Last Stop on the Cosmic Journey: An Estimated Time of Arrival

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Abstract: History is here imagined as a moral, intellectual, and physical journey whose destination involves: penetration to the furthest reaches of the cosmos, complete understanding of the laws of nature, and a perfect system of ethics with respect to the management of society and nature. It is suggested that the exhaustion of material potential implied by the Second Law of Thermodynamics is counterbalanced by the augmentation of informational potential in a process of ephemeralisation or doing more with less. Evolution is modelled as a process of hyper-exponentially increasing combinatorial complexity interrupted by occasional restarts or episodes of creative destruction. Drawing on these speculations, a calculation is developed leading to the necessarily rough and impressionistic conclusion that humanity will reach its above-defined destination some twenty millennia from now.

1. Introduction: a three-stranded journey

The start of the Upper Palaeolithic, traditionally dated to some 40,000 years ago (40 kya), has typically been seen as a turning point representing the onset of modern human behaviour (Gowlett, 1984, p. 120; Pfeiffer, 1982). Although instances of modern behaviour like art have been discovered much earlier, perhaps as early as 200 kya, the Upper Palaeolithic remains a critical horizon after which social evolution became continuous, rapid, and obvious, proceeding through an accelerating series of milestones like microlithics, agriculture, and urbanisation. This turning point is not a biological one. There was no change in morphology. It seems to be a cultural phase transition, perhaps involving the emergence of the first fully general language. For this paper, the issue is that, since the Upper Palaeolithic, global human experience has been characterised by a march of progress whose key themes are demographic increase and technological advance. These themes are chicken-and-egg-wise interdependent insofar as technological advance has made demographic increase possible, while demographic increase has made technological advance necessary.

Some argue that the march of human progress is crescendoing towards a new phase transition, perhaps only a few years or decades away, after which it will shift to a new regime of demographic stability and only modest (exponential rather than hyperbolic, or perhaps decelerating) technology growth (Kurzweil, 2005; Korotayev & LePoire, 2020; LePoire & Devezas, 2020; Korotayev, Malkov & Khaltourina, 2006b, p. 33). I do not wish to reject those arguments, which are well supported by theory and evidence, and which I accept as highly plausible. Nevertheless, I do wish to consider the implications of a rather different, more speculative possibility, which is that human progress will continue to accelerate at its accustomed heady pace, leading to future transformations of human capabilities as profound as those that have taken us from the flint axe to the silicon chip. Specifically, this implies that humans will move beyond earth, first to the solar system, then to other star systems, and eventually throughout the universe, which offers unimaginably vast amounts of living space, energy, and raw materials for a super-abundant human population possessing technologies that today seem impossibly expensive and difficult.

It could be objected that the speculated continuing explosive growth of humanity into the cosmos is contradicted by certain hard limits: (1) the birth rate is constrained by physiological factors, and its ceiling is already being reached; (2) the hostile environment of outer space and other planets precludes human habitation; (3) practicable interstellar travel is in contradiction of the laws of physics. This paper assumes that, like previous limits such as heavier-than-air flight, these are soft limits, which will eventually be overcome by new technological and scientific discoveries, for example artificial wombs, terraforming, and warp drives.

The vision of this paper is of long-term human experience as a journey that not only has a physical dimension, from let us say Africa's Rift Valley to the furthest corners of the cosmos, but also has two other dimensions. The second dimension is scientific-technological or equivalently an intellectual journey, i.e. from very limited understanding of the nature and workings of the cosmos towards complete understanding of those things. The third dimension is a moral journey. This is more controversial and harder to define. It could be said that, with something like same-sex marriage for example, what one person regards as moral progress, another might regard as moral regress (Akpan, 2017). This moral journey, while relevant to the concept of a cosmic journey, is not critical to the calculations presented below and will be left vague. Suffice it to say that a look around the world suggests humans are characterised today by extensive moral failings and they cannot be said to have completed their cosmic journey until they have overcome those failings once-and-for-all, even though we are currently as far from moral perfection as we are from the far-flung galaxies it is suggested we will one day explore and populate. That humanity is at the very beginning of its journey, only just peeking over the side of its cradle, means we do not have the capacity to describe moral perfection or grasp how it could be achieved.

To sum up, this paper proceeds from the idea that humanity is embarked on a journey of physical, intellectual, and moral discovery whose endpoint is complete penetration to the ends of the universe, complete understanding of the laws of nature, and complete adherence to a yet-to-be-manifested system of perfect ethics. This end-state will be called pleroma, a Christian theological term meaning something like the completeness of divine power and knowledge that infuses and sustains the universe. The intended implication is that humanity's destination on its cosmic journey is not only effectively divine omnipotence and omniscience but a kind of identification with the cosmos and responsibility for its existence. Clearly, these ideas, which will be elaborated on in the next section, are highly conjectural and the aim here is not to work towards them in the manner of proof but to start from them and see where they lead.

2. Further speculations

I will discuss three issues that provide additional background for the philosophical context of this paper. These issues are: the Fermi Paradox, the Anthropic Principle, and the Second Law of Thermodynamics.

The Fermi Paradox is as follows (Ćirković, 2018): while it is reasonable to think that intelligent life exists elsewhere than on earth, it is also reasonable to think that, compared to earthlings, some of those forms of life would be say a million years—the blink of an eye cosmically—further on in their development, in which case—remembering how far humans have come in just the last 10,000 years—the signs of their activity ought to be visible in the heavens and they might be expected to be aware of us and to have already made contact. Since we are not in fact aware of any alien life, one or other of those seemingly reasonable propositions must be wrong. There are many proposed resolutions of the Fermi paradox that preserve the idea extraterrestrial intelligence exists (Webb, 2015), for example: that interstellar communication is impossible; that we are being kept in quarantine until we are mature enough to be contacted; or that aliens have indeed already visited us as say Erich von Däniken claims. While any of these resolutions might be true, they can be seen as post hoc rationalisations designed to explain the contradiction rather than things we would naturally predict in advance. For this paper, I will assume the alternative resolution, namely that the reason we are not aware of alien life, even though, if it exists, we ought to be, is because there is none, earth is unique, and humans are alone in the cosmos. It is not suggested the Fermi paradox proves this conclusion, only that it is a reasonable and simple solution to it. At any rate, this assumption is the most convenient one for the present discussion because it does not really make sense to think of humanity being on a special journey towards pleroma if there are countless other species doing the same. This assumption keeps the discussion simple and does not require us to consider say the merging of alien civilisations into a common journey although that is another possibility.

The Anthropic Principle describes the observation that the properties of nature seem to be improbably favourable to the emergence of intelligent life (Vidal, 2014; Barrow & Tipler, 1986; Davies, 2008). To give one example, the stellar fusion reactions known as the CNO (carbon-nitrogen-oxygen) cycle can only occur because of a coincidence in some of the quantum energy levels involved. If it were not for that coincidence, there would be no CNO cycle and no elements heavier than helium, thus eliminating the possibility of the complex chemical reactions that constitute life. There are many other ways in which the laws of physics seem 'just right' like this. The weak anthropic principle says that this is because, if it were otherwise, we would not be here to make the observation and it is ultimately just chance. The strong anthropic principle rejects the idea of chance and suggests that there is something inevitable about it or even that the universe has been designed this way. This paper will assume the latter, i.e. that the universe and its laws are the way they are because of the requirements of producing life. In other words, the universe depends on life as much as life depends on the universe, even though we may not yet properly understand the meaning of that claim. It is relevant to this paper because it chimes with the idea that humanity has a unique cosmic role as its journey takes humanity towards pleromatic identity with and responsibility for the cosmos. One facet of the principle may be that it is humans' conscious awareness that creates the universe as a definite phenomenon out of a sea of possibilities, in the same way that it is the act of observation that causes Schrödinger's cat to take on a determinate state of alive or dead rather than retaining the potential for either (Goswami, Reed, & Goswami, 1993; Kafatos & Nadeau, 1990). Another facet of the principle may be that it is humans who give the cosmos purpose and meaning—perhaps the universe exists in order to create intelligent life which, through its journey to pleroma, is ultimately capable of bringing the universe into existence in a kind of closed causal loop. Again, these statements, which may currently seem grandiose and even absurd, are perhaps comprehensible to a species that has achieved the full understanding of cosmic existence implied by pleroma. What makes them seem more than just idle speculation is that say the idea that consciousness creates reality arises both from spiritual inquiry and from theoretical physics. The fact that philosophers and mystics have in some respects arrived at the same places as modern science (Capra, 1976) suggests that the laws of nature may ultimately be very simple and it is only because our understanding is partial and our perspective is misaligned that we currently need abstruse mathematics to describe them, just as an arch under construction is a mess of scaffolding until it is complete and its simple form revealed.

The Second Law of Thermodynamics tells us that the universe is, in effect, running down to a state of maximum disorder or maximum entropy, the universe's 'heat death', when all its energy will be in a useless form unable even to make stars shine let alone power chemical reactions and living organisms. The disorderly state is the most likely state, to which everything tends. Thus, the universe was created in a highly unlikely, highly orderly state of high thermodynamic potential, and its subsequent evolution has involved the steady consumption of that thermodynamic potential, which will be reduced to zero at the time of heat death. The important question is 'where did the original thermodynamic potential come from?' and that, as Kenneth Boulding has remarked, is something we know nothing about (Boulding, 1981, p. 35). Our understanding of the destruction of thermodynamic potential is well developed; the creation of thermodynamic potential is a mystery.

Consideration of the Anthropic Principle suggests that consciousness—the ability of the universe to be aware of itself—is a mystery similar to the creation of thermodynamic potential. It is fundamental to human and perhaps cosmic existence and yet it is also a topic where we are profoundly ignorant. We know that we humans have conscious awareness, though we are less sure of the extent to which it is present in other organisms or even non-living matter. For some, consciousness is not real but rather an illusion created by high-level neural processes, a point of view supported by demonstrations that conscious awareness follows rather than precedes human decision-making (Edelman, 1992; Dennett, 1993). To others this 'solution' to the problem of consciousness, i.e. declaring it does not exist, is strange if not perverse since, as argued by Descartes and depicted in the Matrix films, our consciousness is the one thing that we can be sure is real and it is the material world that may be an illusion. The fact remains that, while theories abound, there is no real understanding of this phenomenon.

The relevance to this paper is that these two mysteries—the creation of thermodynamic potential and the nature of consciousness—are ones that a pleromatic civilisation, to be worthy of that name, must solve. The Anthropic Principle suggests that the two mysteries are linked: in some still obscure sense, thermodynamic potential was created for the benefit of our conscious existence, and in some other also obscure sense, it is our conscious awareness that gives thermodynamic potential its determinate materiality.

3. Tracking progress towards pleroma

To estimate the time for humans to reach pleroma, or in other words the time for the universe to achieve full understanding and mastery of itself, we need some way of tracking progress towards that end. What is offered here is a rough-and-ready, back-of-the-envelope calculation, to give a feel for how we might approach it and for the magnitude of the answer. It is unlikely that we can do better than a rough-and-ready calculation since it involves properties of future discoveries and developments that we cannot know until pleroma has actually been achieved.

The approach taken revolves around the evolution of technology, which it regards as a process of increasing combinatorial complexity. Chemical and biological evolution could be regarded in the same light, i.e. as involving the creation of new elements from the combination of existing elements, with the new elements becoming available for use in further combinations, resulting in the growth of increasingly complex entities. Thus, although the discussion focuses on technology, it develops principles that ought to have application to cosmic evolution in general.

Technology, as used here, should be understood to include social technologies such as legal systems, which may be just as important as things like agriculture in making it possible for people to live better and at higher densities.

An obvious candidate for tracking humanity's growing technological capabilities on its journey into the wider universe is the Kardashev scale, which characterises civilisations in terms of their management of cosmic resources (Kardashev, 1964). We will use a simple version of the scale whereby a level 1 civilisation manages an entire planet, a level 2 civilisation manages an entire solar system, a level 3 civilisation manages an entire galaxy, and a level 4 civilisation manages an entire universe. Typical estimates of the current Kardashev level of human civilisation range from 0.3 to 0.7 (Lunan, 1983).

The question becomes that of objectively measuring Kardashev level. One suggestion is to consider energy. We know, for example, that the amount of energy available on earth as incoming solar radiation is around 4 million exajoules per year. We could therefore say that when the power consumption of human civilisation reaches this amount it is at Kardashev-1.

The problem with using energy turnover as a measure of civilisational level is that one of the effects of improving technology is to increase energy efficiency. The earliest mobile phones consumed more power than those of today, and yet they were less sophisticated. Thus, more advanced civilisations may use less energy, at least per capita. Figure 1 shows that per capita energy consumption has been stagnating in more advanced countries despite continuing technological progress. It follows that the relationship between energy consumption and civilisational level is complex and energy is far from ideal as a metric.

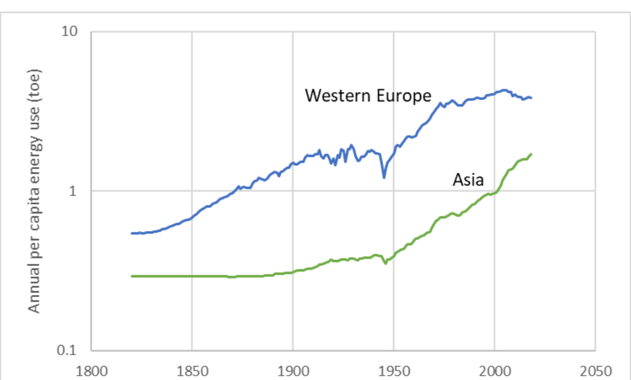

Figure 1: Annual per capita energy consumption (tons of oil equivalent per person). Data: Malanima, 2020.

Let us take another approach, based on technological evolution understood as a combinatorial process. New technologies tend to be built out of combinations of existing technologies. In early times, say, the technology of a carved stick could be combined with the technology of string to create the fire-drill, while the stick could be combined with the technology of flint axes to create a spear. The fire-drill and spear technologies could in turn be combined to create the bow and arrow. Each technology not only is a combination of others but becomes a component for further combinations. There is increasing complexity as more recent technologies incorporate ever more levels of combination.

We must understand a technology not as the gadget that is its end result but as the nexus of human activity that goes into its production. It is the know-how and organisation needed to create components and bring them together in the right way that is the key to a technology. A civilisation cannot acquire a technology simply by being given the gadget. It must have the necessary know-how and organisation if it is to be said to have reached that technological level.

This implies a close connection between technology and population. A technology like the bow and arrow requires a small number of rather simple inputs, and the relevant know-how and organised activity can be supplied by a population of perhaps a few hundred to a few thousand. However, the technology of the smartphone requires a vast array of inputs, not just in terms of computer chips, software, microwave systems, and touch-sensitive screens, but in terms of the machines that make those components and everything going back to the mining of ores and even the cultivation and transportation of food to sustain the retail assistants who market the devices. It seems that such a technology, involving an incredibly large and intricate network of know-how and organised activity, can only be supplied by a population reaching into the billions.

Technology therefore orders human activity—by which is meant purposeful flows of matter and energy—on ever increasing scales. In other words, technological evolution increases order. This is in direct contradiction of the Second Law of Thermodynamics, which says that order must decrease.

A possible resolution of the contradiction is to argue that the increase in order of human civilisation is made possible by decrease in order elsewhere, for example as solar nuclear fusion and fossil fuel burning, which provide the energy for technology networks, are contributing to the heat death of the universe. Thus, local increase in order is offset or more than offset by global decrease in order, so that the Second Law is maintained. If this interpretation is correct, it means that the zone of order must decrease as the zone of disorder expands and, in the long run, human technology and civilisation, along with all life, must eventually be obliterated as the universe succumbs to a state of maximum entropy. This would preclude the possibility of humanity achieving pleroma or Kardashev-4 and full command of the universe, since it will instead cease to exist.

Here, let us adopt an alternative resolution, proceeding from the idea that the know-how and organisation that are the real content of technology represent information, which is non-physical and therefore not bound by the Second Law. Thus, the combinatorial evolution of technology generates ever-increasing amounts of information, and, because the more technology that already exists, the more scope there is for new combinations, this growth of information feeds on itself. As information increases, it can generate new information at an ever faster rate. Thus, while the physical universe began with maximum thermodynamic potential and is steadily using up that potential, the non-physical, informational universe began with minimal potential and is steadily increasing its potential to generate information. While physical matter exhausts its potential in accordance with the Second Law, non-physical information augments its potential in an anti-Second Law.

This process in which information content increases as material content decreases has been described by Buckminster Fuller as ephemeralisation or 'doing more with less' (Buckminster Fuller, 1972). The modern smartphone is lighter, more compact, and less demanding in raw materials than the notorious 'bricks' of forty years ago, yet it is far more capable. Similarly, telephone services that once relied on immense quantities of copper wire are now supplied by intangible microwaves.

If the answer to evolution's contradiction of the Second Law is that information obeys an anti-Second Law, developing in the opposite way to matter through ephemeralisation, we may say that the logical endpoint of doing more with less is to manage an entire universe with nothing. This is pleroma. If we reword slightly to say that the logical endpoint of doing more with less is to create an entire universe from nothing, we may see how a pleromatic civilisation can be expected to achieve divine-like powers, and we perhaps glimpse a solution to the mystery of the origin of thermodynamic potential.

4. Reverse evolution

Technological evolution is not always one-way. Sometimes it becomes necessary to abandon technologies that have led down a blind alley and back up to explore another path. Horse transportation, for example, evolved increasingly sophisticated forms, from the solid-wheeled cart to properly sprung stagecoaches that not only improved passenger traffic but also interacted with printing technology to establish the viability of newspapers and mass communication. Nevertheless, further development became difficult and the horse was never going to facilitate heavier than air flight. There occurred a switch to the internal combustion engine, which meant dismantling the old technology networks focused around the horse at the same time as constructing new technology networks focused around the motor car. This new technology did have the potential for invention of the aircraft.

The phenomenon of shrinking options as one proceeds down a certain path, creating the need to back up and restart, has been called a Sample Space Reducing Process and explored through computational and mathematical modelling (Thurner, Hanel, & Klimek, 2018). Consider the technological evolutionary tree shown in Figure 2. Here each node represents a gadget or technological function, while a technology is the whole network of activity that feeds into providing that function. (This diagram must be understood as a gross simplification intended to show the principle. Because technologies are typically combinations of multiple precursor technologies, there is not really a simple tree but a complex, intercrossing web of functions.) Referring to Figure 2, suppose that technological evolution proceeds down the path shown by the green arrows. The number of further functions that are still accessible shrinks at each step, or in other words each step reduces the remaining sample space. By the time the process has reached function Y, the remaining sample space is reduced to two. If the process is reversed back to point X, the sample space opens up again and many more functions become accessible.

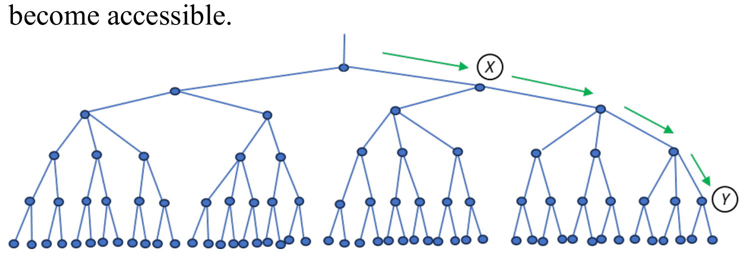

Figure 2: A technological evolutionary tree. Each node represents a gadget or technological function. Descending lines show further functions reachable from that function.

Reverse evolution, i.e. reopening of sample space, can be painful or costly. The switch from the horse to the motor car meant that many businesses and individuals, such as stagecoach companies and stable lads, lost their livelihoods. They eventually found new livelihoods as garages and petrol pump attendants, and indeed the switch created more jobs than it destroyed. Nevertheless, the switch would have been uncomfortable to many as it required learning new habits and it would not necessarily have been obvious that all would be well in the long run.

Reopening of sample space is, in Schumpeter's terms, creative destruction (Thurner, Klimek, & Hanel, 2010; Schumpeter, 1939). The greater the destruction of existing activity networks, the more scope there is to build newer, better networks. The higher the number of companies that go out of business in a recession, say, the larger the amount of land and workforce that becomes available for new companies and new industries to get the economy moving again. In 1945, German planners contemplating the advance of the Soviet armies considered the idea of moving Berlin to a more defensible location after the war. It soon became clear that this was not just a case of relocating the city itself but would require a prohibitively costly reshaping of Germany's road, railway, and electrical distribution systems, which converged on Berlin's existing location (Sauvy, 1974, pp. 444-445). Even the Second World War did not reopen sample space to that extent.

5. Power law

Episodes of creative destruction are power law distributed, meaning that the probability $\text{prob}(x)$ of an episode of creative destruction of size x is related to x by

$$\text{prob}(x) \sim x^{-\beta} \qquad 1$$

where β is a constant. This is illustrated in Figure 3 in terms of the sizes of England's economic contractions, which are episodes of creative destruction in socio-economic networks. The straight line of the rank-size relationship on a double logarithmic plot is the signature of a power law distribution.

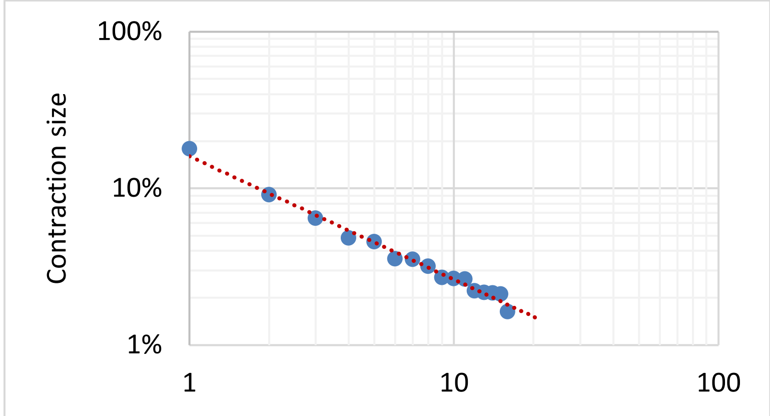

Figure 3: Rank-size plot of economic contractions in the United Kingdom, 1870-2015. The fitted line has R2=0.99. Data: OWID, 2017.

We can understand this mathematically with a rough argument as follows. Suppose that the probability of a reversal by one function is p. Then a reversal by three functions, as from Y to X in Figure 4 below, has a probability of p^3 and, in general, a reversal by F functions has probability p^F, or in symbols

$$\text{prob}(F) = p^F \qquad 2$$

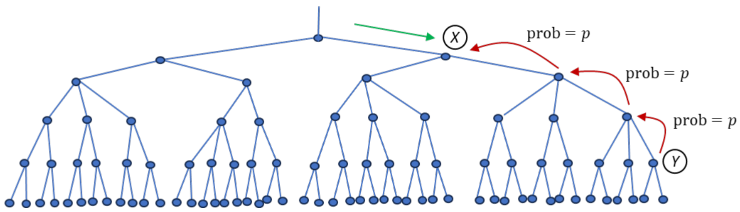

Figure 4: Reverse evolution in a technological evolutionary network.

The number of a society's functions has been found to be proportional to the logarithm of the population of its largest settlement (Ortman, Blair, & Peregrine, 2018). We will make the approximation that the population of the largest settlement is equivalent to the population of the whole society. This is true for many simple societies that have only one settlement, and is roughly true for more complex societies because of Zipf's law of cities (Zipf, 1949) which means that the populations of smaller settlements depend on the size of the largest settlement in a systematic way and therefore so does their total. Writing F for the number of functions and P for population, we have

$$F \sim \ln P \qquad 3$$

We will also say that population is proportional to technology. This follows from the work of Kremer and Korotayev et al., where it is in effect taken as an assumption in deriving the hyperbolic growth of world population (Korotayev, Malkov, & Khaltourina, 2006a; Kremer, 1993). The validity of the assumption is implied by the fact that the population growth has indeed been hyperbolic. The relationship between population and technology essentially expresses the idea that technology affects carrying capacity and that, from a long-term perspective, population tends to be close to carrying capacity (e.g. the new technology of farming allowed the human population to grow to a new limit). Strictly, the relationship holds only for a fixed area, which is however the case for the world as a whole (when area is not fixed, we need to replace population with population density). In symbols, with T for technology, we have

$$P \sim T \tag{4}$$

Substituting in Equation 3 gives

$$F \sim \ln T \tag{5}$$

By a standard identity of probability theory

$$\mathrm{prob}(T)dT \sim \mathrm{prob}(F)dF \tag{6}$$

or

$$\mathrm{prob}(T) \sim \mathrm{prob}(F)\frac{dF}{dT} \tag{7}$$

We have $\mathrm{prob}(F)$ from Equation 2 and we can obtain dF/dT by differentiating Equation 5, so that Equation 7 becomes

$$\mathrm{prob}(T) \sim p^F \times \frac{1}{T} \tag{8}$$

Substituting for F again from Equation 5 gives

$$\mathrm{prob}(T) \sim p^{\ln T} \times \frac{1}{T} \tag{9}$$

If we let $\alpha = \ln p$ or in other words $p = e^{\alpha}$ and substitute this in Equation 9, we obtain

$$\mathrm{prob}(T) \sim e^{\alpha \ln T} \times \frac{1}{T} \tag{10}$$

which, since $e^{\ln T} = T$ while $1/T = T^{-1}$, becomes

$$\mathrm{prob}(T) \sim T^{\alpha} \times T^{-1} \tag{11}$$

Finally, combining the exponents and writing β for $1 - \alpha$, we obtain

$$\mathrm{prob}(T) \sim T^{-\beta} \tag{12}$$

which may be compared with Equation 1 and shows that the sizes of technology reversals, i.e. the magnitudes of episodes of creative destruction, would be expected to have a power law distribution.

6. The cosmic equation

The next question is how fast technology can increase. Again, we can offer a rough argument, using the above suggestion that technology evolution is a combinatorial process.

If technology grows through combination of existing technologies, the rate of technology growth should depend on the number of possibilities for combination among the technologies already in existence. If there are T technologies and each can combine with any of the remaining $T - 1$ technologies, that gives $T(T-1)/2$ possible combinations, where the division by 2 is because A combining with B is the same as B combining with A. This is approximately $T^2/2$ combinations, or if we accept the possibility of a technology combining with itself—for example, string might combine with string to create weaving—then there are exactly $T^2/2$ possible combinations. We have said the rate of technology growth, dT/dt, increases with the number of possible new combinations, so we have

$$\frac{dT}{dt} \sim T^2 \tag{13}$$

The construction of Equation 13 assumes only pair-wise combinations of existing technology. This keeps things simple for the purpose of a rough calculation. In any case, it could be argued that combinations involving more than two precursors are just a series of pairwise combinations. For example, a combination of three technologies could be seen as first a combination of two technologies and then that combined technology joins with the third.

Remembering that technology is an ordering of flows of matter and energy, and that higher technology implies more complex flows, we can see Equation 13 more abstractly as describing the growth of complexity in a combinatorial process. Insofar as chemical and biological evolution also involve the growth of combinatorial complexity, this equation describes the growth of cosmic complexity in general, from molecular synthesis through natural selection to human-mediated elaboration of socio-technical systems. Using y to represent this generalised cosmic complexity, Equation 13 can be seen as a special case of the more general equation (cf. Korotayev, 2018)

$$\frac{dy}{dt} \sim y^2 \qquad 14$$

Equation 14 says that cosmic complexity grows in proportion to the potential for combination within the existing complexity, and this potential for combination is proportional to the square of the existing complexity as argued above for the special case of technology T.

We can rearrange Equation 14 to give

$$\frac{1}{y}\frac{dy}{dt} \sim y \qquad 15$$

While Equation 14 describes the absolute rate of complexity increase, Equation 15 describes the fractional or percentage rate of complexity increase. It says this fractional rate of complexity increase is proportional to the existing complexity. This is again because of combination. While a certain fraction of the existing complexity gives rise to new complexity per unit time, it does so not at a fixed rate but at a rate that depends on the amount of existing complexity with which it can combine.

Alternatively, we can differentiate Equation 14 with respect to y to give

$$\frac{d}{dy}\left(\frac{dy}{dt}\right) \sim y \qquad 16$$

where differentiating y^2 with respect to y gives $2y$ and we have absorbed the 2 into the proportionality sign. Equation 16 says that the complexity growth rate increases with complexity at a rate proportional to the existing complexity. Once again, the statement reflects combination. When existing complexity is low, a given increase in complexity only produces a small number of new combinatorial possibilities. When existing complexity is high, the same increase in complexity makes a much larger number of possible combinations available.

Using dot notation to represent differentiation with respect to time and dash notation to represent differentiation with respect to y, Equation 16 can be written especially succinctly as

$$\dot{y}' \sim y \qquad 17$$

or, if we can choose units for y that make the proportionality constant equal to unity, just

$$\dot{y}' = y \qquad 18$$

Equations 14, 15, 16, and 17/18 are all equivalent and each implies the others. It is a matter of personal preference which one is taken as the baseline 'cosmic equation'. They all have the same solution for y as a function of time, which is

$$y \sim \frac{1}{t_0 - t} \qquad 19$$

This describes hyperbolic growth reaching a singularity (infinite growth) at time $t = t_0$. Such a hyperbolic, 'hockey-stick' or 'J-curve' growth pattern has been demonstrated in population and technology (Korotayev, Malkov, & Khaltourina, 2006a) and seems to be generally characteristic of socio-technical processes (Stiner, Earle, Smail, & Shryock, 2011).

7. Evolutionary envelope

While the cosmic equation predicts that technology and other evolutionary processes will undergo hyperbolic growth up to a singularity, such a point of infinite growth cannot be reached in practice. It is avoided because evolution is not only combinatorial but is sample space reducing. Evolution tends to reach dead ends and needs to be restarted via episodes of creative destruction that have a power law distribution. In other words, evolution encounters resistance and is subject to frequent, small hold-ups and rarer, larger hold-ups.

The resulting evolutionary trajectory is illustrated in Figure 5. It consists of a series of truncated hyperbolas with restarts at irregular intervals. The successive restarts define an envelope curve that represents the overall, long-term path of evolutionary change.

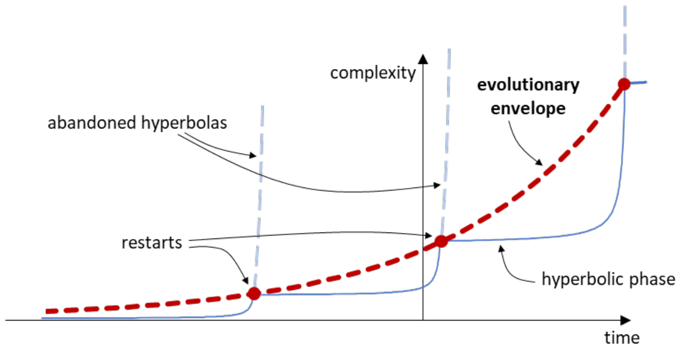

Figure 5: Restarts of the hyperbolic growth process due to the reduction and reopening of sample space.

This pattern has been observed in global population and technology growth, with a shift from an Older to a Younger Hyperbola around the time of the 'Axial Age' in the final few centuries BC, when important new religious, philosophical, and social ideas were introduced (Korotayev, Malkov, & Khaltourina, 2006b, pp. 147-162). Closer examination hints at a series of such shifts, each staving off the approach to singularity by different amounts at different times (Widdowson, 2020, p. 193).

8. Time to pleroma

We now have the equipment to calculate the time to pleroma, which depends not on the hyperbolic growth predicted by the cosmic equation but on the envelope of the repeatedly restarting hyperbolic phases.

First, let us assume that pleroma corresponds to Kardashev-4, i.e. command of an entire universe. Then the problem is to calculate the time to reach Kardashev-4 given what we know about the rate of increase of humanity's Kardashev level so far.

A planet, solar system, or galaxy can be regarded, once it has come under the management of a cosmic civilisation that exploits it in the pursuit of that civilisation's aims, as a tool or gadget, i.e. as a technological function. Kardashev level is therefore a measure of function. Using K to represent Kardashev-level, we can write

$$K \equiv F \qquad 20$$

i.e. Kardashev-level is equivalent to the quantity 'functions'. In making this equation, we are introducing another major assumption, which is that the Kardashev scale of 1, 2, 3, 4 is not just an ordinal scale but a genuine metric, i.e. the leaps say from planet to solar system and from solar system to galaxy are in some sense equal. Since, by Equation 5, functions are related to the logarithm of technology, this would be a geometric rather than arithmetic scale from a technological perspective. That is, the assumption implies that, if it takes say a thousand (1000) technologies to manage a planet, then it takes a million (1000^2) to manage a solar system, a billion (1000^3) to manage a galaxy, and a trillion (1000^4) to manage a universe.

Given Equation 20, Equation 5 can be written

$$K = \gamma \ln T \qquad 21$$

where we also introduce a proportionality constant γ.

While Equation 12 was derived by considering the probability of a technological reversal opening up sample space by a given amount, for our back-of-the-envelope calculation we can postulate that it equally well describes the probability of a technological advance by a given amount—as with the shift from horses to the internal combustion engine, the reversal and the advance are two sides of the same coin. Meanwhile, the probability of Equation 12 is really a probability per unit time. Since the expected time to achieve an event is the reciprocal of the probability of that event occurring per unit time, the expected time t to achieve technology T is

$$t = \frac{1}{\text{prob}(T)} \sim T^{\beta} \qquad 22$$

Or, introducing a proportionality constant A,

$$t = AT^{\beta} \qquad 23$$

Taking logarithms, Equation 23 becomes

$$\ln t = C + \beta \ln T \qquad 24$$

where $C = \ln A$. Substituting from Equation 21 for $\ln T$ and defining $\eta = \beta/\gamma$, this becomes

$$\ln t = C + \eta K \qquad 25$$

This describes the envelope curve representing the overall growth of Kardashev level, which is related to the overall growth of technology via Equation 21.

Since we have two unknowns, η and C, we need at least two points (t_i, K_i) on the envelope curve so that we can solve for them. We can recognise points on the envelope curve as they are points at which the underlying growth shifts from one hyperbola to another, as illustrated in Figure 5.

One such shift point is the present day, insofar as global population growth has recently left its hyperbolic trajectory and is slowing down rapidly, perhaps reaching a ceiling some time in the next century (United Nations, 2019). Another such point is the shift from the Older to the Younger Hyperbola in the Graeco-Roman era.

We now need to make some estimates regarding the times t_i of the turning points and the Kardashev levels K_i of global civilisation at those turning points. For this purpose, we will set the time $t = 0$ as corresponding to the emergence of modern human societies c. 50 kya (rounding up the 40 kya mentioned at the beginning of this article), which is when the process of continuous combinatorial technology growth seems to have got started in earnest. This means the current time is $t_N = 50$ ky (subscript N for 'now'). The current Kardashev level will be taken to be at the low end of typical estimates, i.e. $K_N = 0.3$. This reflects the fact that humans have hardly begun to exploit the oceans, which cover 70% of the earth, while near-earth space is also only inhabited by a handful of people. The time of the shift from Older to Younger Hyperbola will be taken, in round numbers, to be around 500 BC or at time $t_X = 47.5$ ky (subscript X for Axial Age). To assign a Kardashev level, we will assume that, below Kardashev level 1 (command of a planet) is Kardashev level 0 (command of a continent), and below that is Kardashev level -1 (command of a natural geographic area). The Roman Empire that emerged around the relevant time was somewhere between these two levels. Arguably, it was closer to level 0 than to level -1 because, while it did not control any one continent, it did span three continents and it was larger than any Mediterranean polity of today. Let us estimate its Kardashev level as $K_X = -0.3$.

Substituting our values (t_N, K_N) and (t_X, K_X) in Equation 25 gives us a pair of simultaneous equations in η and C that can be solved to give $C = 0.9$ and $\eta = 0.09$.

Knowing C and η, and taking the Kardashev level at pleroma to be $K_P = 4$, we can use Equation 25 again to calculate t_P, the time of pleroma. This turns out to be $t_P = 68.6$ ky. In other words, pleroma will occur 68,600 years measured forward from 50,000 years ago, which corresponds to 18,600 years from today or around AD 20,600.

Thus, we estimate that humanity will reach the destination of its physical, intellectual, and moral journey sometime in the 21st millennium AD. We call this final destination 'pleroma' and what we mean by it is that: (1) humans will have fully traversed, explored and occupied the entire universe, domesticating it in the way that landscapes on earth have been domesticated; (2) humans will understand every remaining mystery of nature, in particular, consciousness and existence, and, through ephemeralisation, they will in effect be able to do everything with nothing; (3) humans will have achieved some kind of ethical perfection that we cannot currently comprehend and that means their custodianship of the universe will be benign and creative.

9. Conclusion

Contemplating the long-term path of humanity, meaning its travels, discoveries, and ethical practices thousands of years in the future, is clearly an imprecise and risky undertaking. This paper has relied on many arbitrary and debatable assumptions and some of its conjectures may seem to veer into the realms of religion, particularly those concerning a self-explanatory or self-referential universe that imagines its way into existence, derives meaning and purpose from one of its own creations, and evolves both towards and away from its beginning through anti-parallel processes of material exhaustion and information augmentation. The possibility of moral perfection may also seem to be far from what can be discussed objectively and scientifically. There can therefore be no authoritative answers and it is certainly not suggested that either the reasoning or the findings of this paper should be regarded as definitive. The calculation that humans will have 'conquered' the universe just 18,000 years from now strikes the author as far too low. Others who are expecting a singularity in the next few decades may find it far too high. Still others, expecting humanity to blow itself up (Rees, 2004), or to be confined to earth by physical law, may regard it as something that will never be achieved at all.

This paper has served as a vehicle to introduce some thoughts about pleroma, humans' place in the universe, and the 'origin and goal of history' (Jaspers, 1953). It is a counterpoint to other theories, not a rejection of them. It takes some assumptions—such as what history so far tells us about where humanity is headed and what the apparent silence we have so far encountered in the heavens tells us about life on earth—and follows where they lead. While those assumptions might be wrong, it is by identifying and exploring them that we gain understanding of the issues they raise. The paper has pondered how seemingly contrasting spiritual and scientific investigations into the nature of the cosmos may converge and collaborate to answer the fundamental questions entertained by both strands of inquiry. It has argued that a suitable way of measuring and modelling the progress of technological civilisation and perhaps of cosmic evolution in general is in terms of combinatorial complexity. A practical consequence of this is the suggestion that singularity-avoiding interruptions to hyper-exponential growth, such as the shift from Older to Younger Hyperbola, might be seen as restarts of a Sample Space Reducing Process, which could be checked, given data with sufficient resolution, by testing whether they have power law statistics.

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