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The Study of Progress: Entropy, Complexity, and the Great Filter

Boyan Angelov

“The fall of Empire, gentlemen, is a massive thing, however, and not easily fought. It is dictated by a rising bureaucracy, a receding initiative, a freezing of caste, a damming of curiosity—a hundred other factors. It has been going on, as I have said, for centuries, and it is too majestic and massive a movement to stop.” — Hari Seldon (Foundation, I. Asimov)

Sea Change

What is progress? What is the future of human civilization? While they are the focus of my research now, such questions did not occupy my mind in the middle of the last decade of that momentous twentieth century. Due to recent historical events and my search for fundamental answers, I started to revisit my memories of that time. I believe my childhood experiences provided me with valuable context, that I am sharing here as an essay.

At that time, I used to spend every summer with my family on the shores of a little known at the time sea - the Sea of Azov (Fig. 1). In the 90s, this 30-meter-deep sea was mostly known for the Azovstal Steelworks - the largest in the Soviet Union placed on the shore. It was heavily supplied by the gargantuan coal industry several hundred kilometers to the north, in the Donbas. It was responsible for most of the steel production at the time.

Towards the latter years of my visits to this sea, a concerning phenomenon began to occur. Before it unfolded, I could see quite a significant biodiversity in the water and the beaches - small fish, shells, and crustaceans. But then, one summer, as we arrived at the beach, we saw the whole water colored dark green. At that time, this did not mean much to me - beyond the fact that we could not enter the water. After several days I remember the water cleared, but the sight was also even more disturbing - the beach was littered with dead fish. Furthermore, the summer after that, I remember there was almost no fauna in the water. Decades later, while working at the Max Planck Institute for Marine Microbiology, I understood the reason for this - the pollution from the Azovstal factory and agricultural runoff of nitrates and trace metals into the seawater¹.

Unfortunately, this was not the only catastrophe to befall this region of the world. After the 2012 Euromaidan protests, the Russian Federation-backed separatist forces attacked Ukraine in a first wave of attacks. Later, in 2014 Russia annexed Crimea, and finally, in 2022, a full-scale invasion².

The Sea of Azov became a site of global significance - demonstrating how a small corner of the earth can serve as an example of runaway complexity in the systems that we need to deal with -

¹ Valerii Kulygin, Sergey Berdnikov, Victor Selyutin, and Liudmila Dashkevich. Oxygen depletion risk assessment in shallow water bodies of the sea of azov region. *International Multidisciplinary Scientific GeoConference: SGEM*, 2:799–805, 2016

² Volodymyr Kulyk. National identity in ukraine: Impact of euromaidan and the war. *Europe-Asia Studies*, 68(4): 588–608, 2016

them being ecological or geopolitical - and our increasingly common shortcomings in doing so.

Current State

If we look beyond this corner of the planet, we are bound to encounter more of the same. We find ourselves in a precarious situation in the second decade of the 21st century. While there are positives in our progress, such as reduced infant mortality, escaping poverty, global vaccination, and the almost extinct threat of an AIDS epidemic - few people would assume that we live in safe, prosperous, and improving times.

Conspiracy theories are a symptom of this trend (as ominously predicted by Carl Sagan³), perhaps driven by the innate human desire to know that someone *is* responsible, while the reality that we feel every day is that nobody is at the wheel. Multinational corporations and governments seem like abstract entities⁴. They are rapidly losing the trust of the population at large, as recent swings towards right-wing and autocratic forms of government worldwide can attest to. This lack of trust in our institutions and fading optimism for the future are the tip of the iceberg of challenges facing us and the following generation. We see looming issues across all areas of importance to progress:

- Our environment: pollution, deforestation, biodiversity loss, loss of agricultural yield, antibiotics no longer working; all these issues pale in comparison with the one that can cripple our whole planet - climate change. Climate scientists have been seen as alarmists for decades, but the evidence has since become indisputable. 2023 will be the hottest year on record yet again after beating the previous record set just several years earlier. Antarctic ice recedes in the winter for the first time, and there is little left in the Arctic in the summer. Unpredictable weather, changing ocean currents - we start to see positive feedback loops everywhere.
- Our society and economy: political issues such as isolationism, far-right movements, growing polarization, a new European war. Economic ones such as rising inflation, energy crisis, instability of financial markets, and the growing gap between rich and poor.
- Our science and technology: the rise of AI in automation, nuclear weapons proliferation, and the potential for engineered viruses. There is concern that we are approaching a plateau of scientific discoveries, with the pace of new ones gradually diminishing⁵.

Many of those domains overlap; for example, the effects of climate change in one area in the world lead to higher reliance on a resource (i.e., grain import), which in turn is affected by a

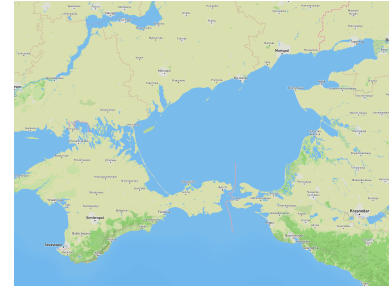


Figure 1: The Azov Sea: a historical hotspot.

³ Carl Sagan. *The demon-haunted world: Science as a candle in the dark*. Ballantine books, 2011

⁴ Fabian Scheidler. *The end of the megamachine: A brief history of a failing civilization*. John Hunt Publishing, 2020

⁵ Thomas S Kuhn. *The structure of scientific revolutions*. University of Chicago press, 2012

conflict (the war in Ukraine), which is also affected by political sentiment in the United States.

Main hypothesis and definitions

Hypothesis

I attempted to reason about the root cause of all of those issues. The result is the central hypothesis of this essay:

The main challenge facing human civilization on the way to its progress through the 21st century is the exponentially growing complexity of the systems we need to design and manage.

I attempt to be as specific as possible - even if the topic is this broad. Still, there are several terms in this statement that can be too open to interpretation, so let me unpack them.

What is Progress?

The word progress is closely associated with the words “change”, “positive,” and “time”. We can use those together to define progress as a positive change over a period of time. The only remaining word to define from this definition is “positive” itself. It can be seen as a vague value judgement; is it quantifiable, or mostly of qualitative nature?

To answer this we can look at the numerous measurable indicators of progress, such as poverty and literacy rates, life expectancy, access to water and sanitation, and human development indices. They are all mostly overshadowed by the most widely cited one: GDP⁶. It has been seen as a de facto proxy of human civilization’s progress over the last decades after the Second World War. But does simple economic growth correspond to a modern and useful definition or progress?

In Western societies, we see a rise in postmaterialism. Still, we cannot assume that we will have a singular indicator for progress worldwide (societies in BRICS countries also expect to have the same trajectory through consumerism as the already developed ones). Also, similarly to the questions as to the ethical use of self-driving vehicles, different cultures would have different requirements⁷. Finally, we will need a combination of those indicators to get the whole picture. All of those are arguments for designing a new, measurable definition of progress for different world regions⁸.

What is Complexity?

The next term that we need to define is complexity. If we look up the word in the Oxford English Dictionary, you will come the

⁶ Diane Coyle. *GDP: a brief but affectionate history-revised and expanded edition*. Princeton University Press, 2015

⁷ Amy Maxmen. Self-driving car dilemmas reveal that moral choices are not universal. *Nature*, 562(7728): 469–469, 2018

⁸ We cannot expect a world government - we need some kind of global control and, at the same time, local responsibility - perhaps more like the school system in federatively organized Germany. Also, accelerationism might provide a solution, but at what cost?

following definition:

Complexity: the state of having many parts and being difficult to understand or find an answer to.

This is a helpful definition because it focuses on why complexity is a problem. Our struggle to understand the black box systems around us and their intricate inter-relationships often lead to untraceable and unforeseen consequences (think of the butterfly effect). Such complex systems can seem fragile, especially from a human perspective. Remember the havoc that the COVID-19 pandemic brought upon China’s global logistic supply lines⁹.

Complexity is not just a helpful word in discussing human civilization, but it is also a fundamental attribute of our Universe, thus a different view can be helpful. It is essential to think on that scale since it will allow us to put a specific emphasis on the potential uniqueness of human civilization on the grandest of scales¹⁰:

⁹ Yanling Xu, Jing-Ping Li, Chien-Chi Chu, and Gheorghita Dinca. Impact of covid-19 on transportation and logistics: a case of china. *Economic Research-Ekonomika Istraživanja*, 35(1): 2386–2404, 2022

¹⁰ Modified from <https://www.preposterousuniverse.com/>

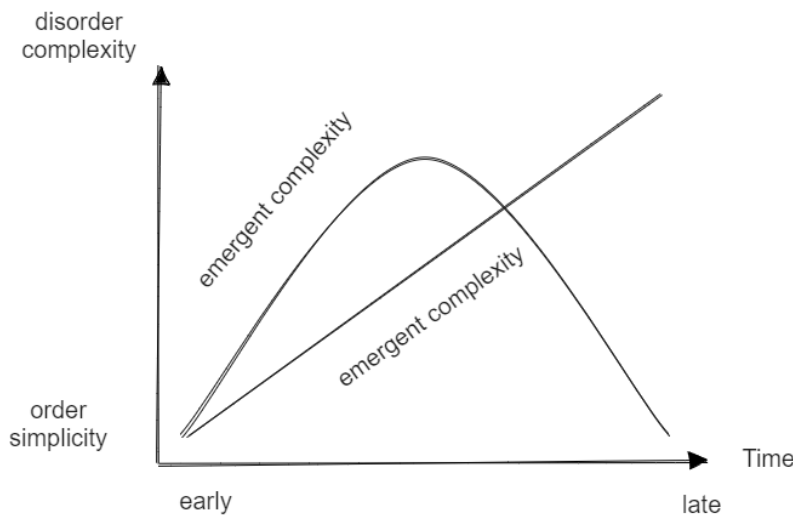


Figure 2: The relationship between complexity and entropy throughout the history of the Universe.

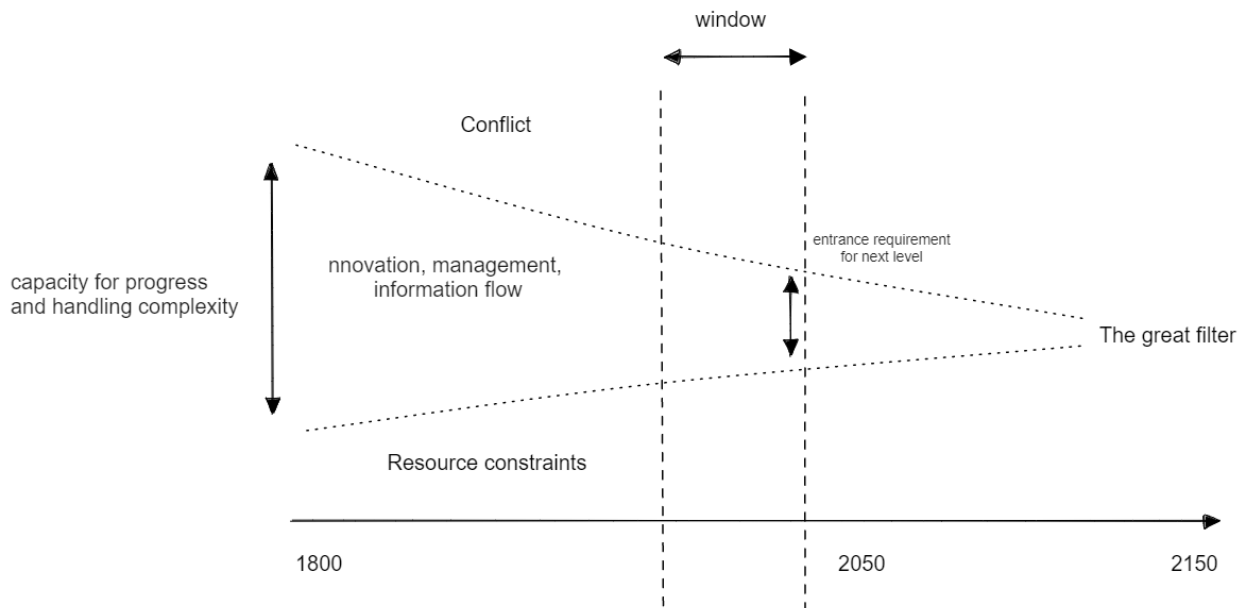
Immediately after the Big Bang, the early universe was an orderly, simple place. The disorder of the universe is constantly increasing (entropy). Broken cups do not spontaneously reassemble to their initial orderly state, and all stars will eventually die - resulting in the cold death of the universe - a state of maximum entropy where nothing ever happens again. There is a “window” where complexity emerges in the middle. Galaxies are formed, stars and planets - and life and civilizations arise. We truly live in a galactic window of opportunity. Interestingly, this is mimicked by a much closer and, unfortunately, a smaller window of opportunity for us in our present and near future.

This graph shows us that runaway complexity is potentially unavoidable. We can look at Ashby’s Law of Requisite Variety which teaches us that to understand a complex system fully,

we need to have the same (or greater) innate complexity (i.e., knowledge)¹¹. Thus it can seem we have just two options in front of us in designing and managing complex systems: reorganize them with long-term antifragility¹² in mind and take maximum advantage of computation and artificial intelligence¹³.

The Great Filter

Why is rising complexity such a problem? In his seminal paper *The Great Filter - Are We Almost Past It*, Robin Hanson originated the term. It is very often used in conjunction with the Fermi paradox. This question is as relevant today as it was back then, and even before - back to the Cuban Missile Crisis of 1967. It is also exemplified by the so-called "Doomsday Clock"¹⁴, which is 90 seconds before midnight at the time of writing¹⁵. Are we past this filter or not? While we have arguably moved on beyond sudden extinction-level events such as all-out nuclear war, we are still threatened by relatively gradual catastrophes such as climate change. Those hide their own dangers if you remember the cautionary tale of the boiling frog. We can attempt to visualize this situation and the factors affecting it:



We do need to pick a relatively long-term scale to see the effects. The essential element here is our capacity for progress (in other words, based on my hypothesis is equivalent to our capability of handling complexity). It decreases with time, based on external forces of complexity effects, such as armed conflict, resource constraints, and others. Opposing forces to those are innovation, improved management of resources and processes, and information flows. Currently, we probably still have enough room in a window that we can meet the entrance requirements for the

¹¹ George J Klir and W Ross Ashby. Requisite variety and its implications for the control of complex systems. *Facets of systems science*, pages 405–417, 1991; and Boyan Angelov. Managing the century of complexity: origins, evolution and productive future avenues with systems thinking, Nov 2022. URL osf.io/wx2j7

¹² Kennie H Jones. Engineering antifragile systems: A change in design philosophy. *Procedia computer science*, 32:870–875, 2014; and Nassim Nicholas Taleb. *Antifragile: Things that gain from disorder*, volume 3. Random House Trade Paperbacks, 2014

¹³ Katharina Loeber. Big data, algorithmic regulation, and the history of the cybersyn project in chile, 1971–1973, 2018

¹⁴ Lachlan Forrow, Tilman Ruff, and Setsuko Thurlow. The 2017 nobel peace prize and the doomsday clock—the end of nuclear weapons or the end of us. *New Engl J Med*, 378: 2258–2261, 2018

¹⁵ You can find out the most recent update here: <https://thebulletin.org/doomsday-clock/>.

Figure 3: A limited window of opportunity for human civilization to pass through the Great Filter.

next level, but the critical question remains - how wide is this window, and what can we do to expand it and act today?

There are other hidden potential causes of a great filter - reduced amount of innovation (have we invented everything which is low-hanging fruit (some argue there are also non-technological innovations we should take into account), helium, phosphorus, and rare earth elements, such as terbium and dysprosium¹⁶. Also, technological issues exist. Can we have large-scale air transport at scale with electricity? How about the melting of steel using renewable energy¹⁷? Is that even possible?

We can also have another view if we look at the Kardashev scale¹⁸ and back into history. The Roman Empire (also the Incans) couldn't handle the complexity of their civilization's growth, but are we better prepared? We can take a big history approach and attempt to visualize the complexity of human civilization through the various stages of its development. Look at Fig. 4.

¹⁶ Yufeng Chen and Biao Zheng. What happens after the rare earth crisis: A systematic literature review. *Sustainability*, 11(5):1288, 2019

¹⁷ Vaclav Smil. *Energy and civilization: a history*. MIT press, 2018

¹⁸ Antong Zhang, Jiani Yang, Yangcheng Luo, and Siteng Fan. Forecasting the progression of human civilization on the kardashev scale through 2060 with a machine learning approach. *Scientific Reports*, 13(1): 11305, 2023

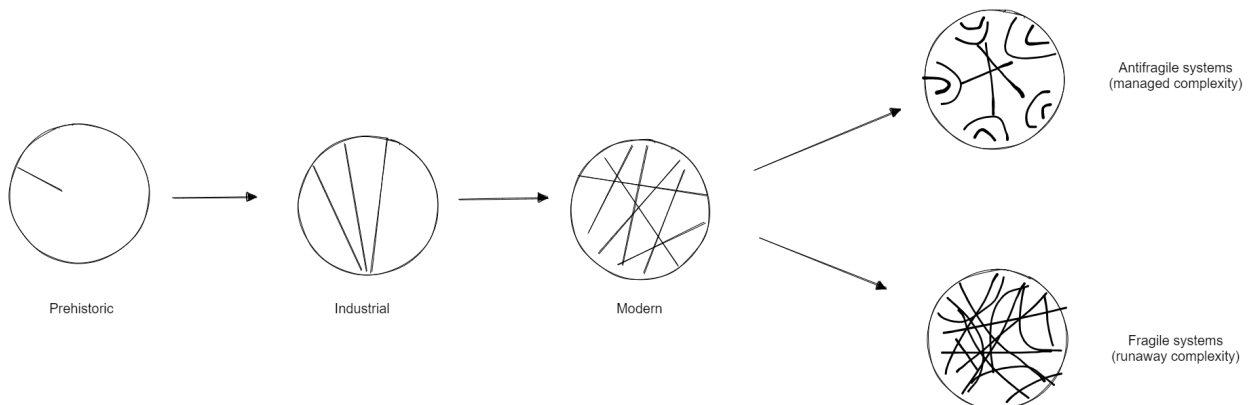


Figure 4: Visualized history of human civilization.

We are at a fork in the road; we can either start designing our systems with complexity in mind or suffer the same fate at a great filter event (black swan or dragon king). Next, let's take a detour into ethics.

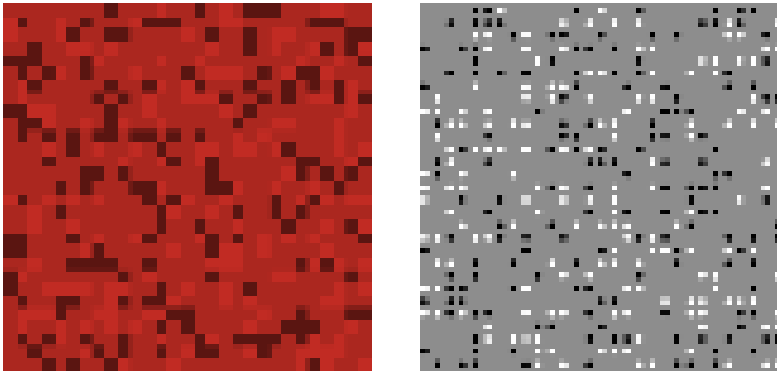
A Humanistic and Anthropocentric Perspective

Morals and ethics are complicated territory. However, to support any solutions to my hypothesis that the number one enemy for the progress of human civilization is complexity, we need to have a moral framework - what is our place and responsibility in this universe? Progress can be seen is a moral imperative¹⁹.

A common argument that can be heard is that *Homo sapiens* is a type of cancer on this planet - fueling exponential growth by destroying its host organism. It turns out we can test this assumption. What would a world without humans look like? This is also a fascinating mathematical model we can use to contrast how the biosphere can regulate itself in conjunction

¹⁹ An excellent write up: <https://rootsofprogress.org/progress-studies-a-moral-imperative>

with the environment (the abiotic system) - the “daisyworld” model²⁰). Have a look at the initial conditions in Fig. 5.



²⁰ Timothy M Lenton and James E Lovelock. Daisyworld is darwinian: constraints on adaptation are important for planetary self-regulation. *Journal of theoretical Biology*, 206(1): 109–114, 2000; and James E Lovelock and Lynn Margulis. Atmospheric homeostasis by and for the biosphere: the gaia hypothesis. *Tellus*, 26(1-2): 2–10, 1974

Figure 5: Initial conditions for the *daisyworld*: temperature distribution and locations of daisies.

And how the situation looks after several iterations in Fig. 6.

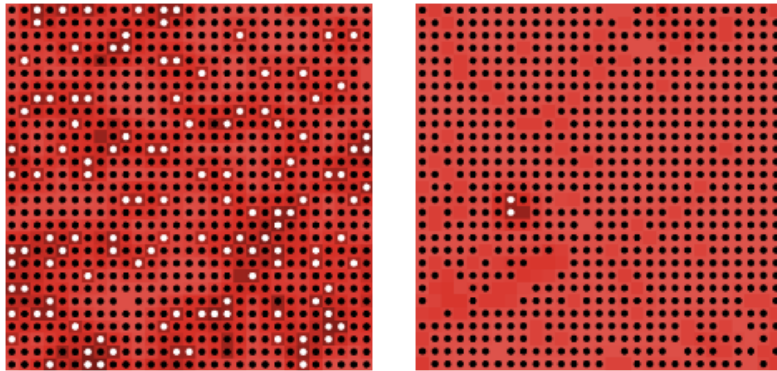


Figure 6: On the left - after a few iterations; on the right - reaching dynamic equilibrium.

Here we have two types of daisy flowers, black and white - with different levels of reflectivity to the sun’s rays. They have different growth rates depending on temperature, and the temperature is calculated based on the amount of energy received in difference to the energy reflected. If we run such a simulation, we get an example of negative feedback from a self-regulating system - the daisies can keep the system’s temperature constant.

Here are the most critical equations, showing the simple math behind this model (reminding me of Stephen Wolfram’s Rule 30 and how complex behavior can arise from simplicity²¹):

$$T = \left(\frac{S(1 - A)}{4\sigma} \right)^{0.25}$$

where T: average temperature of the planet, S: incoming solar radiation. A: albedo of the daisies, proxy for the reflectivity of the planet’s surface and σ is the Stefan-Boltzmann radiation constant.

²¹ Stephen Wolfram et al. *A new kind of science*, volume 5. Wolfram media Champaign, IL, 2002

$$G = G_{\max} \cdot (T - T_{\text{opt}})$$

where G : daisy growth rate, G_{\max} : maximum growth rate, T : temperature of the planet and T_{opt} : optimal temperature for daisy growth.

$$A = A_b \cdot f_b + A_w \cdot f_w$$

where A : albedo of the planet, A_b : albedo value for black daisies, f_b : proportion of black daisies on the planet, A_w : albedo value for white daisies, and f_w : proportion of white daisies on the planet.

And on Fig. 7, we can see how after an initial increase, and subsequent oscillation, the temperature tends to be mostly constant.

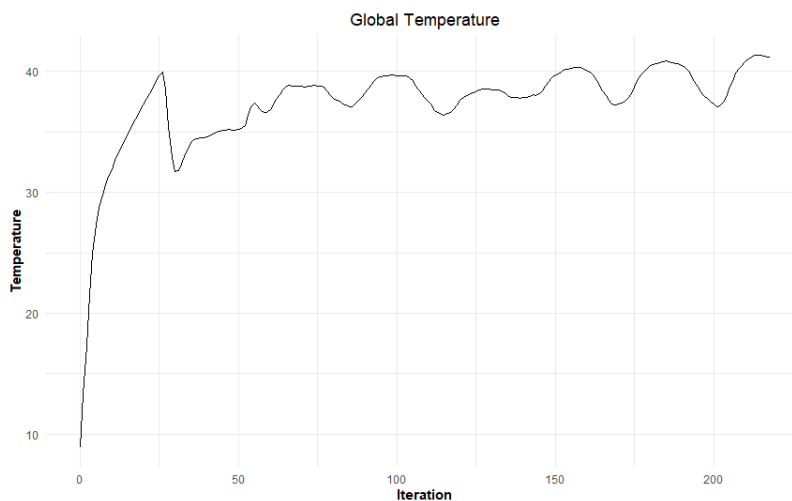


Figure 7: The temperature of the world in the *daisyworld* model.

The population graph looks a bit different, and one species paid the price to ensure the dynamic equilibrium of the system by going almost extinct (Fig. 8).

With the effects of the Anthropocene in full view, it becomes obvious that human civilization upsets this balance in nature, with the effects potentially devastating for us and resulting in a great filter event. Still, there is a big difference between us and other species. One can always argue, similar to what is progress, what is “evolutionary success”? For example, one can say that “primitive” bacteria are far more successful than our civilization simply because they have survived all types of global catastrophes (such as changing climate and asteroid impact) across billions of years. This contrasts greatly with the struggle of human civilization to regulate itself and delegate this task to the environment itself - which would probably not have our best interest at heart²².

While comparison seems to hold true on a local scale, the situation changes if we look at the galactic one once again (as in What

²² Donella H Meadows, Dennis L Meadows, Jørgen Randers, and William W Behrens. *The limits to growth*. In *Green planet blues*, pages 25–29. Routledge, 2018

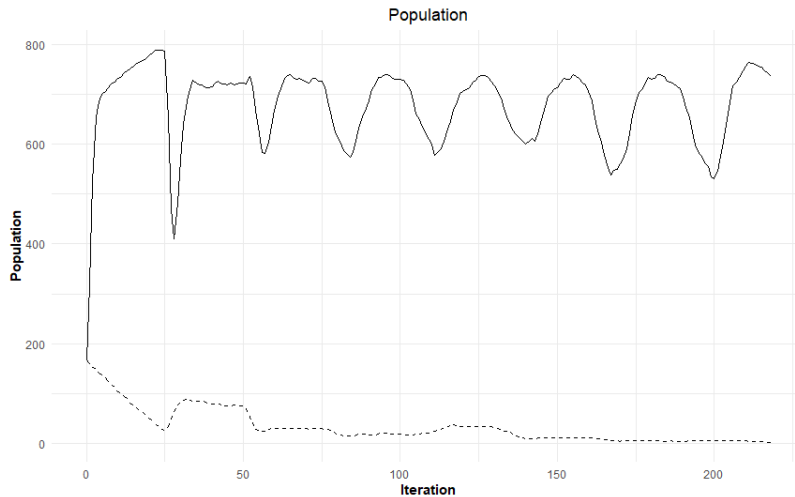


Figure 8: The diverging population of both daisy species in the *daisyworld* model.

is Complexity?). Remember, we also have a window of opportunity in the universe at large - a Goldilocks zone where complexity and entropy are in exactly the right amounts and distribution. The fate of all bacteria on planet Earth is already pre-determined - they will perish in 1.5 billion years when the expanding and dying sun engulfs the earth in flames. The human species is both cancer and savior - we are the only ones that can proliferate life (and emerging complexity) across the universe and potentially give rise to abiotic emerging complexity - artificial life. We will be able to invent new species soon²³; the only important thing is to ensure human civilization's long-term survival and progress. We are the only species to tip the balance and destroy life, but also the only one to spread it long-term.

Such a view contrasts starkly with the opinion of people I hold in the highest regard, such as Carl Sagan:

"If Mars is inhabited, then our moral situation is clear: We must cherish the Martians as a precious cosmic resource. They have a right to their planet. We must explore Mars only with their consent. If they do not exist, then we have an obligation to our descendants to preserve Mars as a world of wonder and beauty, a place where humans can someday live without doing violence to the environment that gave them birth." — Carl Sagan (Cosmos)

I disagree; while life is probably common across the Universe, intelligent life may not be. It is our purpose to proliferate life and complexity. Of course, there are dangers in such a view - anthropocentrism and blind attempts at the dominance of man over matter and nature have been the cause of many of the issues I covered at the beginning of this essay. This is also illustrated in cautionary tales such as Jurassic Park - our attempts at controlling complex systems can often bring the worst results.

²³ Daniel G Gibson, John I Glass, Carole Lartigue, Vladimir N Noskov, Ray-Yuan Chuang, Mikkel A Algire, Gwynedd A Benders, Michael G Montague, Li Ma, Monzia M Moodie, et al. Creation of a bacterial cell controlled by a chemically synthesized genome. *science*, 329(5987):52–56, 2010

Perspectives

The enemy of progress is complexity. We have a limited window of opportunity - not only on a civilization scale but also in the context of the Universe. My goal was to state this and not to go into solutions, but there are some avenues we can explore in the spirit of solutionism:

1. We must define progress globally and locally²⁴ - beyond consumerist and neo-liberalist metrics such as GDP²⁵.
2. We need to reduce the long-term risk of going below the filter by paying the price now and designing distributed, antifragile, and self-regulating systems from a civilization-first, humanistic, and anthropocentric view first.
3. We need a new science of progress that allows us to experiment and measure the results of such experiments based on cybernetic principles and language²⁶.

Autocratic, command, and control centralized systems are fragile and will betray us in the face of exponential runaway complexity (as the current Russo-Ukrainian War also demonstrates). The time is gone for such ways to design and manage systems that we control and interact with.

In *Foundation*, the cracks of the Empire begin to show, with cascading effects eventually. We might be already there, and irreversible trends can be squeezing us below the boundary that we need to pass the great filter. Still, we can pay the price now and start to work on solutions to avoid that fate, and stories such as mine from the Sea of Azov remain isolated, and we witness Fukuyama's "End of History"²⁷. Maybe we are at the edge of a new chance for organized matter to spread, even if it is inorganic (AI) - a new meta-evolution²⁸.

Let us end with Asimov's words once again:

"The future is a black void in which, to my knowledge, we are the only flickering light." — Hari Seldon (*Foundation, I*, Asimov)

²⁴ A great article from *The Atlantic*: <https://www.theatlantic.com/science/archive/2019/07/we-need-new-science-progress/594946/>

²⁵ David M Kotz. Globalization and neoliberalism. *Rethinking Marxism*, 14 (2):64-79, 2002

²⁶ Stafford Beer. Managing modern complexity. *Futures*, 2(3):245-257, 1970

²⁷ Francis Fukuyama. The end of history? In *Conflict after the Cold War*, pages 16-27. Routledge, 2015

²⁸ Cary Wolfe. *What is posthumanism?*, volume 8. U of Minnesota Press, 2010