe were tuned for intelligence transcension, would be curiously constrained. First, it would have to occur in the very brief period before our own transcension, and second, **would in almost all cases be restricted to a benevolent *one-way* message sent to less complex systems, perhaps best exemplified as an "Encyclopedia Galactica" primer to help them along in their journey.**

In this model, *we* wouldn't go to other star systems in person, because intelligence is assumed to overwhelmingly converge on transcension. Thus any robot probes we would send that were *too* intelligent would rapidly transcend themselves soon after beginning their journey. So the primer, sent by an army of simple probes, capable of replicating but *not* of increasing their own complexity (if this were possible, which certainly seems plausible) might be the only reasonable communication we could expect in such a scenario.

But if twenty-first or twenty-second century science discovers that *all* universal intelligence is inescapably on a trajectory toward transcension, we might, as in the Prime Directive in Star Trek, decide not to interfere at all with the development of less complex civilizations. We might even be able to prove, with our near-future simulation science, that such interference would *decrease* either the **internally balanced nature** *or* the **diversity** of their transition, or both. Perhaps the fact that we are limited to these *one-way* messages will soon make it clear that such communication will not be desirable. **On Earth, all the most useful communication appears to be two-way.** *Feedback* is an inherent aspect of building valuable complexity, and we use it whenever we engage in responsible, culturally-appropriate development on this planet. Are we sure we could give that up and still do net good? Can we *prove* it, or might we instead prove the reverse? On Earth, we've seen that centrally planned, command economies (one-way communication from the government), even ones focused on technological progress, have been overwhelmingly replaced by ones that locally self-organize their own laws, markets, and prices via two-way communications equilibria. Perhaps it works the same way with universal intelligence: ever more distributed, ever more local self-organization becomes relentlessly preferred with increasing complexity.

Finally, we come to the **diversity argument**, which from my perspective, may be the most powerful of all for a **communication-censored scenario of universal transcension**. One of the most important lessons that evolutionary development has taught us is that nature abhors sameness, or "clonality" wherever it arises. Enforcing our own path to transcension on all those other civilizations via sending them a primer would substantially decrease the variability of their paths, and *that* might significantly decrease the value of evolution in an evolutionary developmental universe. Assuming each intelligence path will be constrained by the nature of computation to come up with an *essentially incomplete* (Godel, Church, Turing, Chaitin) model of the universe prior to transcension, don't we want multiple independent solutions to be generated to this common and most fundamentally interesting problem? *If* transcension is the default, it almost seems as if our present universe's structure (speed of light limit, almost unbreachable distances between civilizations) is *self-designed* to protect this variability.

Inner Space, Not Outer Space

Committed colonizers might try to override all this anyway (see for example Adrian Berry's *The Giant Leap*, 2001), but perhaps it is very difficult to go against the flow, and even statistically impossible. **As mentioned earlier, it is becoming suspiciously likely that all cosmic intelligence heads inevitably toward "inner space," not outer space, as it increases in computational complexity.** Our historical human era of planetary exploration may appear, on untutored examination, like a journey "out", but actually, no new life zones were colonized. In essence, all of Earth's human explorers have been part of an ongoing unconscious effort to wire up an *already previously verdant Earth* into one pulsating global technological consciousness—making our world smaller, not larger. The trajectory of exponentiating complexity has *never* actually involved a true journey out, in the cosmological sense. Even the cyclic birth and death of suns in supernovas is best seen as an initially universal event that rapidly creates locally interesting, high-metallicity solar systems within which further development occurs. The hyperexponential trajectory is always relentlessly inward, and it amazes me that this fundamental constraint has been overlooked for so long.

Human consciousness, the emergence of inner subjective experience, is yet another prime example of the shift of the most complex local matter towards this inner space. With the anticipated tremendous rise of simulation capacity in our nonbiological intelligent environments, and given the likelihood of an imminent computational closure in our models of universal space and time, this inner subjective experience is likely to become so well-developed that **the computationally accessible aspects of outer space rapidly become an informational desert**, something well understood by our future astrophysics, at least in its developmental architecture, but increasingly also in the constrained shape of its evolutionary paths. But what would be much less easily understandable, by comparison, would be our universe's "transcendent dimensions" (e.g., how things might be in a *different* universe, with a different set of physical laws, our *computational potentials* in the multiverse, vs. our much more easily understood *developmental constraints* within this universe).

Thus I can find no special reason, all emotion aside, why a phase of space operatic expansion for cosmic intelligence would suddenly start now, in violation of all past

complexity trends. At present I am a nearly lone voice making this prediction, and we will have to see if others join me in this perspective as our models and data become clearer. In my own future scenario, I can see post-singularity society building a few large sensor and experimentation instruments in near space, to verify the computational closure that we've *already* almost discovered with human-level simulation. In the process, I expect we will all continue rapidly collapsing inward, into far more complex and interesting realms.

Unique Searches, Less-Random Trajectories, and the Role of Simulation

Transcension is thus apparently occurring multi-locally in isolated pockets of spacetime, in a universe that appears *specially designed to protect the diversity of each emergent intelligence*. Why? Because **each local path is apparently a uniquely important search of total universal computational phase space**. While each system eventually discovers the developmental inevitability of the universal cycle (such developmental structure is apparently always easiest to detect first) comprehending the full evolutionary possibilities of the path taken remains significantly more difficult. Perhaps we discover that we must protect the variation of those paths, for while we may soon discover our local destiny, that doesn't tell us our ultimate destiny in the multiverse. **If the universe, and all complex life, appears to "be" anything, it looks like a sentient system trying as many different ways to understand its path as possible, while it unfolds a constrained developmental cycle**. And then, at regular intervals, it readjusts the entire parametric architecture to create greater individual and collective intelligence emergence in the next cycle.

The likelihood that we don't communicate with other intelligent civilizations from within this universe may be thus be one of the major lessons of evolutionary development. Apparently, the reorganizing of the parameters that we will do at the "bounce" (see Smolin) is just ***less random*** than the reorganizing that has occurred in prior epochs. In a universe that will *always* be essentially incomplete, in multiverse terms (see Patrick Grim's *The Incomplete Universe*, 1991), **the intelligent search process may never get entirely nonrandom, no matter how intelligent the structures at the end of any developmental cycle**. Evolution, while refining itself in yet-unclear ways over cyclic recurrences, may always be an essential feature of computational systems within the multiverse.

Discussing the coming of virtual reality, David Gelernter (*Mirror Worlds*, 1991) has observed that both we and our computers model a tremendous number of actions in the virtual space, but as these models grow in sophistication **we paradoxically execute a progressively smaller number of actions in real space.** We also use the data feeds from those progressively fewer real actions to keep building the quality of our **inner worlds**. Perhaps that aptly describes the local destiny of intelligence in this universe--a system that moves asymptotically toward reflection and computational refinement, and away from action and experience the closer the intelligence seed comes to the point of universal recreation. These are all early speculations, at present, but well worth considering, as we contemplate the real spatio-temporal constraints that will apply to the coming technological intelligence.

SETI as Empirical Evidence of Transcension

What kind of data would we need from SETI to make developmental transcension a testable hypothesis? I argue that based on reasonable frequency numbers in the Drake Equation for intelligence emergence in our galaxy, we should expect to inevitably discover about 8,000 **"radio fossils"** of unintentionally communicating civilizations in the night sky.

Given the brief time between our own emergence of broadcast communications technology and our own anticipated developmental singularity, I propose that the fraction of time in which technological civilizations send out detectable *unintentional* radio emissions (television, etc.) may be, on average, as short as 200 years, after which they would inexplicably wink out of existence, as their civilization transcends, leaving no other universal traces behind. If this timescale is correct, about 40 of these 8,000 concurrently existing civilizations will thus be in their last year of transmission when we inevitably find them in the sky. If we were able to actually *decode* such signals (vs. simply demonstrate their complex and nonrandom nature, which might be all we could do) we might further discover something interesting about them, perhaps right around the time they are entering a singularity.

My early guesstimates (Footnote 1) suggest we'll need to very sensitively monitor the **closest 25 million stars** before we will find our first such limited-lifespan radio fossil. SETI presently has the sensitivity, arguably, to detect such very faint unintentional radio emissions from some fraction of the nearest 1,000 stars we are monitoring. **But with the continued hyperexponential help of Moore's law in coming decades, researchers expect we'll have the ability to sensitively monitor millions of star systems, each across all two billion possible transmission frequencies simultaneously, within the next few decades.**

If such radio fossils are out there, especially with the development of much more advanced space-based SETI programs, we should expect to find our first one with ever-increasing probability in coming years. Roughly extrapolating present trends, by 2080 their detection should be virtually inevitable, but we might get lucky and discover these transcension fossils much earlier, perhaps even within the next decade or two. It remains possible we'll need to use technologies available to us only *after* we reach Singularity. I haven't yet seen reliable enough calculations to definitively answer the sensitivity question with regard to unintentional signals. But either way, I propose we can expect a powerful cosmic confirmation of transcension, both theoretically and empirically before this century is out, if these early estimates are even approximately correct.

If we can simultaneously develop the technology to detect **"optical fossils,"** such as the spectroscopic life signs (e.g., oxygen and methane lines) for the atmospheres of living planets, we should expect to find much larger numbers of these, and again, we'd notice large numbers of them winking out of existence shortly after developing radio emissions technology. Finally, it is possible that the creation of small mass **"intelligent black holes"** might also sent out unique and detectable signals (**neutrino**, **X-ray signals,** or a characteristic type of **"ringing gravity waves"** are a distinct possibility), in which case we might again reasonably expect to see some hard astronomical evidence for transcension even in the few remaining decades before the technological singularity.

So while I don't expect that we are the first intelligent life in our galaxy by any means, I agree with Ray Kurzweil (see his SETI section in "The Law of Accelerating Returns," 2001) in his assessment that we should *act as if we are the first*, at least until we have incontrovertible data that prove otherwise. That just sounds like a responsible policy for intelligent civilizations in general.

And I do think that a variety of tests and confirmations will be used to verify both the technological and developmental singularity hypotheses in coming years, and turn these topics into the formal scientific disciplines they deserve to be. Whether any of the specific proposals give above turn out to have been correct, usefully wrong, or quite off the mark, if they stimulate a program of progressively better experimentation and analysis, they will have been well worth the effort.

Footnote 1:

The least understood parameter in the Drake equation is the last one: the fraction of technological civilizations that will want to, or be capable of, transmitting. On Earth we've been transmitting for approximately 70 years. If you assume we'll reach a developmental singularity before 2150, as I do, then 200 years is a reasonable estimate for the length of time our civilization will send out unintended radio signals into space.

If we assume that 5 billion years earlier than Earth is the earliest that any planets with sufficient metallicity and distance from the radiative galactic core might have emerged to support complex life (half the lifespan of the universe, a reasonable gross assumption, and accurate within an order of magnitude), and if we combine this with Seth Shostak's estimate of 400 billion Sun-like stars in our galaxy, and my estimate (a Gaussian Midpoint principle, generically applied in this complex evolutionary developmental system) that 200 billion of these will harbor life capable of creating intelligence and technological civilizations, that gives:

(200 years/5 billion years)(200 billion civilizations) = 8,000 "radio fossils" in the night sky.

We call these radio fossils, because they represent *past* records of intelligence, now long gone on to better things. And that fraction that are close to the end of their 200 year span (on average, 40 of these would be in their last year of life when we find them) should be especially interesting.

So where are these 8,000 fossils? With its current funding, SETI technology allows us to monitor the closest 1,000 out of 400 billion sun-like stars (and primarily for *broadcast*, not unintentional signals, which is a separate issue, at present). That's 0.0000000025 of them. I'd expect half of these to eventually develop technological civilizations. But at present, only (200/5 billion), or 0.00000004 of them should be expected to be transmitting. With this calculation, 25 million stars would be the average number of stars we'll have to sensitively monitor before we should reasonably expect to find our first transmission.

Obviously, we're going to have to be systematically monitoring a whole lot more stars, a whole lot more sensitively, before we hit paydirt. Fortunately, Moore's Law is coming to the rescue. SETI researchers expect we'll be monitoring over 10,000 local stars within the next few years, and millions within the next few decades. And with these stars, we can already monitor millions of perhaps 2 billion possible transmission frequencies. By 2050-2080, especially if we get adequate funding for this effort, and see continued double exponential growth in computing power, and perhaps get our SETI effort out to Saha crater on the far side of the moon—shielded from all Earth's electromagnetic noise—if that looks promising and important, as SETI folks think it might, and use near-singularity or post-singularity sensitivity increasing technology, we should expect to be continuously monitoring several hundred million stars, with extreme sensitivity, just a few decades hence. I think the confluence of these capabilities will be the ticket for uncovering some of the most interesting, and important, fossils in our observable universe. By 2100, I'd suggest their detection would be effectively inevitable.

We are not alone. But I'd bet that cosmic intelligence doesn't stay in our neighborhood for long. We will soon be in a position to answer this fascinating open question.

References:

Barrow, John and Tipler, Frank. 1988. *The Anthropic Cosmological Principle*, Oxford U. Press.
Berry, Adrian. 2001. *The Giant Leap: Mankind Heads for the Stars*, Tor Books.
Clarke, Arthur C. 1968. *2001: A Space Odyssey*, New American Library.
Clarke, Arthur C. 1982. *2010: Odyssey Two*, Ballentine Books.
Ferris, Timothy. 1992. *The Mind's Sky: Human Intelligence in a Cosmic Context*, Bantam Books.
Gelernter, David. 1991. *Mirror Worlds: Or the Day Software Puts the Universe in a Shoebox, How it Will Happen and What it Will Mean*, Oxford U. Press.
Grim, Patrick. 1991. *The Incomplete Universe*, MIT Press.
Harwit, Martin. 1981. *Cosmic Discovery*, Basic Books.
Horgan, John. 1997. *The End of Science*, Basic Books.
Kurzweil, Ray. 2001. *The Law of Accelerating Returns*, KurzweilAI.net
Livio, Mario. 2000. *The Accelerating Universe, Infinite Expansion, the Cosmological Constant, and the Beauty of the Cosmos*, Wiley.
Lloyd, Seth. 2000. Ultimate physical limits to computation. *Nature* 406:1047-1054.
Smolin, Lee. 1992. Did the Universe Evolve? *Classical and Quantum Gravity* 9:173-191.
Smolin, Lee. 1997. *The Life of the Cosmos*, Oxford U. Press.
Ward, Peter and Brownlee, Donald. 2000. *Rare Earth*, Springer.

John M. Smart
Los Angeles, 2002
http://www.SingularityWatch.com
Understanding Accelerating Change
johnsmart@singularitywatch.com