I. EVOLUTIONARY PUZZLES

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How does the Universe Determine How Long We Live?

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Abstract

The question of how the Universe determines how long we live is motivated by the human lifetime as a fundamental unit of time in civilization. Currently we experience unprecedented technological and social change. If too much change happens quicker than a human lifetime, then the changes might not be tested for efficacy in the variety of situations that might arise. Technology that has not been fully tested might lead to instability and chaos in unusual, although expected situations such as global pandemics. In the case of Big History's hyperbolic trend toward a singularity, it determines the maximum rate of change that can be supported in this trend. Previous analysis has demonstrated one perspective that stages occur for every decrease in time to the singularity by a factor of 3. This leads to the determination of the number of stages in the Big History hyperbolic pattern as being the logarithm (base 3) of the ratio of the age of the Universe and the human lifetime. About 50 years ago, the weak anthropic principle was applied to estimate many characteristics of items from atoms to universes. While it provided an approach to determine the mass of 'large' animals on Earth (like humans), it did not find a way to estimate the life of humans based on the fundamental physics parameters. This paper presents one approach that uses techniques covering aspects throughout Big History including the relative strength of electromagnetic and gravitational forces, the size of atoms, evolution-development laws extending into cultural topics, allometric scaling laws of organisms, the rate at which DNA can be reliably copied, and the minimum length of DNA required to support life. An estimate is derived but is based on many uncertain assumptions. This analysis will hopefully be updated as new information and understanding are discovered.

Keywords: *Big History, evolution, human, lifetimes, scaling.*

Evolution: Environmental, Demographic, and Political Risks 2024 15–22
DOI: 10.30884/978-5-7057-6399-3_02

Introduction

What is the ratio of the age of the Universe compared to an average human lifetime? This question is relatively simple to address numerically with our current knowledge – 13.6 billion years / 75 years which is about 200 million. But why and how does this matter? Also, can it be expressed as a function of fundamental parameters?

The question arose as I was considering the trend in historical events which seems to be hyperbolic, that is, the rate is inversely proportional to the time until some (soon) time in the future (Korotayev and LePoire 2020). For example, estimates of historical global human population follow a trend that is not exponential over this time period but hyperbolic. This can be understood as follows: the population growth rate is not just dependent on the population present with a rate constant (exponential) but instead as if the constant were replaced with one varying with the technology progress, allowing the capacity to grow at a quicker rate (*e.g.*, inventions of agricultural practices, and disease prevention). If this factor is proportional to the population then the corresponding equation can be simply solved leading to population = a/T where *T* is the time until some point in the future where the population would get very large and very quick. While this pattern was followed for a long time, it recently has been broken as global limits are being approached.

If the hyperbolic growth pattern continues from the Big Bang to the present time with rapid change, then the amount of overall change is then proportional to the logarithm of the ratio of the longest and shortest times. The longest time is the age of the Universe. The Earth and solar system formed about two thirds along this way, at about 4.5 billion years ago. Other major events can be observed on the way to the present for about every factor of 3 reduction in time (LePoire 2019b). Therefore, the number of stages is proportional to the logarithm in base 3 of the ratio of the largest and smallest times. The smallest time that a major change can occur has been assumed to be a human generation (or lifetime), since learning, adapting, and adopting technology happens with humans, and the changes need to be tested over a full cycle of situations throughout life. This leads to about 17 stages (factors of 3) if a human lifetime of 75 years is used. (The uncertainty of this can be estimated with the range of human lifetimes from 60 years to 106 years giving 17.5 and 17.0 stages.)

But what factors determine this number of stages? That is, is there a way to calculate the age of the Universe and the human lifetimes from fundamental principles? There has been much effort in developing estimates of the first, *i.e.*, astronomical scales of time, mass, and length, based on fundamental physics constants (Carr and Rees 1979; Press and Lightman 1983; Barnes 2012; LePoire 2020). Many of these are attributed to studies of the weak anthropic principle, although many are just applications of reasoning of dimensions and relative force strengths. For example, in 1937 the physicist P. A. M. Dirac noticed the unusually large number, 10 to the 40^{th} power (1E40), coincidence between two completely different combinations of constants [ratio of electromagnetic and gravitational force of protons compared to the ratio of times for light to cross the Universe and an atom]) (Carter 1974).

Approach to Finding Human Lifetime Estimate

The second question concerning human lifetime is quite different. There might be many ways to approach this question. While the estimate of a large animal size, based on the need to survive falling under gravity (about 50 kg) (Press and Lightman 1983), has been known for a long time, its lifetime is more complicated to estimate. We might approach the question of what can be done in a short time. Some bacteria can reproduce every 20 minutes. At a multicellular level, adult forms of mayfly insects last for usually less than a day. Elephants, macaws, and giant lobsters have similar lifespans of humans. The Greenland shark is believed to reproduce at an age of 200 years and can live to 400 years old. An Antarctic sponge can live quite long with a slow metabolism in the frigid waters, with some estimates of lifetimes over 10,000 years.[1] The clock frequency of a standard computer is about 50 million times the frequency of the fastest gamma brain waves in humans.

Other approaches may be based on the time it takes to accumulate mass or perform reproduction. The time to capture enough sunshine energy to grow into a large mass seems to apply more to estimates of a plant's minimum lifetime (Barrow and Tipler 1986). Jeremy England (2013) uses an approach based on entropy generation during replication to constrain replication time. While this method clearly distinguishes the different entropy needs of RNA and DNA replication based on their stability, it is more difficult to estimate lifetimes of more complex systems partly due to the low sensitivity of this entropy need to the relative lifetimes.

The approach used here is a combination of these two. The steps involved span the aspects of the evolution of life on Earth. Many of the various studies that are included are still being studied and debated.

The steps are outlined here so that the details and strategy can be more easily followed. The key is to relate the human lifetime to gestation and then to single cell reproduction rates. The relationship between lifetime and human gestation concerns the required stages a human passes through to contribute to a society with cumulative learning. The link for gestation to single cell reproduction time is based on allometric scaling (*i.e.*, empirical and theoretical understanding of how certain animal characteristics scale with size, specifically mass). The single cell reproduction time is based on the limit in copying DNA under quantum uncertainty.

[1] URL: https://www.swisslife.com/en/home/hub/ten-longest-living-creatures.html.

The gestation time is the time to construct a viable human starting from a single cell. A human at birth requires many additional growing stages to contribute to cumulative learning (Potts and Sloan 2010; Ekstig 2010). After being born, the brain is not fully grown, so there is a long period of growth before it is somewhat independent of the mother (for food and transport) at about age 1.5 years old (Powell *et al.* 2019). This is followed by a period to explore basic human socialization before starting formal education (at about six years old). Next there is a period of intense training to become capable of performing work in a technological society at about 19 years old. Then to make the process efficient, there needs to be a period where work is done, up to the retirement age of about 60 years old. If the age of the human is measured from the first cell division (not the birth), then the sequence of ages are: 0.75 years, 2.25 years, 6.75 years, 20 years, and 61 years. This forms a geometric sequence with four scaling factors of 3 from the gestation period of 0.75 years.

So now the problem is reduced to estimating the gestation time of 0.75 years (nine months). Many animal characteristics scale based on mass (Andresen *et al.* 2002; Linstedt and Calder 1981; Linstedt and Schaeffer 2002). For example, the number of heartbeats in a lifetime is about the same for animals, independent of size. If they are small, the heart beats faster than if the animal is large. It seems that the gestation time scales as the mass of the adult organism to the ¼ power, *i.e.*, an organism 16 times as massive as another would have a gestation time that is twice as long. This is related to the way in which organisms grow, somewhere between uniform growth based on surface area and volume. An extreme test for this would be between bacteria (about a 20-minute doubling time in ideal environments with a mass of about 1E–12 g) and humans (gestation time of 9 months = 6500 hr with mass about 50 kg). Applying the scaling of the bacteria duplication time gives an estimated human gestation time of .33 hr * (5E4 g /1e–12 g)^(¼) = 5,000 hr. This is a good approximateon given the large scale difference.

So now the problem has been reduced to determining the mass and duplication time of simple life, *i.e.*, bacteria.

Again, just like for humans, the mass estimate is a bit easier. Since we really do not know the minimum criteria for life (although there is much research into this question including the characteristics of the last universal common ancestor), the assumption will be made that the size is determined by a simple liposome membrane structure with enough interior volume to contain the molecules to sustain life. The E. coli bacteria has a size of about one by two microns. (There have been studies into a potential form of nanobacteria but that is still ongoing.) The liposome membrane is assumed to be formed by lipid molecules of a certain length. It is believed that the volume of the interior is a certain number of times (*e.g.*, 100) larger than the volume of this cell wall since it would be very inefficient to construct the many molecules of the membrane wall with little room for the life sustaining molecules inside. The volume ratio is $(4/3\pi r^3) / (d*4\pi r^2) = r/3d$, where r is the radius of the cell and d is the thickness of the wall. If the wall thickness is assumed to be 3 nanometer (about 30 atomic distances), then these numbers are consistent with the bacterial size and mass, *i.e.,* the equation gives a cell diameter of about two microns, which leads to a mass of water of 4E–12 g.

So finally, we are down to estimating the duplication time of the bacteria based on fundamental parameters. There are many empirical studies of environmental factors determining the duplication time but no theoretical estimates were found. The duplication time might be constrained by processes such as molecular diffusion, expelling heat, or copying the genetic information. Since reaction and extraction of materials can happen in parallel, the copying of the genetic information might be the limiting factor. In humans and mammals, the DNA is copied in parallel, making what would be a duplication time of about one month down to one hour as seen in human cells. Bacteria do not have this complex machinery to copy their DNA. So the time to copy is just the length of the DNA divided by the velocity of the copying mechanism. Again, there is ongoing research into the minimum length of DNA for a viable living organism. For E. coli the DNA length is about three million base pairs. There is also ongoing research to understand the copying mechanics of polymerase, however, one estimate for the fastest speed possible is based on the quantum uncertainty principle based on the size of the polymerase molecule which yields an estimate for the speed of about 1E–5 cm/s (about 1,000 base pairs/s) (Davies 2004). Based on this, the estimate of the bacteria's lifetime is for copying three million base pairs at one thousand base pairs/s which is 3,000 seconds or 50 minutes. This is about double the actual time, but is a good rough estimate.

Now the parameters have been narrowed to the length of the bacteria's DNA. While there has been much research in understanding the minimum amount of instructions to support life, it does not seem that a fundamental reasoning of the value of about a million base pairs has been presented. Recent studies in artificial life have resulted in the creation of an artificial organism that requires less than 500 genes within about 500,000 base pairs (Hutchinson *et al.* 2016). About 40 % of the genes are for the recursive task of expressing genes.

Assuming a base pair represents two bits (one of four bases) and a text character represents five bits (one of 32 characters), then the minimum length of the DNA is about 200,000 characters. Since the average one-spaced page of text has about 3,000 characters (500 words), this represents about 67 pages of text. This set of a million bits is much less than the number of objects in other complex systems such as stars in a galaxy and neurons in a brain (LePoire 2019a). This seems very small since the DNA must include all the information of the software (with various tradeoffs similar to a compiler and higher language instructions) and data for the structure of the proteins. Progress is being made to understand the genomic network which might later lead to a better estimate of the needed DNA length based on more fundamental properties (Murray 2012).

Conclusions

So now we have all the parts of a highly uncertain chain of reasoning (see Fig.).

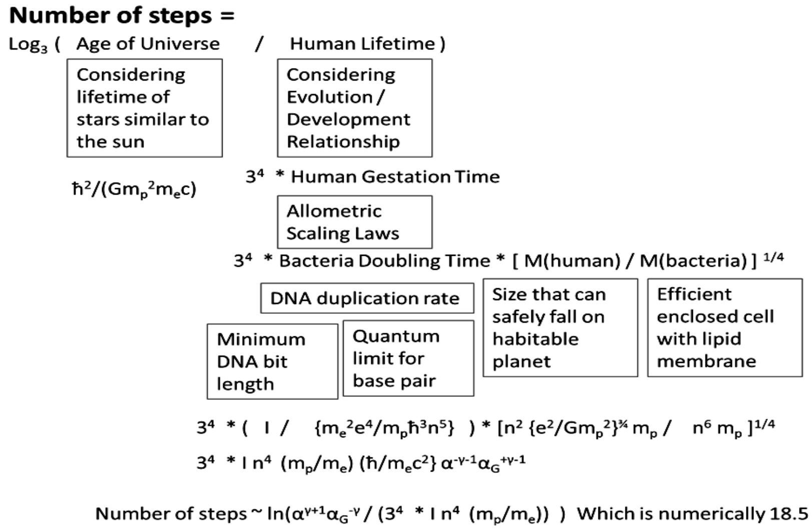

Fig. Development of the relationship of the number of evolutionary steps based on biological and physical principles

Table. Definition and values of fundamental parameters used in the above figure

Symbol	Value	Definition
$\hbar$	1E-34 Js	Planck's Constant over 2 pi
α	1/137	Electromagnetic fine structure constant
α_G	5E-39	Gravitational fine structure constant
m_p/m_e	2000	Ratio of proton and electron masses
n	100	Approximate length of interesting biological molecule in atomic units
γ	13/16	Exponential constant of force structure constant
I	1/137	Minimum bit length of DNA for life

This approach attempts to calculate the number of potential stages in the hyperbolic pattern of complexity development seen in the Universe with conscious life on Earth. The goal is to identify this number and its relationships to fundamental constants of nature. Previous physical relationships had been identified through anthropic reasoning to provide estimates of the age of the Universe, the mass of large animals on a suitable planet, and the size of atoms. However, this approach makes many assumptions and estimates such as the physical and informational size of fundamental life. It also uses allometric scaling laws based on energetics relating the time and size scale of lifeforms.

This is intended to be the beginning of exploring this approach. Researchers continue to provide deep insights into the evolution and development of life and how it relates to fundamental principles of energy, entropy, and information (*e.g.,* Vidal 2010; Ellis, Davies, and Walker 2017). However, this approach brings many fascinating aspects of Big History together from fundamental physics, astronomical evolution, further evolution of life, mind, and civilization on Earth. The result is a fundamental key to understanding the hyperbolic trend toward a singularity, but it does not offer insights to the important aspects of the current transition now as the trend transforms. Hopefully, discussion and insights will continue to further elucidate these relationships.

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