Expected human longevity

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ABSTRACT
In this paper we discuss the fall of ancient civilizations and possible future extinction causes for humans. Then we estimate the longevity of human civilization based on the absence of observable extraterrestrial civilizations and astronomical data using the Drake equation. If there are not many advanced civilizations in our galaxy, our longevity can be estimated at up to 10 000 years.

Keywords
Human extinction, Drake equation, Civilization collapse

1. INTRODUCTION
It seems that nothing in this world can last forever. For example, our Sun burns 600 million tons of hydrogen per second, generating the light that is required to make our planet habitable. According to astronomers, in 4-5 billion years it will go through an exciting, yet terrifying death, probably swallowing the Earth in the process. On the other hand, humans are familiar with the fact that nobody has yet lived over 122 years, but again find it hard to accept that nations and countries face similar destiny. When presented in the National Council of Slovenia that with the fertility rate below 1.6 Slovenians and other major nationalities in Slovenia will cease to exist in a couple of hundred years, the social media protests seemingly related to man-woman issues appeared, although the event was centered around the longevity issues [5]. But history teaches us that in the past there were many flourishing developed civilizations, yet none of them survived for a very long period of time. As people rise and fall, so do civilizations. The same is valid for human civilization – it will inevitably die out one day.

What are the possible causes of the end of our civilization? Using the Drake equation, can we predict how much time we have left and how can we extend it?

Finally, are we like a child cognitively incapable of accepting the incoming fate? Children understand the meaning of death only at the age of 5 [11]. Will we as a civilization live healthy and long or perish at first major obstacle?

1.1 Definition of a civilization
A civilization is defined as a complex society which is characterized by urban development, social stratification imposed by a cultural elite, symbolic systems of communication and a perceived separation from and domination over the natural environment [14].

1.2 Fall of ancient civilizations
There are many different reasons why ancient civilizations went into decline or even extinction. Here we mention a couple of civilizations and the reasons for their decline.

- **The Maya civilization**
  There are several theories about the fall of Maya civilization but the prevalent is that climate changes and consequent drought were the main causes. Other possible causes include social disorder, over-population and warfare [2].
- **Minoan Civilization**
  Minoans were one of the first civilizations in Europe. They were located in Crete, Greece and were wiped out by tsunamis following a volcanic eruption [4].
- **Roman Empire**
  Roman civilization probably collapsed due to many reasons. A weak army, constant barbarian invasions, political instability, overpopulation and epidemics are only few of the causes that might have lead to downfall of this once powerful civilization [12].
- **Native Americans**
  The decline of Native Americans happened when Europeans discovered America in 1492. They brought new diseases to the continent which no Native American was immune to. Furthermore, Europeans started with colonization and Native Americans had no proper weapons to resist them [15].

A recent theory from [8] claims that the downfall of most civilizations was accompanied by ideologies that conflicted with the production process due to changed conditions. The stories of civilization declines are, however, often presented as cautionary tales to frighten us into correcting the error of our ways to prevent the end of our own global civilization [8]. They focus on climate change, human-caused environmental impacts and overpopulation because these three factors are the major global concerns of our time. They have a strong appeal to us because of the ubiquity of disaster-based stories. There are also several positive components in these stories, e.g. they promote environmental responsibility, global concern and sustainable growth.

Space or earth phenomena can cause extinction or at least significantly decrease the number of humans, as the Toba supereruption around 70 000 years ago indicates. It is estimated that at most 10 000 people survived at some point afterwards [9]. But these events might be less likely in the near future due to long intermediate intervals between Earth catastrophes and the relative short-term predictions of the human civilization [1], [10]. In this paper we concentrate on the human-induced problems.

While the doomsayers are a constant phenomenon in our life, and they come indeed in all forms and ideas, more often than not unsupported by data [6], serious analyses were often able to predict the human-caused grim outcomes. The scientific warnings should not be perceived as a pessimistic or doomsayer viewpoint, but as cautions to prevent major problems and even the collapse of our civilization. Whatever the case, with current knowledge and technology it might be possible to scientifically correctly predict most likely current civilization dangers and at least some estimations for the time-span of our civilization.

1.3 Possible causes of extinction of the human race

In this section we will discuss some of the possible causes for human extinction, based on an article by Bostrom [1].

- **Nuclear holocaust**
  USA and Russia hold about 93 percent of all nuclear weapons, but other countries are starting to stockpile them as well. Even worse, the treaty preventing arms races has been called off.

  There are various opinions whether an all-out nuclear war could eradicate humankind. Some believe that it would be hard to reach all possible settlements, for example the ones that are isolated from other people like the mountains of Tibet or remote islands in the South Pacific [13]. Also, there are nuclear shelters preventing the chosen ones. But even if we survive the initial impact, the long term climatic effects would lead to a nuclear winter and the number of people would decrease to drastically low numbers. While humans as a species would probably survive, the level of human civilization would decline dramatically, probably demanding several centuries to regain the former technological state – if ever.

- **Global warming**
  Ever increasing releases of greenhouse gasses could start a feedback loop and the temperatures could continue to rise. Even more species would go extinct and we would be unable to produce crops. If a negative spiral would enhance heating up the planet, life would become unbearable outside with negative consequences similar to those of a nuclear winter.

- **Artificial intelligence**
  The development of artificial intelligence will likely lead to superintelligence in the future. It is possible that in the case of a conflict between humans and superintelligence the entire human civilization could get annihilated [16].

- **Pandemic**
  A new deadly disease could infect the entire world population. There could be an genetically engineered biological agent with long latency and high mortality. Those viruses could be released by a lunatic or spawned unintentionally [7].

- **Asteroid or comet impact**
  This is a very small risk, but if an object 100 km wide would collide with Earth all advanced life could perish. There have been multiple extinctions on Earth and at least some were caused by impacts from space. The best known is the one eliminating dinosaurs around 65 million years ago when an object about 10 to 50 kilometers in diameter hit the Yucatan peninsula in Mexico. As a consequence, around 75 percent of all plant and animal species went extinct.

- **Accidental or deliberate misuse of nanotechnology**
  It might be possible to construct bacterium-scale nanobots that are self replicating and can feed on organic matter. Such robots could ultimately eat or destroy the entire biosphere. This is one of the examples where humans construct a new mechanism capable of destroying civilization.

Can we avoid extinction of a particular nation or the human civilization in the first place? Clearly, the answer is no, and the real question is how long will human civilization persist, analogous to a question about a particular individual. In the next section we present a model that predicts the longevity of human civilization based on the Drake equation.

2. THE DRAKE EQUATION AND ESTIMATING THE LONGEVITY OF HUMAN CIVILIZATION

In 1961 Frank Drake proposed an equation for calculating the number of detectable civilizations in our galaxy at any given moment. The equation consists of several parameters [3]:

$$N = R_* f_p n_e f_l f_i f_c L,$$

where R_* is the rate of star formation per year, f_p is the fraction of stars with planets, n_e is the number of Earth-like (or otherwise habitable) planets per star that has planets, f_l is the fraction of habitable planets with actual life, f_i is the fraction of life-bearing planets that develop intelligence, f_c is the fraction of intelligent civilizations that are detectable and L is the average longevity of such civilizations. Finally, N is the number of detectable civilizations. In the original article the authors used point values to estimate each one of the parameters. Sandberg et al. used a different approach in [10] - instead of using point values they used probability distributions for the parameters listed on table 1.

We used the Drake equation with the Sandberg's approach for the basis for our calculations. Since the parameters in the equation are all estimates we can solve equation for L and take N as a variable. The estimation of N can be somewhat limited from observations of our stellar neighbourhood. The equation for computing L is therefore as follows:

$$L = \frac{N}{R_* f_p n_e f_l f_i f_c} \tag{1}$$

2.1 Estimation of parameters

We used probability distributions to model each variable as in the paper presented by Sandberg [10]. For the distribution of the number of civilizations in our galaxy we set the lower bound at $N = 1$ and the upper bound at 10^4. The reason for this estimate is as follows: We have been trying in vain to get a signal from foreign civilizations even though quite extensive and expensive searches of the universe were performed. The search for extraterrestrial intelligence (SETI) is a collective term for scientific searches for intelligent extraterrestrial life. Various methods and approaches are used to detect signs of transmissions from civilizations on other planets, but most commonly monitoring of electromagnetic radiation is performed. The first scientific investigations began in the early 1900s, and focused international efforts have been going on since the 1980s. While some consider UFOs as a proof of foreign civilizations visiting us, there are no scientifically confirmed results so far. Since some projects were carried out using huge resources and time, that is a rather disturbing indication. Furthermore, it should be noted that this paper relies purely on the known and generally accepted scientific knowledge and UFOs are not part of it. If we therefore assume that detectable civilizations are evenly distributed throughout the galaxy, then there are at most 10 000, since otherwise we would have already observed one (radius of the galaxy is 10^5 light years while we can detect signals as far as 10^3 light years). Consequently, the range of L is theoretically from 10^{-2} to 10^{13}, i.e. from 3 days to ten trillion years.

Parameter	Distribution
R_*	log-uniform from 1 to 100
f_p	log-uniform from 0.1 to 1
n_e	log-uniform from 0.1 to 1
f_l	log-normal rate, described in paper[10]
f_i	log-uniform from 0.001 to 1
f_c	log-uniform from 0.01 to 1
N	point values: 1 to 10 000

Table 1: Probability densities for the parameters in Equation (1)

To estimate the longevity of human civilization, we did not model the parameter N with distributions. Instead we used multiple point-values as inputs to the equation. For example, suppose there are 1, 10, 100, 1 000, 10 000 civilizations in our galaxy now – what can we conclude about our longevity in that particular case?

Several hundreds of models either of different nature or of significantly different parameters were designed and tested, but here we present only one.

3. EXPERIMENTS

The computing was performed in a stochastic way: for a chosen N, a value of each parameter was randomly generated using the predefined probability density, and L was computed according to the Drake equation. The obtained probability distribution denotes the longevity of human civilization under chosen probability distribution for the given parameters and for the chosen N – the number of technologically advanced civilizations in our galaxy, i.e. the ones that transmit electromagnetic signals to space. From the obtained probability density, several derived graphs can be generated, e.g. the one in Figure 1.

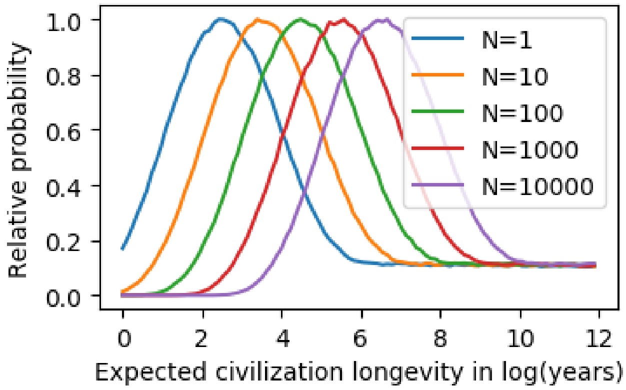

Figure 1: Graph for log(L), i.e. for expected human longevity based on the values of N – the number of civilizations in our galaxy.

N	median	stabilization	volume
1	2 200	13 600	2700
10	22 000	11 100	10 000
100	220 000	9 300	63 700
1000	2 200 000	5 800	545 600
10 000	22 000 000	/	1 000 800

Table 2: Median and stabilization values for different N.

The same relations are also presented in side-view in Figure 2 and in 3D in Figure 3. Bigger N seemingly corresponds to better chances for longer human longevity, in a positive correlation with N. In addition, our longevity is obviously limited, but the exact relations are somehow difficult to comprehend due to the non-linear scale.

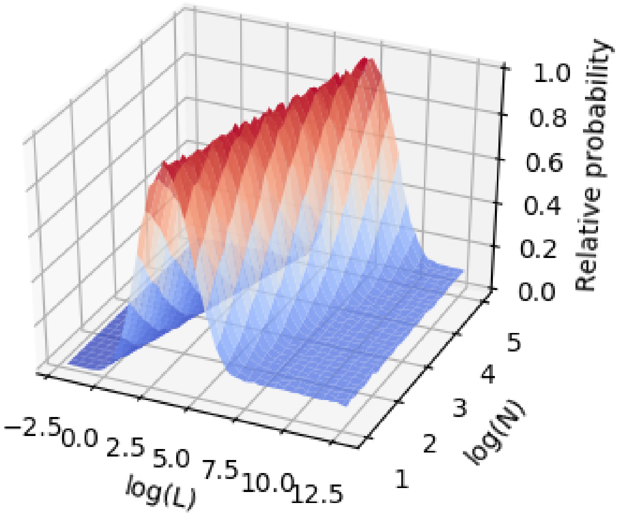

Figure 2: Longevity based on N, side view.

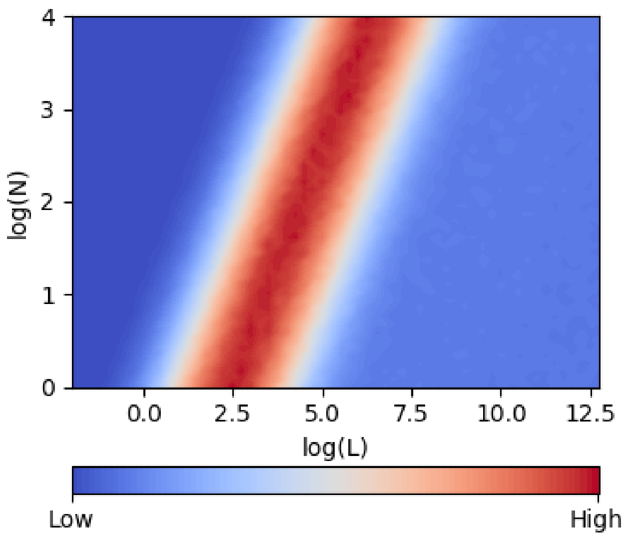

Figure 3: Longevity based on N, top view.

If instead of logarithmic scale, the graph of probability densities is presented in a linear scale (Figure 4), the impression is now quite different. The "true" relation between N and L is as follows:the majority of possibilities for smaller N are at the left part of the graph resulting in a bigger bump accompanied with a slower decline. The point of stabilization, i.e. when a decline is less than 1 percent in a corresponding 100 years is presented in Table 2 as "stabilization". One can also calculate median longevity by computing it for each graph, denoted as "median". The difference between "stabilization"

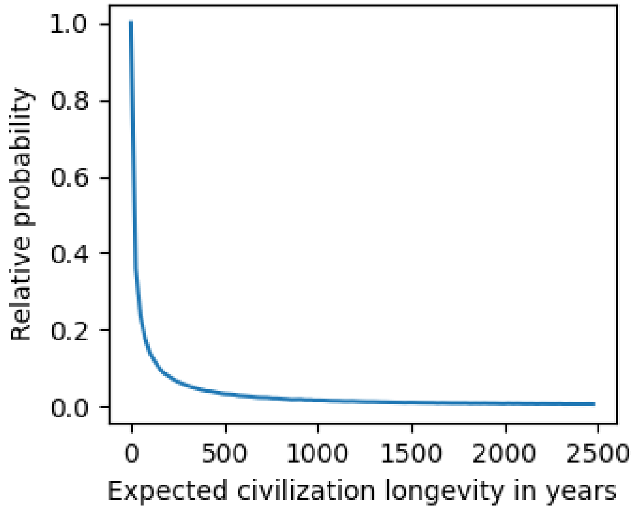

Figure 4: Graph for longevity, i.e. $\log(L)$ in linear scale for $N = 1$.

and "median" is that median represents a point dividing all simulations into two equally frequent intervals, while stabilization indicates the end of steep, i.e. more than 1 percent decline in the probability densities. While median linearly grows with the number of civilizations, stabilization declines denotes where the peak in probability densities on the left is getting smaller than 1 percent. At N equal to 10 000, no decline is bigger than 1 percent. The right-most column "volume" denotes the percentage of the current integral of probability densities in a millennium decreases to less than 1 percent compared to the best 100 years (normalized). These relations are highlighted in Table 3 where the average over an interval 0..1000, 1000..2000, 10 000..11 000 etc. is divided by an average over best (i.e. usually the first) 100 years. These numbers denote how much more probable are the first 100 years compared to the first 1000 etc.

N	0-1000	1000-2000	10 000-11 000	100 000-101 000	1 000 000-1 001 000
1	0.186	0.024	0.002	0.000	0.000
10	0.289	0.073	0.010	0.001	0.000
100	0.600	0.276	0.058	0.006	0.000
1000	0.871	0.789	0.298	0.053	0.005
10 000	0.275	0.749	0.843	0.299	0.048

Table 3: Probability densities of 1000 years for different N at 5 specific longevities normalized to the highest value in 100 years.

The reason why we present graphs in logarithmic scale is that the linear scale does not enable the reader to comprehend anything outside the relevant scope. For example, Figure 4 would consist of two lines if the max years would be 25 000 instead of 2 500 – one vertical on the left and one horizontal on the x axis.

4. CONCLUSION

The aim of this research was to establish probability densities of longevity of human civilization. In this paper we presented results of just one model while we have tested hundreds of them. The model analyzed here shows that if there are more civilizations, we have higher probability of living longer. Regardless of N and after initial fluctuations very close to the left, the curve of longevity is monotonic, decreasing. At N equal to 1, i.e. if we are the only ones in our galaxy, we will probably live only for approximately 2 000 - 14 000 years. At N equal to 10, the expected high-probable longevity is from 11 600 to 22 000 years. At N equal to 10 000 there is no peak at the left and the probability density very slowly declines. In other words – there is not any explicit pattern and predictions are undecidable.

Our maximum survival time seems to be about 10 000 - 20 000 and maybe up to 100 000 years. But most likely, the expected time is substantially shorter.

This study might be relevant because it indicates that we need to start acting wisely sooner rather than later to prevent grim scenarios. Namely, if the predicted time would be say millions of years, there would be no need to go to Mars and other planets soon, we should not worry too much about global warming or other problems. But if the predictions indicate that these dangers might hamper our progress relatively quickly, at least in terms of cosmic timing, we should actively analyze them and react appropriately.

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