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There Are No Limits To The Open Society

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There Are No Limits To The Open Society

(1) The laws of physics as we presently understand them place no ultimate limits to growth. The wealth of society can grow to become literally infinite at the end of time. That is, Popper's vision of life as being an *Unending Quest* (Popper 1976) is literally true. Conventional wisdom has the absolute opposite view: we live in a finite world, and there are definite limits to growth. Such perceived limits now form the ideological basis for government oversight of the economy. In the words of the biologist Garrett Hardin, writing in *The New Republic*: "Economic libertarians and doctrinaire free-market economists ... are today's providentialists. ... Only political restraints (which are unacceptable to libertarians) can keep a laissez-faire system from destroying itself in a limited world. ... The specter that haunts the minds of libertarians and cornucopists is the specter of material limits." (Hardin 1981)

(2) I intend to exorcise this specter. And in so doing, I shall outline the framework of a dynamic, ever-progressing and truly universal society. What I shall do is show that human beings—or more generally any rational life form—can utilize the known laws of physics to surmount all purely physical barriers to their survival, and that by doing so, they will necessarily increase their knowledge and wealth, with both becoming literally infinite by the end of time.

(3) When I say that there are literally no limits to growth, I'm not saying merely that we have plenty of resources for the next 10 years, the next 100, or even the next 1,000 years. I'm going to claim that the laws of physics as we currently understand them will permit exponential economic growth to continue forever! Now "forever" is a very long time; infinity is larger than any finite number. But in developing my argument, I'm going to mention time scales that will seem "infinite" enough for the average person: billions and trillions of years. Why should the average person care what happens so far in the future?

(4) There are two reasons the average person should be interested in the ultimate future, however far away in time it may be. The first is psychological. If we really and truly believe that the future will be dismal and horrible—if we think that civilization and indeed the biosphere of the entire universe is inevitably doomed to certain annihilation—then this pessimism will cast a pall over our daily decisions. If the universe imposes ultimate limits on history and ambition, even it those limits are so far off as to be apparently irrelevant to recorded history, something fundamental is wrong with the classical-liberal view of open-ended history and possibility. If on the other hand the potential for intelligence is actually unlimited, then it is in fact worthwhile to see human endeavor as open-ended, and to worry about

our unlimited posterity.

(5) The second reason the average person should consider the ultimate future is that, if the wealth and happiness of future generations increases fast enough, then the present value of the far future could be vastly greater than the present value of the present. We should act today to ensure that there are indeed an infinite rather than a finite number of future generations. Being too frugal with our resources today in the mistaken belief that they are forever finite may prevent us from developing the unlimited resources permitted by the laws of physics. This could happen; companies have been bankrupted by being too miserly with R & D expenditures.

(6) The picture I'm going to present in this article about the far future will strike the average person as extremely speculative. This is due to the fact that the average person has no explicit theory of the far future. I say "explicit" theory, because if the far future is ignored, it is tacitly assumed that present value of the far future is negligible. But as I just pointed out, this may be false. It is better to adopt explicit theories rather than theories we are unaware we are adopting, because only the former can be tested to see if they are true. My theory of the far future will actually be a very conservative picture in that I shall invoke only the known laws of physics. In fact, I shall demonstrate in a Technical Appendix to this paper that acceptance of the known laws of physics *requires* the picture of the far future I shall describe to be true. The known laws of physics *require* Popper's world view to be correct.

(7) Popper's world view has had a great deal of opposition. He recalls in his autobiography that in his post at the University of Canterbury in New Zealand:

> I had a desperately heavy teaching load, and the University authorities not only were unhelpful, but tried actively to make difficulties for me. I was told that I should be well advised not to publish anything while in New Zealand, and that any time spent on research was a theft from the working time as a lecturer for which I was being paid.
>
> (Popper 1976, p. 119)

(8) I can fully sympathize with Popper. My own Tulane University has informed me that I can expect no raises to write papers like the current paper on the Open Universe (Popper 1982). Since my current salary is more than $20,000 below that of the average Tulane full professor (more than that in the natural sciences), I have to "steal" time to write papers like the one you are now reading. Which is why this essay is appearing more than a year after the conference at which it was given.

(9) If the limits-to-growth people are correct in their basic premise—that resources are finite—then we and the rest of the biosphere are finished. Period. It's a matter of elementary-school mathematics: if you have a finite amount of anything, and you use them at a constant rate, then you use them all in a finite amount of time. Suppose, for example, we have 1000 units of resources. If we use them at a constant rate of 1 unit per year, then we have zero resources in 1000 years. We're dead in 1000 years. In the Club of Rome computer simulations made to show the "advantages" of a constant-sized human population, a finite amount of resources was assumed, and the resources ran out—the human race dropped dead—within 500 years of the present, no matter what we did (Meadows et al. 1972). A stable human population merely delayed the inevitable. Finite resources means finite amount of survival time. Of course, you could take the view of John Maynard Keynes, and shrug one's shoulders: "In the long run we're all dead." In other words, since the entire biosphere inevitably is wiped out after a finite number of generations whatever we do, why bother to have any further generations? Why not just enjoy ourselves by using up all of these finite resources in this generation? I shall argue on the contrary that although the laws of nature are subtle, they are not malicious.

(10) The limits-to-growth people not only underestimate what science can accomplish, they also underestimate what it has already accomplished. For example, the doomsayer Paul Ehrlich accuses the late economist Julian Simon of a belief in "... large-scale alchemy and science fiction" (Ehrlich 1981) because of Simon's claim that "copper can be made from other metals. Even the total mass of the earth is not a theoretical limit to the amount of copper that might be available to earthlings in the future. Only the mass of the universe would be such a theoretical limit" (Simon (1980); reprinted on page 52 of Simon (1990)). The biologist Garrett Hardin quoted "... every scientist [as saying] 'My God, alchemy. We got rid of alchemy 300 years ago, and here's this idiot ... proposing to revive alchemy"' (Hardin and Simon (1982); quote is on page 396 of the reprint of this article in Simon (1990)).

(11) I was amused by these attacks on poor Julian Simon. Not only can copper be synthesized from other metals, it has been synthesized from other metals, and you can actually buy some synthetic copper on the open market! Zinc-65 decays, with a half-life of 245 days, into the stable isotope copper 65. Zinc-65 is regularly manufactured in uranium fission reactors because its decay yields a gamma ray useful for calibrating radiation detectors. But if you buy a picogram of zinc-65, then in 245 days, you'll have half a picogram of copper-65. So I bought some zinc-65 and sent it to Julian so he could have in his possession some of this "scientifically impossible" substance. Copper-65 currently isn't cheap; I paid 30 cents a picogram for the trillion atoms of the stuff which I sent Julian. But the price would be much lower if we really wanted to synthesize it: certainly it would cost no more per kilogram than plutonium, which we've manufactured by the ton. The key point is, if we have an unlimited supply of energy, we can manufacture an unlimited amount of anything we please. But the limits-to growth people claim that the Conservation of Energy Law prevents us from obtaining an unlimited amount of energy. This is not true.

(12) If the size of a physical system can go to zero, then gravity can provide unlimited "available" energy, which is energy that can be used for human purposes. Gravitational energy obtained from a massive system shrinking to a small size is actually a major source of energy we use today. In fact, most of the electrical energy used in France is from this source! France obtains most of its electricity from uranium fission. Uranium is produced during the supernova explosions of stars much more massive than the Sun. The energy released in the supernova—and hence the energy stored in the uranium—comes from the gravitational collapse of the core of the star, which has an initial radius of about a million kilometers, down to ten kilometers, which is the radius of the neutron star that is the remnant of the explosion.

(13) In terms of the energy, what happens is this. The total energy of the stellar core is just the sum of its "potential" energy and the "kinetic" energy. (In other words, to get the total energy, one adds the potential and kinetic energies.) Conservation of Energy says that this total energy is finite and constant. (In Newton's theory of gravity, the value of this constant is arbitrary, because no physics depends on its magnitude. Only changes in the potential and kinetic energies have physical significance.) According to Newton's law of gravity, the gravitational potential energy is negative and inversely proportional to the stellar core's radius. Thus, the smaller the stellar core, the more negative will be the core's potential energy. In fact, the potential energy would go to minus infinity if the radius of the core were to go to zero. And the radius of the core will tend to go to zero: gravity is attractive. Since the total energy of the core is conserved, and equal to the sum of the two separate energies, if the potential energy goes to minus infinity, then the kinetic energy must go to plus infinity! Now kinetic energy, which is the energy of motion of the collapsing star, is available energy. It is some of this kinetic energy that is stored for our use via the synthesis of uranium. Extracting the kinetic energy from gravitational collapse to zero size would thus provide a literal infinity of available energy, even though the total energy is finite.

(14) Of course, the ten kilometers of a neutron star is a far cry from zero kilometers. In terms of energy released, a gravitating system of zero size is infinitely smaller than a system of ten kilometers. Repulsive pressures eventually stop the collapse of a star. Is it possible for any physical system to shrink to zero size? Yes. The laws of physics permit, and in some cases require, the universe as a whole to collapse to zero size. In Einstein's theory of gravity, pressures on the universal scale actually make the universal collapse faster rather than stopping it. But if the collapse of the universe is to be utilized, the economic system must have spread into interstellar space.

(15) But it is obvious that the human species must eventually leave the Earth and colonize space if it, or indeed any part of the biosphere, is to survive. For the simple fact of the matter is, the planet Earth is doomed. The Sun is becoming more luminous every day, and in about 7 billion years, its outer atmosphere will have expanded to engulf the Earth. Due to atmospheric friction, the Earth will then spiral into the Sun, and the Earth will be vaporized. If life has not succeeded in moving off the planet before this occurs, life also will be doomed. So if life is to survive, what must it do? The answer is clear and unequivocal: it must leave the Earth and colonize space.

(16) Let us follow many environmentalists and regard the Earth as Gaia, the Mother of all life (which indeed she is). Gaia, like all mothers, is not immortal. She is going to die. But her line of descent might be immortal. Indeed, every being now alive on the Earth is the direct lineal descendent of one-cell organisms that lived 3.8 billion years ago. The age of the lines of descent of those ancient organisms, our ancestors, is a substantial fraction of the age of the entire Universe, about 20 billion years. So Gaia's children might never die out—provided they move into space. The Earth should be regarded as the Womb of Life—but one does not remain in the Womb forever. Trying to do so would kill both mother and child.

(17) Ultimately, all forms of wealth, even life itself, can be reduced to information. If the amount of information processed, and the amount of information stored at any given time, increases without limit as the end of time is approached, then wealth increases to infinity, and life has existed forever. For a human being is just a particular pattern in matter, the Earth is just a particular pattern in matter, and matter itself is just a particular pattern in the collection of quantum states. This idea of life being information goes back to Schrödinger, in his book "What is Life."

(18) Karl Popper, I regret to say, disagrees with Schrödinger, myself (and most molecular biologists) on this definition of life. Popper gave his reasons:

> Now admittedly organisms do all this. But I denied, and I still deny, Schrödinger's thesis that it this which is Characteristic of life, or of organisms; for it holds for every steam engine. In fact,

> every oil-fired boiler and every self-winding watch may be said to be "continually sucking orderliness from its environment". Thus Schrödinger's answer to his question cannot be right.
>
> (Popper 1976, p. 137)

(19) But it can be right—*if machines are alive!* They must be, by Schrödinger's definition, and by mine. In fact, the famous Oxford evolutionist Richard Dawkins gives automobiles as examples of living things in his book *The Blind Watchmaker* (Dawkins 1986, p. 330).

(20) Now information processing and storage is constrained by Conservation of Energy and the Second Law of Thermodynamics: the irreversible storage of one bit of information requires the expenditure of a definite minimum amount of energy, a minimum which is proportional to the temperature at which the storage is taking place. This means that an infinite amount of information processing and storage can occur between now and the end of time, provided that available energy increases faster than the temperature.

(21) As everyone knows, the universe is now expanding out of the Big Bang explosion which occurred about 20 billion years ago. The cosmic background radiation—radiation which fills the entire universe—is a relict of that explosion. Cosmologists know that if our universe is a "closed" universe, then it will eventually stop expanding and collapse upon itself. (A "closed" universe is one which has has finite volume, and which has the shape of a sphere.) The Hawking-Penrose singularity theorems tell us that if a closed universe begins to collapse, it will necessarily contract to zero volume in a finite amount of what physicists call "proper time."

(22) It is this collapse to zero volume that will provide the unlimited amount of energy we need for life to go on forever and the amount of wealth possessed by society to increase without limit. Cosmologists have long known that almost certainly a collapsing universe will collapse faster in some directions than others; this is called "gravitational shear.". But this means that the temperature of the cosmic background radiation will be different in different directions: it will be hotter in directions where the universe is smaller and cooler in the directions where the universe is larger. (This is a consequence of a familiar phenomenon: gases get hotter when they are compressed, and cooler when they expand. Refrigerators and air conditioners work by exploiting this phenomenon.) Now available energy—energy which can be used to process information—can be extracted from a temperature difference. In fact, this is what currently drives the biosphere: energy is extracted from a hot spot in the sky called the Sun, and waste heat is dumped into space. If life in the far future does the same—extract energy from the hot directions and dump waste heat in cooler directions—over the entire universe, then one can show that a literal infinity of available energy can be extracted from the collapse of the universe: enough to process and store an infinite amount of information between now and the end of time.

(23) But this can be done only if life has expanded out from whatever planets it is now on to engulf the entire universe. There are two reasons for this. First, although a closed universe collapses at different rates in different directions, the spatial variation in the collapse rate generally won't be large enough to give the required temperature difference between the various directions in space. Thus life must actively intervene in cosmic evolution to guide the collapse of the universe into those rare collapse modes which do provide the temperature difference required for life's survival. Life can guide the entire universe into these modes because the Einstein field equations, which govern the universe on large scales, are chaotic. Everyone knows that chaos in physical systems allows a tiny action now to have an enormous effect later. The standard example of physical chaos is a butterfly flapping its wings: if atmospheric conditions are just right, this tiny disturbance can over time build up into a hurricane. What is less well known is that physical chaos permits human experimenters to guide large systems into very improbable states by miniscule adjustments of control parameters. This effect has recently been demonstrated in the laboratory. Slight changes in the density of matter, done in concert throughout the universe, are the cosmic control parameters, the universal analogues of the butterfly wing flaps.

(24) These particular rare collapse modes are just what is needed to eliminate event horizons, barriers to communication in the universe. Event horizons arise whenever the universe—or part of it—collapses so fast that not even light can cross it more than a finite number of times before the end of time. If event horizons are present, then communication is restricted to just the region inside the horizon. But the region inside the horizon decreases in size much faster than the universe itself, so fast in fact that there is only a finite amount of energy available inside the event horizon between now and the end of time. On the other hand, if event horizons are not present, then signals can be sent infinitely many times back and forth between any two points in the universe. Event horizons must be absent if the different regions of the universe are to be able to communicate with each other without limit, and if there is to be an unlimited amount of available energy. Unfortunately, almost all collapse modes for the universe generate event horizons. Fortunately, life can act collectively to eliminate event horizons if it has become ubiquitous throughout the universe.

(25) The English mathematician Roger Penrose showed more than two decades ago that the structure of event horizons in the universe could be

used to define a "boundary" to space and time: if different observers who made it all the way to the end of time have distinct event horizons, they are said to end in distinct "points" on this boundary (Hawking & Ellis, 1973, pp. 217–221; Tipler, 1994*b*, pp. 432–445). The collection of all such points would constitute the future "c-boundary," which thus is a precise formulation of the idea of "the end of time." Mathematicians call such a boundary a "completion." Perhaps the simplest example of a completion is obtained from the interval of real numbers between 0 and 1. The two end numbers 0 and 1 complete the interval: the number 1 completes the unit interval on the upper end. Similarly, the future c-boundary completes space and time in the future: it constitutes the end of time, though it is not in time (or space), just as the number 1 is not in the interval of all points which are less than 1.

(26) The future c-boundary can be quite complicated. (In the most simple model of a closed universe, it is a three-dimensional sphere.) However, if life succeeds in eliminating all event horizons, then all observers have the same event horizon structure, namely no event horizons at all. In this case, and in only this case, the future c-boundary of the universe is a single point. I propose to call it the *Omega Point*, and this model of life going on forever and wealth increasing without limit the *Omega Point Theory* (Tipler 1986, Tipler 1992, Tipler 1994*b*).

(27) The alert reader will have noticed an apparent inconsistency: I have said that a closed universe ends after finite proper time, while I have also said that life goes on forever; that is, for infinite time. How can these two statements be reconciled? The two statements are not inconsistent because two scales of time are being used: proper time and "subjective time". Actually, according to general relativity all time scales—measures of duration—are allowed; this is what is meant by "general relativity" ("general relativity" is the technical name for Einstein's theory of gravity). In the present environment of the Earth, we use proper time, because it is proportional to the rate at which atoms undergo transitions, and since our brains are made up of atoms, it also measures our thinking rate.

(28) However, if the information processing rate speeds up relative to proper time, as I have argued that it will near the Omega Point, then proper time will no longer be a good measure of time as we experience it. Instead, we should use the information processing rate itself—what I shall call subjective time—as the basic measure of duration. Life is the measure of all things! Thus there will be an infinite amount of subjective time, but a finite amount of proper time between now and the Omega Point. The rate of mental processes increases without limit relative to proper time, and this rate becomes literally infinite at the Omega Point itself. But no bit is processed in zero proper time, because all bits are processed in time, before the Omega Point is reached.

(The Omega Point, you will recall, is not a point in time, but rather the end, the completion, of time.)

(29) The limits-to-growth people often claim that if resource use could grow without limit, pollution would grow even faster, wiping us out. Not so. If our energy resources grew without limit, all familiar pollutants, for examples smog, sludge in the water, and greenhouse gases, could easily and cheaply be removed from the environment. However, using energy to remove these standard pollutants would generate waste heat, which cannot be eliminated. The elimination of waste heat, the name for energy which has become unavailable, is forbidden by the Second Law of Thermodynamics. The ultimate pollutant, then, is waste heat. Here and now on Earth, waste heat is ultimately being dumped into interstellar space. In the far future, if all the waste heat were dumped homogeneously into the cosmic background radiation—the ultimate heat sink—then the universal temperature will rise slightly above what it otherwise would have been at any given epoch, but not enough to interfere with the ever-increasing information processing and storage.

(30) However, one can show the irremovability of waste heat means the temperature of the cosmic background radiation must vary inversely as the radius of the universe. Thus, as the size of the universe goes to zero, the temperature will go to infinity. Certainly life cannot survive in its present form. Can it survive in any form?

(31) Yes. To understand how, recall that physics regards all forms of matter as just patterns in quantum states. Physics also tells us that quantum states can be considered to be waves inside of a box, and thus all matter is just a superposition of these waves. Suppose we focus attention on just one of these waves, the wave whose wavelength is equal to the wavelength of the box. If the box is now compressed, the wave will also be compressed, since its wavelength is equal to the size of the box. But physics tells us that the energy of the wave is inversely proportional to the wavelength of the wave, so the energy of the wave gets greater as the box is compressed. If the box is compressed to zero size, the energy of the wave will increased to infinity. (Think of a wave inside a box as analogous to a coiled spring, and the wavelength of the wave as analogous to the spacing of the turnings of the coil. If the spring is compressed, the spacing of the turnings gets smaller, and the energy of compression in the spring gets larger.)

(32) If we now regard the entire universe as our box, and imagine we have stored our information in such waves across the entire universe, then the rising temperature will not have any effect on the stored information, because the energy of the stored information is increasing as rapidly as the universal temperature: the energy of the stored information and the universal temperature are both inversely proportional to the size of the universe. Life currently stores information in chemical bonds, and if the average energy of environment—which is what temperature actually measures—becomes greater than the energy of the chemical bonds, the bonds are broken, and the information is lost: life dies. But as long as the information coding the pattern of life is stored in energy levels which are higher than the average environmental energy (temperature), life can survive.

(33) This is the strategy life currently uses to survive at high temperatures. The PCR technique, an essential tool in DNA analysis, uses Taq polymerase, which is taken from a bacterium that lives in boiling hot springs. All life on Earth synthesizes and uses polymerase, the enzyme enabling DNA to copy itself. But the chemical bonds of human polymerase are too fragile—the bonding energies are too low—to survive the near-boiling temperature used at one stage of the PCR process. The bonds of Taq polymerase are sturdier—the bonding energies are higher—and so the Thermus aquaticus bacterium survives in the hot springs.

(34) Life can also survive the high temperatures of the far future if it adopts the same strategy. But such a strategy will require storing information in coherent states (waves) across the entire universe. Setting up such states will be quite difficult, but would be easier if the collapse of the universe slowed down before the universal temperature got too far above room temperature. I predicted several years ago that the laws of particle physics might permit such a slowing, and the slowing will be maximized, and thus the probability of the survival of life will be maximized, if the top quark has a mass of 185 ± 20 GeV, and the Higgs boson has a mass of 220 ± 20 GeV (Tipler 1994*a*, Tipler 1994*b*). (The Higgs boson is responsible for giving masses to all fundamental particles, like the electron, and it can do this because it manifests itself in an energy field which permeates the entire universe. This energy field can interact with the gravitational shear in the far future to slow the universal collapse. The slowing will be maximal if the strength of the Higgs energy field is maximal. But if the top quark and Higgs boson masses are greater than the above values, the the Higgs energy field will strong enough to rip the universe apart right now.) But never mind the details; the important point is that these numbers show the advantage of an explicit as opposed to a tacit theory of the far future. Explicit theories can be tested. In March of 1995, Fermilab announced that they had finally detected the top quark, and they measured its mass to be 179 ± 13 GeV.

(35) Life may survive, but will we? I had trouble surviving last summer's heat wave. I imagine I would have even more trouble if the temperature outside reached a million trillion degrees. Surprisingly, it is nevertheless possible for us humans to survive until the Omega Point. Recall that we are currently just a pattern in matter, and matter in turn is just a pattern in quantum states. In other words, we are a pattern in a pattern. Suppose instead we became a pattern in a pattern in a pattern?

(36) That is, suppose the pattern which makes up the matter upon which we are based were instead coded in a computer program? If the computer upon which the program is being run is in turn based on energy levels higher than the universal temperature, the program would run perfectly well. The "matter" inside the program—the computer-simulated matter—would be at normal human room temperature, and we could survive indefinitely in this environment. We would be virtual humans, made of virtual matter, but we would be just as real as we now are. We would just exist at a higher level of implementation (the technical computer science term for this hierarchy of patterns of reality). This computer science concept is, in my opinion, essentially what Popper was trying to express in his proposals of "World 2" and "World 3". The advantage of the computer science concept is that we can see that there is really no limit to the number of worlds—there are worlds 4, 5, ... all built on the most basic level of reality, the level of we now call "material", what Popper refers to as "World 1". Popper defined his World 2 and World 3 explicitly in terms of human beings—formally, his Worlds 2 and 3 would cease to exist if Homo sapiens did—but surely an intelligent computer would be an equally good "container" for these two worlds. I have been criticized by Ray Percival in *The Critical Rationalist* for failing to explain how life, taken as a whole, can be regarded as an infinite state machine (Percival 1996). It's simple how. The diverging number of energy states constitute a diverging amount of "squares of tape" required for the existence of an infinite state machine. (I should mention in regard to this criticism that there is a distinction between information and knowledge: knowledge is "information"—in the technical sense of information theory—that has been subject to criticism—in the sense of Popper.)

(37) It is quite possible that each and every individual currently alive, or who has ever lived, will actually be brought back into existence by life in the far future. Physicists have just recently realized that the Heisenberg Uncertainty Principle can be equivalently formulated as: the information coded in the entire visible universe is finite at any instant of time. This means that since the information coded in the universe is increasing without limit in the far future, it would be possible, in fact very cheap, for the far-future computers to recreate our present universe, even if they have to do this by simulating all possible pasts. If life in the far future does bring us back, we will have been resurrected.

(38) I have argued above that the information coded in the universe diverges to plus infinity as the universe approaches the Omega Point; that is, the total information stored in the universe is growing without bound, becoming literally infinite at the Omega Point. Since the universe ends in the Omega Point in finite proper time, the growth in information stored is faster than exponential growth—at least in proper time. I have argued, however, that proper time is not the appropriate time scale for life. The true time for life is subjective time, defined to be the time required to store irreversibly one bit of information; that is, the rate of growth of information in subjective time is unity by definition.

(39) I now show that if the amount of information stored always strictly increases, and this information goes to infinity as the universe moves into the Omega Point, then the total wealth possessed by the biosphere as a whole increases exponentially in subjective time literally forever; that is, not only does total wealth diverge to infinity, but it diverges to infinity exponentially.

(40) The key idea one needs to show that exponential growth can continue literally forever is provided by the great Nobel-prize winning economist Friedrich Hayek, who showed many years ago that the capital stock of a society is equal, not merely to the number of machines possessed by the society, but rather to the total number of possible uses these machines actually have. As Hayek phrased it:

> The datum usually called the "supply of capital" can thus be adequately described only in terms of the totality of all the alternative income streams between which the existence of a certain stock of non-permanent resources (together with the expected flow of input) enables us to choose. ... Each of the constituent parts of this stock can be used in various ways, and in various combinations with other permanent and non-permanent resources, to provide temporary income streams ... What we sacrifice in order to obtain an income stream of a particular shape is always the parts of the potential income streams of other time shapes which we might have had instead.
>
> (Hayek 1941, p. 147)
>
> [Thus] ... the only adequate description of th[e] "supply of capital" is a complete enumeration of the range of possible output streams of different time shapes that can be produced from the existing resources.
>
> (Hayek 1972, p. 222)

(41) More generally, the wealth possessed by an individual or the wealth possessed by the society is proportional to the number of opportunities it has;

to the number of different alternative actions he, she or it has available. We are wealthier than our ancestors because (for example) most of us can afford to have fresh strawberries for breakfast on any day of the year. Eating fresh strawberries on any day of the year was not an alternative action possessed by many of our ancestors a thousand years ago. Many of our ancestors lived in regions of the Earth where strawberries did not exist, and in the regions where strawberries were grown, they were not available in the winter to anyone except perhaps for a few people who had the produce of greenhouses available to them. I am currently writing these lines in Florida, but if I wished, I could be in Paris tomorrow. The alternative action of going from North America to Europe (or vice versa) in less than 24 hours was not available to any of my ancestors a century ago.

(42) By definition, the number of possible arrangements which can be coded by I bits of information is 2^I. Following Hayek and equating total wealth with the number of possible arrangements, we get 2^I for wealth of society, so the wealth grows as $2^{(\text{subjective time})}$. This is exponential growth. Since subjective time goes from zero to plus infinity, this means that wealth increases exponentially forever in subjective time.

(43) This exponentially increasing wealth allows life in the far future the power to resurrect us all, and furthermore, allows life in the far future to share wealth in such a way that our share is an ever decreasing percentage of the whole, yet nevertheless our share also diverges to plus infinity.

(44) As a consequence of this, I must disagree with Julian Simon's estimate of the ultimate limit to the amount of copper we can have for our use. It cannot be limited to the mass of the universe, for the total mass-energy of the universe is zero! The total mass of the universe is the sum of the masses and energies in the universe. Penrose has shown that in Einstein's theory of gravity, the gravitational potential energy of a closed universe is equal in magnitude but opposite in sign to sum total of all the positive energies. The two energies cancel out, giving zero. This does not mean that there is no copper in the universe. Indeed, there is no limit to the amount of copper we can have for our use. We can, if we wish, have an unlimited amount of virtual copper at higher levels of implementation.

(45) The implications of truly unlimited progress can be restated in more provocative words. As I pointed out, in order for the information processing operations to be carried out arbitrarily close to the Omega Point, life must have extended its operations so as to engulf the entire physical cosmos. We can say, quite obviously, that life near the Omega Point is omnipresent. As the Omega Point is approached, survival dictates that life collectively gain control of all matter and energy sources available near the Omega Point, with

this control becoming total at the Omega Point. We can say that life becomes omnipotent at the instant the Omega Point is reached. Since the information stored becomes infinite at the Omega Point, it is reasonable to say that the Omega Point is omniscient; it knows whatever it is possible to know about the physical universe (and hence about Itself). Summing up, the Omega Point can be called omnipresent, omnipotent, and omniscient! I'm tempted to identify the Omega Point with GOD. Defending this identification would require a book—which I've written! (Tipler 1994*b*)—not a short article, so I shall not continue with this line of thought (but for a defense of this identification by one of the world's most famous theologians, see my web page, `http://www.math.tulane.edu/faculty_html/tipler.html`). But any theory of unlimited progress—which means progress to literal infinity at the end of time—necessarily implies that the knowledge and the physical power of life will be infinite at time's end, whether or not one wishes to use traditional language to describe this end state. What I have shown in this article is simply that physics as we now understand it places no ultimate limits on progress and rationality: there are no limits to the Open Society.

Technical Appendix: *Why the Acceptance of the Known Laws of Physics* Requires *Acceptance of the Omega Point Theory*

(46) Astrophysical black holes almost certainly exist, but Hawking has shown that if black holes are allowed to exist for unlimited proper time, then they will completely evaporate, and a fundamental quantum law called "unitarity" will be violated. Unitarity, which roughly says that probability must be conserved, thus requires that the universe cease to exist after finite proper time, which in turn implies that the universe must be closed in space, with the universe ending in a finite proper time at a final singularity (Tipler 1987). The Second Law of Thermodynamics says the amount of entropy—the amount of disorder—in the universe cannot decrease, but the amount of entropy already in the cosmic background radiation will eventually contradict the Bekenstein Bound near the final singularity unless there are no event horizons, since in the presence of horizons the Bekenstein Bound implies the universal entropy must be less than the square of the radius of the universe, and the radius of the universe goes to zero as the final singularity is approached. Roger Penrose showed how to define the shape of a singularity by using the number of horizons that terminate in that singularity. The absence of event horizons in Penrose's construction by definition means that the shape of the final singularity is a single point, call it the Omega Point (Tipler 1986, Tipler 1992). The British physicist Malcolm MacCallum has shown that a closed universe with a single point final singularity is very improbable; technically we say "of measure zero". The English astronomer John D. Barrow has shown that the evolution of a closed universe into its final singularity is chaotic. The American physicist James Yorke has shown that a chaotic physical system is likely to evolve into a measure zero state if and only if its control parameters are intelligently manipulated. Thus life (which in the far future is more appropriately thought of as intelligent computers) almost certainly must be present arbitrarily close to the final singularity in order for the known laws of physics to be mutually consistent at all times. The American physicist Charles W. Misner has shown in effect that event horizon elimination requires an infinite number of distinct manipulations, so an infinite amount of information must be processed between now and the final singularity. The amount of information stored at any given time diverges to infinity as the Omega Point is approached, since the total entropy of the universe diverges to infinity there, implying divergence of the complexity of the system that must be understood to be controlled.

(47) When a closed universe collapses into its final singularity, the average temperature of the universe increases without limit. So in order to survive, life must transfer its information into some other medium besides carbon, a medium which can withstand the arbitrarily high temperatures near the final singularity. The ability of life to transfer its information has several implications. First of all, the density of the universe must be great enough to close the universe. This means that the "density parameter" which cosmologists call "Omega-naught" (*not* the same thing as the "Omega Point"!) must be greater than one. But it can be shown that the ability of life to transfer its information to another medium means Omega-naught must be quite close to one. Specifically, (Omega-naught - 1) must be between a millionth and a thousandth.

(48) In the body of this paper, I mentioned another prediction: the mass of the most important elementary particle, the Higgs boson. The successful transfer of life's information from its current basis to a high temperature basis implies that the Standard Model Higgs boson mass must be within 20 of 220 GeV, where "GeV" is a measure of mass used in particle physics (Tipler 1994*a*). "Supersymmetry", a hypothetical property which many particle physicists believe in (without any experimental evidence) gives a Higgs boson mass of at most 100 GeV. If the universe is indeed open (as some astrophysical evidence suggests) and unitarity is violated, then Hawking has shown that the Higgs particle will never be seen in a particle accelerator. Experimentally, the question of the Higgs boson mass should be resolved fairly soon: the Tevatron at Fermilab is currently being upgraded, and if the Higgs is less than 100 GeV, the upgraded machine—expected to go on line before the year 2000, will be able to detect it. The Large Hadron Collider currently being built at CERN in Geneva, will be able to detect the Higgs if it has a mass of less than 300 GeV. The Large Hadron Collider is projected to start collecting data in the year 2005, so the Open Society/Open Future prediction of the Higgs mass should be confirmed within the decade.

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Tipler was the post-doctoral student of four scholars: Abraham Taub, Ranier Sachs, Dennis Sciama, and John Wheeler. Taub was the post-doc of John von Neumann, who made the first American digital computer. Sachs was the Ph.D. student of P.G. Bergmann, who was the post-doc of Albert Einstein. Sciama's Ph.D. students include Stephen Hawking, and also Sir Martin Rees, the current Astronomer Royal of England. Wheeler, the man who named the "black hole", was the post-doc of Niels Bohr (Nobel Prize for the Bohr model of the atom), who was the post-doc of Ernest Rutherford (Nobel Prize for discovering the atomic nucleus), who was the student of J.J. Thompson (Nobel Prize for discovering the electron), who was the student of Lord Rayleigh (Nobel Prize for discovering Argon), who was the student of James Clerk Maxwell (Maxwell's equations). Wheeler's other students include Richard Feynman (Nobel Prize for quantum electrodynamics).

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