The Information Catastrophe and Space Settlement

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Abstract. A further argument for human space settlement is formulated on the basis of the risk of information catastrophe, as recently outlined by Melvin Vopson. Both the increase in the overall material basis of the human civilization and the lowering of operational temperature will act to mitigate this type of risk. Human space settlement and the creation of the Solar System technosphere is certain to advance both these important trends.

Keywords: futures studies – information – computational physics – artificial intelligence – space settlement – technosphere – philosophy of physics

1. Introduction: The Information Catastrophe

In a recent provocative study, Vopson (2020) argues that the exponential increase in the digital information production we are witnessing in this internet day and age leads to unpalatable consequences in the near-to-medium future term. Upon a broadly plausible set of assumptions, the amount of digital information increases so quickly (about $N_b \approx 7.3 \times 10^{21}$ bits/yr today) that Earth's resource base will of necessity fail to keep up. "Even assuming that future technological progress brings the bit size down to sizes closer to the atom itself, this volume of digital information will take up more than the size of the planet, leading to what we define as the information catastrophe." (Vopson 2020, p. 085014-1) Power consumption necessary for creation and reliable storage of such an amount of digital information will become unacceptably large much before the extreme number-of-atoms benchmark; for realistic growth rates of the amount of digital information ranging from 1% to 50% per annum, the timescale for overcoming the total power consumption on Earth ranges from 4500 to 110 years, minuscule values compared to evolutionary, geological, and astrophysical timescales.

This particular "Big Trend" is likely to be very hard or impossible to reverse without an existential catastrophe, even if it will turn out that the reversal is either possible or desirable. In a wider sense, plethora of related values such as the bit-erasure entropy cost and the energy expenditure in creating and maintaining such huge amounts of digital information also exhibit similar exponential divergences. These divergences are clearly unsustainable – and on timescales increasingly comparable with the human (ever-increasing) lifetime.

The idea is not entirely new, similar issues having been discussed in at least vague terms by Stanislaw Lem and Daniel Bell, among others (Lem [1964] 2013; Bell 1974), although it still does evoke a kind of science-fictional image and consequently is often not taken seriously enough.[1] In the parlance of technofuturists, it is the concept of matter of various kinds being transformed into computational devices which encapsulates the phase transition of resources in the postindustrial, information-based civilization. Toffoli and Margolus (1991) dubbed it "programmable matter", but is better known as *computronium* (Amato 1991). The abundance of computronium is the key factor in expansion of the digital civilization and especially its future evolutionary trajectory (Sandberg 1999). While various chemical kinds of matter may comprise computronium, it is clear that – with a few radical and entirely hypothetic exceptions, such as the black-hole computation – computronium is made of atoms (baryonic matter, in the cosmological context). Its amount is hence limited by the number of available atoms, as concluded by Vopson.

Much before we approach the limit based on the number of atoms, we shall face problems with the energy consumption necessary for production of the exponentially increasing amount of digital information. Minimal energy dispersion necessary to write (or erase) N bits of information is, per Landauer principle, equal to:

$$Q_{\min}(N;T) = Nk_B T \ln 2 , \qquad (1)$$

where k_B is the Boltzmann constant and T is the operational temperature. It is immediately clear that diverging $N \to \infty$ implies $Q_{\min} \to \infty$ for any vanishing value of T ($T = 0$ being forbidden by Nernst's heat theorem). Vopson (2020) uses room temperature ($T \approx 300$ K) as representative for terrestrial computing, which is satisfactory enough – and represents a conservative assumption especially from the point of view of the total expended power, since cooling computational facilities significantly below the room temperature usually disperses orders of magnitude more energy from the thermodynamical limit in (1). While present-day human technology is still far from the thermodynamical limit, it is important to understand that it is a limit following from the laws of physics and not based upon contingencies of particular human historical and technological pathways. There is no reason to doubt that, barring some other existential catastrophe, our computing efficiency will eventually approach this limit. The information catastrophe will *still* be a problem then, in

[1] One can perhaps mention Teilhard de Chardin in this context as well (Steinhart 2008), although in his case we can properly talk about *eucatastrophe*.

spite of all the progress achieved in the meantime – that is, if the number of atoms supporting *N* bits of information and the corresponding power consumption remain limited to the terrestrial resources.

The information catastrophe as discussed here *in the terrestrial context* is a particular case among rapidly widening variety of issues stemming from the thermodynamic/information trends related to our planet and its complex systems. The topic is particularly relevant in the Earth System analysis, a multidisciplinary field which "explores possible future development pathways compatible with the coevolutionary dynamics of the biogeophysical and socio-technological spheres and aims at identifying management options for navigating to sustainable safe operating spaces while avoiding undesirable Earth System states such as 'catastrophe domains'" (Donges et al. 2017, p. 24) The information perspective on our cosmological and geophysical environment (Lloyd 2002; Margolus 2003; Kleidon 2009; Vopson 2021) has been combined with the entropy concerns at the level of Earth's biosphere and its complex ecology (Kirsta 2001; Liu et al. 2021) – and even elevated to the status of an ongoing major evolutionary transition (Gillings, Hilbert, and Kemp 2016). The same approach has been applied to the globalized Earth-system economy (Kåberger and Månsson 2001). Even the radical speculation of Lisewski (2007) that the entropy increase could trigger gravothermal catastrophe on planetary scale belongs to this category and in light of the magnitude of hypothetical risk should be analyzed carefully (cf., Ćirković 2012).

Of course, one is entitled to doubt the extent to which the concept of the information catastrophe is a realistic one. We have encountered many examples of failed apocalyptic predictions in contexts of both scientific and extrascientific thought. Some of these predictions were based upon the unlimited growth of some quantity with cataclysmic consequences; for instance, Von Foerster, Mora, and Amiot (1960) predicted unlimited growth of human population reaching singularity on November 13, 2026. Nowadays, this seems rather naive since we are witnessing demographic transitions all over the world, radically changing the pattern of human population growth. Today's best demographic models indeed tend to predict *declining* global populations later in the century. One could argue, however, that it is exactly that kind of divergence from the model predictions that indicates new and interesting phenomena to be studied.[2] There is no reason not to apply the same reasoning to the concept of the information explosion as present by Vopson (2020): subsequent developments in the domain of information technologies could preempt the catastrophe, but we are still interested in elaborating and studying the baseline scenario.

In the next section, we shall show that human space settlement resolves – or at least mitigates and postpones – the problem and doubly so. Section 3 is devoted to some auxiliary issues conntecting the explosion of information with future evolutionary trajectories, notably the usefulness of the technosphere concept in this regard. The final section (4) will

[2] See Carter (2012) for an example of this in connection to the population models.

summarize the argument. While the approach taken here may be rightly deemed common-sensical, one should bear in mind that there is a profound and frightening dearth of common sense in the contemporary debates about space settlement.[3]

2. Space Settlement as Information Risk Mitigation

There are two separate reasons why the future information catastrophe will be mitigated by space settlement: abundance and temperature of computronium.

2.1. The dearth of computronium

If the number of bits grows larger than the number of atoms available on Earth – as Vopson formulates the information catastrophe – a straightforward solution is to obtain more atoms. Even without all rather obvious problems of growth of civilization limited to a single planet, which have been pointed out in the relevant literature (e.g., Zuckerman 1985), as well as the classical temporal limits on Earth's habitability (e.g., Caldeira and Kasting 1992), the terrestrial computronium is clearly an exhaustive resource. Cosmic computronium is not – at least not obviously, neglecting cosmological and physical-eschatological issues for the moment. Therefore, as in the case of lack of other material resources within a finite system – the clear and obvious solution is to fetch them from elsewhere; as Jared Diamond has masterfully shown, resource exhaustion has been among the major causes of civilizational collapse, Rapa Nui being a particularly poignant example (Diamond 2005).

Huge material resources are, obviously, available in the Solar System, our immediate neighborhood (Zubrin 2019). This includes the resources on the Moon, Mars, asteroids in the Main Belt, and elsewhere relatively nearby (Badescu 2009, 2013; Crawford 2015; Maiwald 2018). Still larger resources are available in the outer Solar System – which is additionally appealing for computing, as we shall discuss below – where gas and ice giants and their satellites possess huge resources, not to mention millions of Kuiper Belt, scattered disc, and Oort Cloud objects. The total amount of matter gravitationally bound to Sun is poorly constrained, due exactly to the large number of undiscovered distant icy objects and the possibility of a massive "Planet X" perturber in the transneptunian space (e.g., Trujillo and Sheppard 2014). There is no doubt, however, that this matter presents a huge bounty for producing computronium, at least two orders of magnitude more abundant than the resources available on Earth; this remains true irrespectively from the ways chemical composition of computronium will change in the future.

It is important to keep in mind, in view of all the space skepticism in the media and public discourse, that there are no substantial obstacles of either principle or general applicability

[3] For two examples out of many, see Klee (2017); Torres (2018); cf., Ćirković (2019a,b).

for space mining (e.g., Sivolella 2019). The number of atoms available for computronium supporting the exponentially increasing digital information is increased by a large factor even if we limit ourselves to planets, satellites, and small bodies.[4] Taking into account the possibility of stellar uplifting, as pioneered by Criswell (1985), the resource basis of the Solar System and its future posthuman civilization will become indefinitely large (see also Beech 2007). All this can be viewed from an ethical perspective as well: waste of cosmic resources which could be transformed into computronium incurs not only economical, but a moral loss as well (Bostrom 2003).

Ironically, it is exactly the rise of the *digital* civilization on Earth which enables highly efficient ISRU ("in situ resource utilization") activities, since 3-D printing and nanoassembling will allow for construction of computing equipment all around the expanded, Solar System technosphere. There is no need to transport anything but modest initial hardware from Earth; at least no more than there was need, from the perspective of the *Mayflower* colonists, say, to transport thousands of glass panes from Europe in order to construct the Empire State Building and other great American skyscrapers.

2.2. Cooling computronium

The major consequence of Eq. (1) is that the efficiency of computation with fixed amount of energy expenditure scales inversely with temperature. While we can never achieve T = 0, cooling computronium as much as possible is therefore an imperative in any optimization pathway; this will grow in importance exponentially as the amount of digital information grows and we approach the information catastrophe. The fact that present-day data centers and cloud farms are already moving to polar regions in order to save on cooling expenses, often motivated by new processes in the human technosphere such as cryptocurrency mining (e.g., Quirk and Stabinski 2021), is a signpost of the things to come. It is even more so if we imagine, with many futurists, the transition of human civilization from the biological to the *postbiological* stage of evolution (e.g., Dick 2003; Kurzweil 2005; Ćirković 2017).

Ultimately, this trend can be connected with the biological scaling hypothesis of Freeman Dyson in his seminal discussion of the future of our universe (Dyson 1979, especially pp. 453-457). He argues that, for any Hamiltonian, including those of living systems, the following scaling with temperature will hold:

$$H(T) = \frac{T}{T_0} \hat{U} H(T_0) \hat{U}^{-1}, \qquad (2)$$

T_0 being a fiducial temperature (could in principle be the room temperature as well) and U the standard unitary evolution operator. From this, Dyson derives a bunch of intriguing

[4] For summary of masses see https://ssd.jpl.nasa.gov/planets/phys_par.html (last accessed May 06, 2022).

results concerning the subjective rate of time experience, as well as the (im)possibility of life surviving into the indefinite future of an ever-expanding universe.[5] In any case, it is clear that taking longer and longer view toward the future tallies well with the decrease of operational temperature of processes essential for civilizational survival. This is easiest to achieve by bringing our hardware in contact with thermal reservoirs at lower and lower temperature, such as those across first interplanetary, and subsequently interstellar and intergalactic, space.

For starters, it is not difficult to dramatically decrease *T* within our Solar System neighborhood. Moon's surface cools down to about 100 K in the course of the lunar night and high-latitude areas in permanent shadow are always this cold; similar situation occurs on Mercury (Vasavada, Paige, and Wood 1999). The temperature of the Kuiper Belt objects is generally $T \sim 50\ \mathrm{K}$ (e.g., Jewitt and Luu 2004), although transient higher temperatures are inferred for some of them. Neptune's large moon Triton is often considered the coldest body of the Solar System with temperature measurements giving $T = 38^{+2}_{-1}\ \mathrm{K}$ (Tryka et al. 1993). Going beyond the Solar System will bring the temperature down to 10–30 K in the disk of the Milky Way, depending on the environment (interiors of giant molecular clouds outside of the galactic spiral arms being generally the coldest). Of course, depending on the position in the Galaxy, the intensity of the interstellar radiation fields varies, so the equilibrium operational temperature for computation also does – and this may offer some tangible predictions for SETI studies (Ćirković and Bradbury 2006).

Only far beyond the Galaxy, in the coldness of the intergalactic space, could one hope to approach the cosmic microwave background limit of $T_{CMB} = 2.72548 \pm 0.00057$ K (Fixsen 2009). Computation at this temperature is overall most efficient, since no additional energy would be expended for cooling of the computing equipment, at least as long as the civilization lives far from black holes' horizons (cf. Opatrný, Richterek, and Bakala 2016).

[5] While the cosmological model Dyson used has been superseded by the modern-day λCDM models, many of his results are of crucial importance for physical eschatology (see, for instance, Adams and Laughlin 1999; Ćirković 2004).

Figure 1. This painting by Denise Watt shows an asteroid mining mission to a NEO asteroid. Solar power is utilized for resource extraction and transport, and it could be used for computation all the way to the Dyson limit. As argued in the text, the extension of the future human technosphere to encompass most of the Solar System will enable vast expansion of its material basis and more efficient working temperature. *(Courtesy: NASA.)*

3. Some related issues

Vopson's description of the information catastrophe does not explicitly take into account the technological singularity: it assumes exponential expansion throughout, without vertical asymptote which is usually associated with the concept of technological singularity (e.g., Vinge 1993; Kurzweil 2005; Shanahan 2015). Presumably, further qualitative step forward in AI studies and computing in general will have occur to transform the exponential growth into singularity-like blowing up at finite time. Clearly, this makes mitigating this risk an even more pressing concern.

According to the Copernican principle, we should not consider ourselves special in a wider reference class of, for instance, intelligent beings in the Galaxy (or some other large set). Therefore, we could use the SETI-relevant analogy of the discussion of the information explosion for other Galactic intelligent communities: as Dick (2003), Ćirković and Bradbury (2006), Smart (2012), and others warn, there are reasons to suspect that most of extraterrestrial civilizations are postbiological, hence placing much stronger emphasis on the efficiency of digital computing. (Or quantum computing which even more vehemently requires low operating temperatures.) It is entirely conceivable – and unfortunately little studied in the literature so far – that such postbiological civilizations are comprised of most of the total information budget in the universe (cf., Vopson 2021).

As already mentioned, limits on Earth's resources, development, and entropy production have recently been studied from multiple points of view, including fields such as systems ecology, Earth System studies, complexity studies, or ecological economics (e.g., Kåberger and Månsson 2001; Liu et al. 2021). The *technosphere* is an emerging concept in both Earth System analysis and in the futures studies (Zalasiewicz et al. 2017; Donges et al. 2017); it can be best understood as the "large scale technology" which contains and modifies parts of the conventional Earth "-spheres", such as atmosphere, hydrosphere or biosphere. The information catastrophe, as formulated by Vopson, is a prototypical issue of technospheric significance. If humans decide (or are forced by another existential catastrophe) to relinquish their information technology, the information catastrophe will never occur. While the prospect is unlikely, it serves to underscore that the only viable alternative is, in fact, to transform the future human technosphere into something more sustainable – which is, arguably, possible only in the context of the human space settlement. Therefore, the discussion of the information catastrophe is another opportunity to fruitfully join multiple strands of both research and policy-making, within both theoretical and practical spheres of constructing the sustainable futures.

Finally, in considering the information catastrophe, one should keep in mind the possibility of radical departures from the conventional physics of computation which could, at least in principle, obviate the issue. An example would be black hole computing (Sandberg 1999) or the possibility of dumping waste heat onto a black hole event horizon (Opatrný et al. 2016; Hsiao et al. 2021), or perhaps CDM-based computing. While such radical innovations are plausible, human civilization is clearly far from them – and, considering the timescales relevant for the information catastrophe, it is only reasonable and prudent not to rely on such "magical" solutions too much and consider "conventional" alternatives. While these radical ideas are likely to be relevant in the fulness of time, and perhaps do represent attractors in the space of technoevolution parameters, the likely timescale is much larger than timescales associated with the information catastrophe. In other words, we need to push the information catastrophe further into the future in order to have sufficient temporal margin for development of these radically new ways of computing. Hence, we need to worry about the temporal "window of risk" as far the information catastrophe is concerned.

4. Conclusions

Consideration of the information catastrophe offer further incentive for undertaking ambitious human space settlement, across the Solar System and beyond it. Both increasing the mass (the number of atoms) and decreasing the operational temperature will mitigate the issues underlying the physics of the information catastrophe. These goals are easiest to realize in the context of an industrialized Solar System, where most of economic activity is widely dispersed on the spatial scales of $10^{-1} - 10^{3}$ AU. The other benefits of industrialization of our Solar System – quite independently of issues such as terraforming – have been discussed extensively in the existing literature. Future human technosphere spanning the cold and rich regions of both the inner and especially the outer Solar System is the best warranty of long-term survival of our species and all its values and creations. In the same time, it is the best shot for saving the planet itself and its non-human inhabitants, which are virtually certain to be the first victims of this, as well as of any other human-induced existential threat.

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