

# The Future of Scientific Simulations: from Artificial Life to Artificial Cosmogenesis.

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## Abstract:

This philosophical paper tackles the question of the future of simulations in science from a cosmic viewpoint. We argue that it will result in a simulation of an entire universe. This leads to the challenge of simulating open-ended evolution at all levels in a single simulation. The simulation should encompass not only biological evolution, but also physical evolution (a level below) and cultural evolution (a level above). A second challenge is to probe what would happen if we would “replay the tape of the universe”. The status of an entire universe simulation is discussed distinguishing between *real-world* and *artificial-world* modelling. Assuming that intelligent life could indeed simulate an entire universe, this leads to two tentative hypotheses. Some authors argued that we could be in a simulation run by an intelligent entity. Or, if this simulation could be realized, this would lead to an artificial cosmogenesis. This last direction is argued with a careful speculative philosophical approach, emphasizing the imperative to find a solution to the heat death problem in cosmology. The reader is invited to consult Annex 1 for an overview of the logical structure of this paper.

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**Keywords:** future of science, ALife, simulation, realization, cosmology, heat death, fine-tuning, physical eschatology, cosmological natural selection, cosmological artificial selection, artificial cosmogenesis, selfish biocosm hypothesis, meduso-anthropic principle, developmental singularity hypothesis, role of intelligent life.

*The intent of this work is to synthesize rather than simulate life.*

(Ray 1992, 372)

## Introduction

The practice of artificial life (ALife) as a scientific approach has profound philosophical consequences which remain to be explored. The goal of this paper is to examine one of such consequence: what would be the future of ALife on a cosmological time scale? Our focus is greater than the "influence of machines on the next major evolutionary transition of life" (challenge 12 proposed by (Bedau et al. 2000)). We assume that in the future there will still be an intelligent civilization, whatever its form. We continue and radically extend Dennett's idea that ALife can be viewed as a philosophy which allows the "*creation and testing of elaborate thought experiments*" (Dennett 1994, 291). We believe however that in the far future of scientific enquiry, ALife has the potential to go much further.

"What is ALife?". From a cosmic perspective, a simple answer is: it is *life simulating itself*. Indeed, evolution formed organisms capable of "reverse engineering" the very processes that gave rise to them. This self-referential aspect of life has certainly a profound meaning, which has been most often noticed in discussions about the existence of sentient beings. The general evolutionary theory can outline this emergence of complexity from physical and chemical to biological and sociological systems (Laszlo 1987; Turchin 1977). What could scientific activity become in the future, and what could be its relation to the future of the universe?

It should be immediately stressed however that most often the goal of ALife is not to model life exactly as we know it, but to decipher the most simple and general principles underlying life, to implement them in a simulation. With this approach, one can explore new, different life-like systems. Traditional science focuses on modelling or simulating reality, whereas this is not the aim of most of the endeavours of ALife. There is thus a *creative* aspect to ALife, which is why many artists have enthusiastically depicted imaginary ALife worlds.

We start by arguing that the path towards a simulation of an entire universe is the most likely evolution of our simulation endeavours. We then examine how such a simulation could be realized and solve the irreversible thermodynamic death (heat death) of the universe, expected to happen at some future time.

## Towards a simulation of an entire universe

In this section, we suggest two new challenges for ALife. The first is to simulate open-ended evolution not only in biology, but also to link it together to physical evolution (a level below) and to cultural evolution (a level above). The second challenge is to probe what would happen if we would "replay the tape of the universe". We then discuss in more depth the status and potential usefulness of a simulation of an entire universe, with the distinction between real and artificial world modelling. We outline and criticize the "*simulation hypothesis*", according to which our universe would be just a simulation. Let us first summarize the steadily increase of computer resources.

### ***Increase of computing resources***

I note two important transitions in the history of human culture. The first is the *externalization of memory* through the invention of writing. The second is the *externalization of computation* through the invention of computing devices. The general purpose computer inspired by the work of Church, Gödel, Kleene and Turing, because of its formal

specifications constitutes the most general computing device (see e.g. Davis 2000 for an history of computation). The consequences of this last transition are arguably as significant -or even more significant- as the invention of writing. In particular, the changes induced by the introduction of computers in scientific inquiry are important, and certainly still underestimated and understudied (see however e.g. (Floridi 2003) for a good starting point).

What can we expect from the exponential increase of computing resources? There is much literature about this subject (see e.g. Kurzweil 1999; 2006). Moore's law famously states that the number of transistors doubles every 18 months on a single microprocessor. The increase in processing speed and memory capacity are direct consequences of the law. What are the limits of computer simulations in the future? Although there is no Moore rule for the efficiency of our algorithms, the raw computational power leaves us free computational energy to increase the complexity of our simulations. This should lead to longer term and more precise predictions. Apart from the computational limitation theorems (uncomputability), the only limit to this trend is the physical limit of matter or the universe itself (Lloyd 2000; Krauss and Starkman 2004). As argued by Kurzweil (2006, 362), it should be noted that the ultimate computing device an intelligent civilization could use in the distant future is a very massive object, i.e. a black hole.

From a cosmic outlook, Moore's trend is in fact part of a much more general trend which started with the birth of galaxies. The cosmologist and complexity theorist Eric Chaisson proposed a quantitative metric to characterize physical, biological and cultural complex systems (Chaisson 2001; 2003). It is the *free energy rate density* (noted  $\Phi_M$ ) which is the rate at which free energy transits in a complex system of a given mass. Its dimension is energy per time per mass ( $\text{erg s}^{-1} \text{ g}^{-1}$ ). Let us illustrate it with some examples (Chaisson 2003, 96). A star has a value  $\sim 1$ , planets  $\sim 10^2$ , plants  $\sim 10^3$ , humans  $\sim 10^4$  and their brain  $\sim 10^5$ , current microprocessors  $\sim 10^{11}$ . This increasing efficiency develops at a more than exponential rate, to do ever more, requiring ever less energy, time and space; a phenomenon also called *ephemeralization* (Fuller 1969; Heylighen 2007), or “Matter Energy Space-Time Compression” (Smart 2002)

In Tomas Ray's simulation *Tierra* (Ray 1991), digital life competes for CPU time, which is analogous to energy in the organic world. The analogue of memory is the spatial resource. The agents thus compete for fundamental properties of computers (CPU time, memory) analogous to fundamental physical properties of our universe. This design is certainly one of the key reasons for its impressive success.

### **Bridging physical, biological and cultural evolution**

We saw that a metric can be found to compare complex systems traditionally considered as different in nature. This important insight is just a first step towards bridging physical, biological and cultural evolution. The information-theoretic endeavours are certainly going in this direction (e.g. (Von Baeyer 2004; Prokopenko, Boschetti, and Ryan 2007; Gershenson 2007; Floridi 2003))A general challenge for ALife is to obtain an artificial system capable of generating open-ended evolution. Some results have been obtained linking for example the evolution of language with biological traits. Working towards the design of a digital universe simulating this rise of levels of complexity in the physical, biological and cultural realms is the challenge of simulating an entire universe. An important step in this direction, although it stays on the physical level, is the “Millennium Run” simulation , which starts from the very beginning of the universe to generate the large scale structures of the universe (Springel et al. 2005).

However, we must acknowledge important difficulties of conceptual, methodological and cultural integration between the different disciplines involved. In such an endeavour, human-made social and academic boundaries between disciplines of knowledge should be

overcome (see e.g. Grandpierre 2003a; 2003b). I proposed to construct an integrative scientific worldview with *system theory*, *problem solving* and *evolutionary theory* as three general key general approaches (Vidal 2008). There should be a seamless link between simulations in physics, biology and social sciences (culture). In fact the search for such bridges is obviously necessary if we want to tackle such problems as the origin of life, where we aim at explaining the emergence of life out of physico-chemical processes.

## ***Replaying the tape of the universe***

The biologist Stephen Jay Gould (1990) asked the famous question: "what would remain the same if the tape of life were replayed?". Paraphrasing and extending it to the universe, the question becomes: "what would remain the same if the tape of the universe were replayed?". We should first notice that the tape metaphor has some limits. Indeed, if the tape and its player were perfect, we should obviously get exactly the same results when re-running the tape. The question then implicitly assumes that small fluctuations could lead to a different (or very different if for example the system is chaotic) outcome.

By exploring other simulated universes, this approach would allow us to face one of the main difficulties in cosmology, which is that -as far as we know- there is only one object of study: our unique universe. Interestingly, it is a very relevant research program for tackling the difficult "fine-tuning" problem in cosmology, which states that if any of a number of parameters, fundamental constants in physics and also initial conditions in cosmology were slightly different, no complexity of any sort would come into existence (see e.g. (Leslie 1989) for a good review). To give just one example, let us consider the ratio of electrical and gravitational forces between protons, which is  $10^{36}$ . Changes either in electromagnetism or in gravity « by only one part in  $10^{40}$  would spell catastrophe for stars like the sun » (Davies 1984, 242).

The simulation of an entire universe can be seen as the ultimate challenge of simulations in science. But what kind of simulation would it be? What could it be used for? To answer these questions we will now distinguish between two kinds of modelling.

## ***Real-world and artificial-world modelling***

A computer simulation can be defined as a model wherein some aspects of the world are chosen to be modelled and the rest ignored. This makes possible to run the model faster than the phenomena modelled, and thus to make predictions about reality. In our discussion, it is important to distinguish between *real-world modelling* and *artificial-world modelling*.

*Real-world* modelling is the endeavour to model processes as-we-know-them. This includes traditional scientific modelling, such as models in physics, weather forecast models, but also applied evolutionary models etc. The goal of such models is to better understand our world, and make predictions about it. What would be a *real-world* simulation of an entire universe useful to? At first sight, it would provide us very good understanding and predictive power over our world. However, this view has some severe limitations. First, if the simulation is really of the entire universe, it should be "without anything left out". This is a strange situation, since it would imply that the model (simulation) is as complex as our universe. Such a simulation would thus not provide a way to systematically predict all aspects of our universe, because it would not be possible to run it faster than real physical processes. Another limiting argument is that more computational power does not necessarily mean better predictive abilities. This is pretty clear when considering chaotic systems such as the weather system. How much computational power would be needed to predict the weather in ten years? A simulation still has to be simpler than reality if to be of any practical use. This means that in the context of "replaying the tape of our universe", we would still have to investigate a simplified simulation of our universe.

*Artificial-world* modelling is the endeavour to model processes as-they-could-be. The formal fundamental rules of the system (of life in the case of ALife) are seeked. A new digital world is then set up and explored. This includes for example almost all kinds of ALife models. What would be an artificial-world simulation of an entire universe useful to? We would be able not only to “replay the tape of *our* universe”, but also to play and replay the tape of *other possible* universes. We saw that it constitutes a research program for tackling the fine-tuning issue in cosmology. The concept of “a universe” then needs to be redefined and extended, since we only know by definition our unique universe.

Should this artificial world of an entire universe be interpreted as a simulation or as a realization (Pattee 1989)? Let us first consider the *simulation hypothesis*.

### **The simulation hypothesis**

Let us assume what we have argued in the previous section, i.e. that intelligent life will indeed be able at some point to simulate an entire universe. If such a simulation is purely digital, thus pursuing the research program of soft ALife, this leads to the *simulation hypothesis*, which has two main aspects. First, looking into the future, it means that we would effectively create a whole universe simulation, realizing what was imagined in science fiction novels such as the ones of Greg Egan. Very well then! A second possibility is that we ourselves could be part of a simulation run by a superior intelligence (see e.g. (Bostrom 2003; Barrow 2007; Martin 2006)). Although these scenarios are fascinating they suffer from two fundamentals problems. First, the "hardware problem": on what physical device would such a simulation run? Is there an infinity of simulation levels? Second, such an hypothesis violates Leibniz' logical principle of the identity of the indiscernible. It states that “if, for every property F, object x has F if and only if object y has F, then x is identical to y”. Let x be reality, and y be the supposed simulated universe we would be living in. If we have no way to distinguish between them, they are identical! Unless we find a “bug” in reality, or a property F that could only exist in a simulation and not in reality, this hypothesis is useless. A more comprehensive criticism of these discussions can be found in (McCabe 2005).

The ontological status of this simulation would be reflected by the states of the hardware running it, whatever the realistic nature of the simulation. From this point of view, we can argue that it remains a simulation, and not a realization (Harnad 1994). Is there another possibility for realizing the simulation of an entire universe? That is what we will explore now.

## **Towards a realization of an entire universe**

We first outline some aspects of the heat death problem concerning the far-future of the universe. We then put forward a philosophical approach to tackle this problem, and suggest a speculative solution called “artificial cosmogenesis”.

### **The heat death problem**

What will happen to the Earth and the Sun in the far future? First, it will be the end of our solar system, with our Sun turning into a Red giant star, making the surface of Earth much to hot for the continuation of life as we know it. Even if life would be able to colonize other solar systems, there will be a progressive end of all stars in galaxies. Once stars have converted the available supply of hydrogen into heavier elements, new star formation will come to an end.

In fact, the problem is even worst. Consider the second law of thermodynamics which

is one of the most general laws of physics. It states that the entropy of an isolated system will tend to increase over time. Hermann von Helmholtz applied it to the universe as a whole in 1854 to state the heat death (HD) problem, i.e. that the universe will irreversibly go towards a state of maximum entropy. It is estimated that even black holes will evaporate in about  $10^{98}$  years (Adams and Laughlin 1997). Let us note however that there are some other models of the end of the universe (such as Big Bounce, Big Rip, Big Crunch...) but the point is that none of them allows the possibility of the infinite continuation of life as we know it. The study of the end state of the universe, or *physical eschatology*, is a scattered but exciting field of research that we cannot detail more here (see (Ćirković 2003) for an extensive literature guide).

In an optimistic picture, that is if our civilization does not self-destructs (or if it does, we can add the hypothesis that we are not alone in the universe...), we can see the HD problem as the longest-term problem for intelligent life in the universe. How should we react to it? Charles Darwin's thought is still perfectly relevant: "Believing as I do that man in the distant future will be a far more perfect creature than he now is, it is an intolerable thought that he and all other sentient beings are doomed to complete annihilation after such long-continued slow progress" (Darwin 1887, 70)

### **A philosophical approach for a speculative topic**

The shrewd reader may have guessed that we will propose a solution to the HD problem. However, we have to make a methodological clarification at this point. The solution proposed in the next section will be approached from a *speculative* philosophical stance (as opposed to *critical* philosophy (Broad 1924)). We should be well aware of the difficulty of the question we are tackling; an age-old philosophical problem which is: "what is the ultimate fate of humanity and the universe in the very distant future?". This problem is philosophical because (1) we do not have unambiguous empirical or experimental support to favour a unique outcome and (2) it is such an ambitious question, that the proposed answer can only be tentative and speculative. It is however still very worth considering because the philosophical inquiry aims to answer our most profound questions here and now, whatever their difficulty and our limited knowledge. I proposed a general philosophical framework to tackle speculative problems in (Vidal 2007).

### **Cosmological artificial selection**

The cosmologist Lee Smolin proposed a theory called Cosmological Natural Selection (CNS) in order to tackle the fine-tuning problem (Smolin 1992; 1997). According to this natural selection of universes theory, black holes give birth to new universes by producing the equivalent of a Big Bang, which produces a baby universe with slightly different physical laws. This introduces variation, while the differential success in self-reproduction of universes via their black holes provides the equivalent of natural selection. This leads to a Darwinian evolution of universes whose laws and constants are fine-tuned for black hole generation, a prediction that can in principle be falsified.

Smolin is not the only cosmologist reasoning with multiple universes (multiverse). Although the idea of a multiverse is accordingly a speculative idea, it is surprisingly popular among many cosmologists. Kuhn (2007) multiverse models: by disconnected regions (spatial); by cycles (temporal); by sequential selection (temporal); by string theory (with minuscule extra dimensions); by large extra dimensions; by quantum branching or selection; by mathematics; by all possibilities.

It should be noted that in Smolin's theory (1) the roles of life and intelligence in the universe are incidental. Another problem is that (2) the theory does not propose a mechanism for universe replication. Is it possible to overcome these two shortcomings? A few authors

have dared to extend CNS by including intelligent life into this picture, correcting those two problems and also bringing indirectly a possible solution to the HD problem (Crane 1994; Harrison 1995; Baláz 2005; Smart 2000; Gardner 2000; 2003). Simply stated, the thesis is that advanced intelligent civilization will solve the HD problem by reproducing the universe. This direction can be seen as the ultimate challenge of strong/wet ALife, to realize a new universe.

This leads to an attempt at what we could call *artificial cosmogenesis*. Let us note however that there is not (yet) an uniform terminology among the five mentioned authors. Inspired by Smolin's terminology we could speak of a "Cosmological Artificial Selection" (CAS), artificial selection on simulated universes replacing natural selection of real universes (Barrow 2001, 151). Instead of having many generations of universes needed to generate randomly an interesting fine-tuned complex universe, a CAS would dramatically improve the process by artificially selecting (via simulations) which universe would exhibit the desired features for the next generation universe. This would facilitate and guide the (certainly) extremely difficult task of producing a new universe.

This solution to the HD problem gives a general challenge to intelligence in the universe: to continue to explore and understand the functioning of our universe so as to possibly reproduce it in the far future. It also fits with the ultimate goal of evolution as a whole: survival. It is likely to be a difficult and stimulating enough challenge to encourage and occupy many generations of scientists. The degree of control that intelligence could have in this process still had to be discussed. For example, for the production of a new universe, in how far the selection of a simulated universe would be constrained by the physical properties of our own universe? The issue of the ethical responsibility of humanity in this proposition is outside the scope of this paper and remains totally to be explored.

## Conclusion

ALife constitutes a revolution in the way we practice science. We have outlined the fast-moving changes occurring in our universe, and argued that the limit of scientific simulations is the simulation of an entire universe. Furthermore, we have formulated an hypothesis that heat death of our universe could be solved through an *artificial cosmogenesis*.

Scientific inquiry today undertakes to understand our world; in the future, this will be through simulations of our and other universes. Such simulations would be indispensable tools if intelligent civilization moves towards an artificial cosmogenesis.

## Annex 1 - Logical structure of the paper.

This annex presents the logical structure of the main arguments presented in this paper (Fig. 1., Fig. 2.). This has many benefits, such as:

- Allowing the reader to quickly and clearly grasp the logic of the argumentation.
- Presenting an alternative structure of the content of the paper. The table of content and the abstract tend to present a rhetorical (and not logical) structure.
- Allowing the possibility of a constructive discussion of assumptions and deductions. For example, a critique can say "the core problem is not P but Q"; or "I disagree that hypothesis X leads to Y, you need implicit hypothesis Z, ..." or "hypothesis H is wrong because"; or "there is another solution to your problem, which is..." etc.

It should be clear however that reading those diagrams can't replace the reading of the paper. The statements are necessarily simplified in the diagram and some more subtle details are thus omitted.

To draw those maps we used some of the insights of Eliyahu Goldratt's Theory of Constraints

(TOC) and its "Thinking Process" (see Goldratt and Cox 1984; Goldratt Institute 2001; Scheinkopf 1999). The TOC is a well proven management technique widely used in finance, distribution, project management, people management, strategy, sales and marketing. We see it and use it as part of a generic problem solving toolbox, where causes and effects are mapped in a transparent way. In our paper, the core problem is: "how to make the infinite continuation of life possible?"; and the proposed solution is: "artificial cosmogenesis". In this TOC framework, three fundamental questions are used to tackle a problem:

(1) What to change?

A core problem is identified as the undesirable effect, and mapped in a "Current Reality Tree" (CRT), see Fig. 1.

(2) To what to change?

A solution is proposed and mapped in a "Future Reality Tree" (FRT), which leads to the desirable effect, see Fig. 2.

(3) How to cause the change?

A plan is developed to change from CRT to FRT. This third step in the context of this paper is even more speculative, so it is almost not developed.

To tackle the problem in practice, six important questions should be addressed, constituting the "six layers of resistance to change" (Goldratt Institute 2001, 6):

- (1) Has the right problem been identified?
- (2) Is this solution leading us in the right direction?
- (3) Will the solution really solve the problems?
- (4) What could go wrong with the solution? Are there any negative side-effects?
- (5) Is this solution implementable?
- (6) Are we all really up to this?

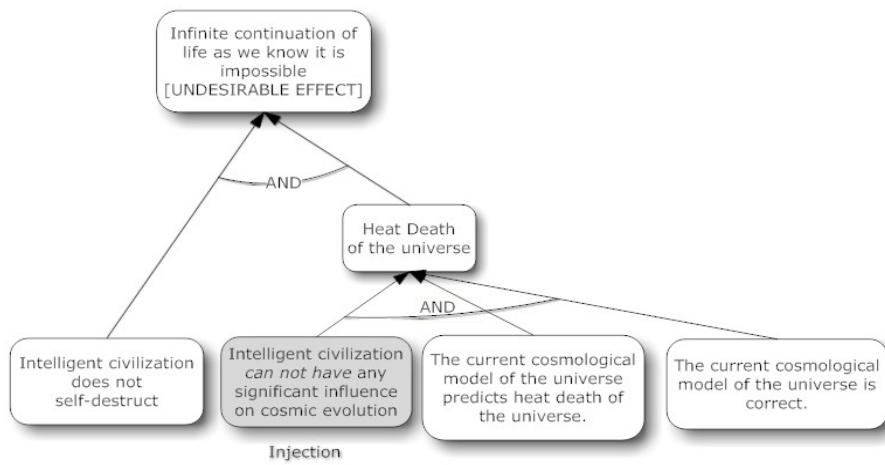


Fig. 1. The Current Reality Tree (CRT) represents the core problem underneath this paper (how to make the infinite continuation of life possible?). The "injection" (grayed) is the proposition which is challenged. It is the statement that "intelligent civilization can not have any significant influence on cosmic evolution".

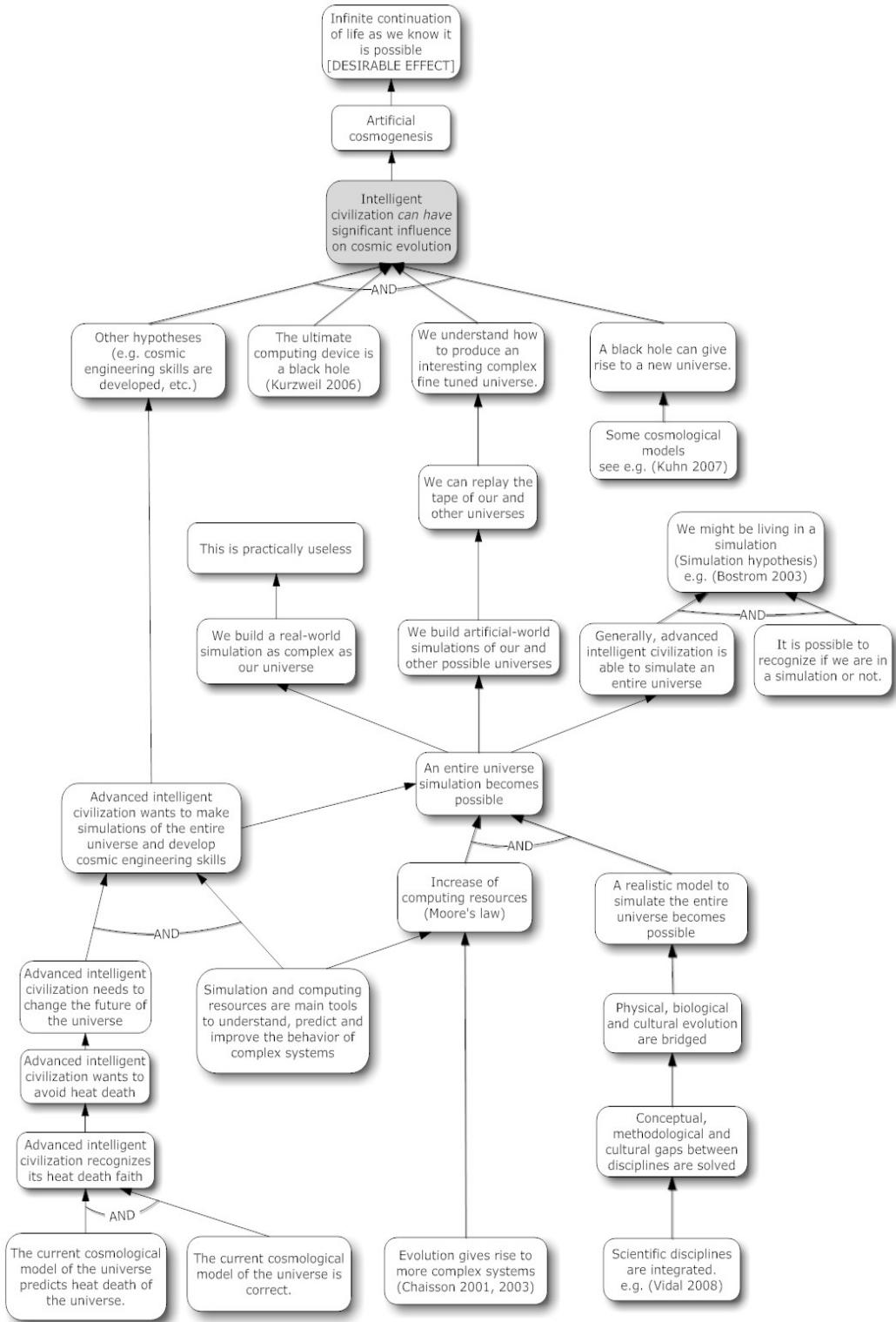


Fig. 2. The Future Reality Tree (FRT) shows "artificial cosmogenesis" as a solution to the problem mapped in the CRT. The "injection" chosen to solve the core problem is that "intelligent civilization can have significant influence on cosmic evolution".

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