Major transitions in evolution and finite time singularities: Human wealth history

Paolo Sibani[1*] and Steen Rasmussen[1,2*]

[1]FLinT Center, University of Southern Denmark, DK-5230 Odense M
[2]Santa Fe Institute, Santa Fe, NM 87501, U.S.A.
*paolo.sibani@sdu.dk; *steen@sdu.dk

1 Introduction

Diverse dynamical systems, living or not, were recently (1) discussed with focus on whether their evolution rate was decreasing or increasing.

The first type of dynamics optimizes a target on fast timescales, e.g. all spontaneous physical processes minimize their free energy and bacterial monocultures optimize fitness in a constant environment (2). Evolutionary progress can be viewed as overcoming a series of ever increasing 'record sized' dynamical barriers of system specific sort (3; 4).

The second type, evolutionary expansion, is less common and not as well understood (5). An example is given in (1) based on a time series of British GDP values per person per year (6), a quantity whose trend has kept increasing faster than exponentially since the late Middle Ages.

Gross National Product (GDP) per capita (7) is not directly linked to the abundance or scarcity of material resources but rather gauges economic activities carried out by means of the infrastructures and institutions that maintain a population with shared cultural values and social and technological know-how. GDP history yields therefore insights into human cultural evolution.

A recent study (8), to which we refer for most details, defines 'wealth' as the ability to generate the economic activities e.g. measured by per capita GDP and introduces a simple causal albeit strongly aggregated model assuming that the observed wealth growth is mainly driven by human collaborative efforts whose intensity itself increases with increasing wealth.

As detailed in (8), finite time singularities are strongly supported by key data sets (9; 10) and rapid changes in the mechanisms producing them must occur to avert social disruption. The mechanism proposed in (8) to generate the singularity could be of general relevance and begs the question of how finite time singularities extracted from data analysis can predict major transitions of evolutionary processes.

As an example, GDP per capita data (6) from the UK (blue dots) and the corresponding model generated trend (red hatched curve) are plotted vs. time in Fig. 1. The insert

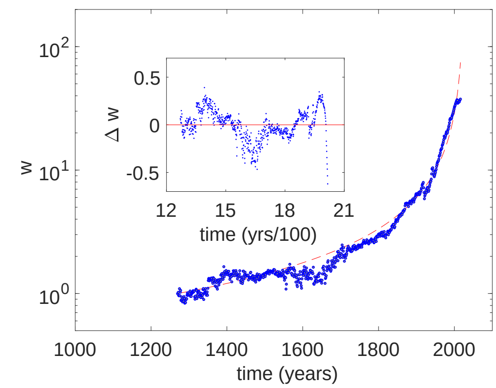

Figure 1: Data and fitted trend for the UK utilizing Eq. 5.. Time series of GDP per capita (6) are scaled by their initial value and plotted as blue dots on a logarithmic axis. A red hatched line depicts the fitted trend and the inserts show the de-trended data Δw divided by 100 for typographical convenience.

shows the de-trended data vs. time.

2 The model

The difference between evolutionary expansion and evolutionary optimization partly lies in which independent 'time' variable best fits their description. Evolution processes promoted by events uniformly distributed in astronomical or 'wall-clock' time, e.g. random energy fluctuations in an aging spin-glass, cosmic rays, or genetic mutations in biological organisms, have wall-clock time as their natural variable and progress at a decelerating rate, through a series of metastable stages (4) Human culture is also a staged process, but since its metastable stages are of shorter and shorter duration the process is accelerating.

Note however that cultural evolution is mainly controlled by personal interactions whose intensity has increased dramatically over time. Increasingly faster and more intense communication has underpinned the coordination and collaboration efforts behind human achievements.

In terms of our 'natural' time variable τ, we posit that wealth per capita is controlled by the simple ordinary differential equation

$$\frac{dw}{d\tau} = \alpha w(\tau) + \beta. \tag{1}$$

where α and β are positive real parameters. In a system with constant interaction intensity and initial wealth w_0, wealth will thus grow as

$$w(\tau) = \frac{\beta}{\alpha}\left(e^{\alpha\tau} - 1\right) + w_0 e^{\alpha\tau} \approx \beta\tau + w_0 \text{ for } \alpha\tau \ll 1. \tag{2}$$

For small values of α we see a slow linear increase proportional to β, which mirrors the absence of a mechanism destroying wealth once it is created.

The connection between 'natural' and wall-clock time variables were discussed in (1) for different examples. For human wealth evolution we here assume that

$$\frac{d\tau}{dt} = \gamma w(t), \tag{3}$$

where γ is a proportionality constant. The above relation implies that some fraction γ of the wealth produced is used to improve communication speed and efficiency, be it by e.g. building better roads or faster computer chips. For constant wealth, τ and t are simply proportional. However, if wealth grows, so does the intensity of human interactions, and $\tau(t)$ increases faster than linearly.

To transform Eq. (1) from 'natural' to 'wall clock' time, we substitute $\frac{dw}{d\tau}$ from Eq. (1) and $\frac{d\tau}{dt}$ from Eq. (3) in $\frac{dw(t)}{dt} = \frac{dw}{d\tau}\frac{d\tau}{dt}$, to obtain

$$\frac{dw(t)}{dt} = (\alpha w(t) + \beta)w(t) = \alpha w^2(t) + \beta w(t). \tag{4}$$

The proportionality constant γ is absorbed in the fitted parameters α and β, and is left unspecified.

The solution to Eq. (4),

$$w(t) = \frac{\beta w_0}{e^{-\beta t}(\beta + \alpha w_0) - \alpha w_0}, \tag{5}$$

features a finite time singularity at

$$t^* = \frac{1}{\beta}\log\left(1 + \frac{\beta}{\alpha w_0}\right). \tag{6}$$

Predictions for the obtained wealth trend evolution compare favorably with GDP time series over eight centuries indicating super-exponential growth (8). Previously, it has also been reported that successive overlays of new significant social and physical technologies, each growing exponentially, do generate a super-exponential wealth-growth over an extended period (11; 12; 13), without reaching a finite time singularity.

To summarize, wealth evolution versus 'wall clock' time features a finite time singularity based on two model assumptions: *(i)* interaction between individuals drives the process and *(ii)* a positive feed-back mechanism is present, whereby the interaction intensity itself increases with wealth. The existence of an external supporting environment that provides food, energy and raw materials is (somewhat unrealistically) assumed available.

3 Discussion

Assuming that wealth generation has been driven by the same mechanism for eight hundred years begs the question of which cultural traits have staid put through the dramatic changes that have happened in the same period, e.g. turning from agricultural to industrial and to service based economies. White (14) and others (15) highlighted the strong emphasis that Western culture puts on the value of individuals together with their special relation to God and the rest of the world. In the Jewish and Christian ethos these elements encourage individuals to pursue self-fulfilment and the achievement of the common good through a cooperative effort that communication among peers and the exploitation of available natural resources. The same principles permeate our moral codices and strengthen deep-lying human interaction patterns, in particular the fact that wealth in part is used to increase human communication intensity.

Obviously, an infinite GDP will not be attained in a few years, so our analysis simply indicates that some sort of major disruption follows if human interaction intensity keeps intensifying. To mitigate the disruption, humans must adjust their interaction patterns to adopt a collaborative in stead of an exploitative attitude to the rest of the biosphere. Further, humans will have to redefine the concept of wealth e.g., as access to solutions for human problems rather than the sum of the market value of products and services as a measure of achievement. Both changes are elements of a major cultural transition that are discussed in (16; 18; 19; 17).

Large scale transitions involving drastic changes of the physical and the chemical environment linked to interaction patterns have occurred multiple times in the biosphere. For example, significant oxygen levels evolved in the reducing atmosphere of the early Proterozoic (20) due to the proliferation of phytosynthetic organisms. Further more, a series of oxygenation events in an anoxic ocean is linked to the appearance of complex multicellular eukaryotes between 1600 and 1000 million years ago (21).

One could speculate whether previous major transitions in the history of life on Earth could be viewed as singularities driven by the way the involved organisms interact? Gaining access to detailed time series documenting such historical events in the biosphere is undoubtedly out of the question. However, Artificial Life style simulations could elucidate how systems may pass through an evolutionary crisis by having interaction pattern that themselves are able to evolve. Perhaps such investigations would reveal similarities to the current interaction driven human crisis.

References

1) S. Rasmussen and P. Sibani. Two Modes of Evolution: Optimization and Expansion. *Artificial Life* 25:1, 9-21, 2019.

2) R. Lenski and M. Travisano. Dynamics of adaptation and diversification: A 10,000-generation experiment with bacterial populations. *Proc. Natl. Acad. Sci.*: 91: 6808, 1994.

3) P. E. Anderson, H. J. Jensen, L. P. Oliveira, and P. Sibani. Evolution in complex systems. *Complexity*, 10: 49-56, 2004.

4) Paolo Sibani, Stefan Boettcher and Henrik J. Jensen. Record dynamics of evolving metastable systems: theory and applications. *Eur. Phys. J. B*, 94:37, 2021.

5) N. Packard, M. A. Bedau, A. Channon, T. Ikegami, S. Rasmussen, K.O. Stanley, and T. Taylor An Overview of Open-Ended Evolution: Editorial Introduction to the Open-Ended Evolution II, Special Issue *Artificial Life*, 25, 93, 2019.

6) Our World in Data. https://ourworldindata.org/grapher/GDP-per-capita-in-the-uk-since-1270

7) R. Costanza, M. Hart, I. Kubiszewski, J. Talberth. A Short History of GDP: Moving Towards Better Measures of Human Well-being. *The Solutions Journal* 5:1, 91-97, 2014.

8) Paolo Sibani and Steen Rasmussen. Human wealth evolution: Trends and fluctuations. *Physica A*: 558,124958, 2020.

9) Sergei P Kapitza. The phenomenological theory of world population growth. *Physics-Uspekhi* 39: 57–71, 1996.

10) A. Johansen and D. Sornette. Finite-time singularity in the dynamics of the world population, economic and financial indices *Physica A* 294, 465-502, 2001.

11) E. Mosekilde and S. Rasmussen. Technical economic succession and the economic long wave. *European Journal of Operational Research*, 25, 27-38, 1986.

12) S. Rasmussen, E. Mosekilde and J. Holst. Empirical indication of economic long waves in aggregate production. *European Journal of Operational Research*, 42, 279-293, 1989.

13) M. Rosenlyst, H. Siboni and S. Rasmussen. Socio-technical evolution Eds., T. Ikegami, N. Virgo, O. Witkowski, M. Oka, R. Suzuki, H. Iizuka *Artificial Life 2018 Proceedings, MIT Press, 2018*

14) L.T. White. The historical roots of our ecological crisis, *Science* 155 (3767) 1203-1207, 1967.

15) A. Ness. *Ecology, community and lifestyle* Cambridge University Press, 1989.

16) Eric D. Beinhocker. The Origin of Wealth: Evolution, Complexity, and the Radical Remaking of Economics. *Harvard Business School Press*, Harvard 2006.

17) Doyne Farmer, Fotini Marcopolo, Eric D. Beinhocker, and Steen Rasmussen, Collaborators in creation: Our world is a system, in which physical and social technologies co-evolve. How can we shape a process we do not control? *AEON*, February 11, 2020

18) E. Beinhocker and N. Hanauer. Private communication, Santa Fe Institute, 2017.

19) S. Rasmussen, D. Farmer, E. Beinhocker, and Fotni Markopoulou, Organizers, The Growing Gap between our Physical and Social Technologies, *Santa Fe Institute Workshop*, July 31-August 10, 2018. Project website: https://www.santafe.edu/research/projects/growing-gap-between-physical-and-social-tech

20) I.B. Lambert and T.H. Donnelly Oxygen levels in the precambrian: a review of isotopic and geological evidence. *Palaeogeography, Palaeoclimatology, Palaeoecology* 97,83-91, 1991.

21) Kan Zhang, Xiangkun Zhu, Rachel A. Wood, Yao Shi, Zhaofu Gao and Simon W. Poulton Oxygenation of the Mesoproterozoic ocean and the evolution of complex eukaryotes. *Nature Geoscience* 11, 345-350, 2018.