The Ultimate Meaning of the Universe

A finger exercise on an all-pervasive machine

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…
so the odd time
out there
somewhere out there
like as if
as if
something
not life
necessarily

- Samuel Beckett
(from *Something There*)

Prologue

It is the greatest *skandalon* of our being here, that we do not know (even) why the world exists, and thus why we exist, and for what purpose, if any.

It is also widely agreed upon, that whenever someone comes up with a proposal, or even claims to know an "answer", this person must be met with careful reservation, at the very least. A corresponding principled scepticism is appropriate, particularly also when the claims, as well as their criticisms, are of a scientific nature. Thus, to begin with, I should have to clarify what exactly the title of the present Essay is meant to mean, or indicate. I prefer, though, to leave "meaning" undefined, for the time being, and be content with its use in a general, colloquial sense. Then, of course, a first question could be: Why "meaning"? Throughout the history of ideas, as well as on the basis of the alleged evidence from diverse scientific disciplines, one option has always been, and therefore still is, that there is no meaning to existence at all. At present, such a stance cannot be refuted on scientific grounds, and thus stands for itself: end of story.

Opposed to that, just for the sake of further pondering, the first *assumption* my arguments will be based on, is that there does exist a "meaning" of the universe. I specify this meaning to be of a teleological nature in assuming that, for a very distant, but still imaginable future, a "decisive transition" can be expected, based on our present-day assumptions and projections. Insofar as the meaning of this transition, or some aspect of it, is possibly within our grasp today, it could radiate "back" on us (i.e., in our imagination).

Still, according to estimates in modern information theory, the maximal mental capacity of a person is only roughly three billion bits [1]. As a consequence of *Chaitin's theorem*[1], then, no human can *prove* the universe to be more complex than the said (or a similar) number of bits. In the same context [2], Gregory Chaitin has shown that the possible existence of some "ultimate meaning of the universe" cannot be disproven. However, according to Charles Bennett [3], even if this meaning existed (say, as a bit string *B*), it would take a practically infinite time to deduce something meaningful *for us*, due to its incompressible *logical depth*[2]. Thus, to paraphrase Rudy Rucker, the meaning of the universe may not be worth knowing, i.e., for us.

However, this Essay shall deal with the following possibility. Considering that processes of *emergence* are of central importance for the evolution of the universe, a situation may arise in a distant future where, ultimately, said logical depth is within the grasp of computations. The "decisive transition", then, I define as the evolutionary phase where this is accomplished. Insofar as it is the mentioned processes of emergence which lead to the transition, the study of these processes themselves may give us a glimpse of that future state already now, or at least some hint, because they cover some number of computational steps which will also constitute the bit string with the "ultimate" logical depth. In this perspective, therefore, we are presently actively engaged in work on bit strings whose logical depth will eventually evolve into the logical depth of the bit strings expressing the (or a?) meaning of the universe. Very probably, though, this meaning will not concern humans.

1. An observation

If one looks for an answer to the question on what is "ultimately" possible in physics, it is most likely advisable not to consider present-day unresolved questions such as "is there dark energy and, if yes, what is it?", or, "how can we achieve a theory of quantum gravity?". Important as these questions are today, it is no immodest hope to expect that questions like these can be answered in this century. (If not, then perhaps the problem is deeper than we are aware of today.) In other words, one can rather safely assume that open questions of today will not remain so until the "final days of physics", but that, rather, they will either be resolved or "elevated" ("aufgehoben") in a Hegelian sense, before what is ultimately possible in physics comes into focus. The latter situation, then, rather concerns topics such as, for example, the limits of physics itself, like its bordering to, or even merging with, other areas of science.

It has already been hinted at in the Prologue, that a major assumption in this Essay is the existence of some future evolving state of the universe, somehow its "destiny", albeit without any *a priori* transcendental meaning. By this, I do not intend to touch upon present-day theories in cosmology, where similar questions are discussed, like, e.g., on the "big crunch", "the oscillating universe",

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[1] If *T* is a mathematical theory, and is i) finitely given, and ii) consistent, then iii) there is a number *t* such that *T* cannot prove that any specific bit string has a complexity greater than *t*.

[2] The logical depth is defined as the number of computational steps a Universal Turing Machine (UTM) needs to compute *B* from *B*'s shortest program.

“wärmetod”-type prospects of the universe, etc.. These questions, although important and interesting, are not the only ones that one can arrive at when extrapolating present observational data, along with the known laws of physics, into a distant future. For, there may be other “trends” in the cosmos, threads of developments, which have not been reflected much upon in this context, but which may turn out as equally important for the discussion of where, or what, the universe is heading towards.

Consider, for example, the range of oscillations, or cycles, in nature, or their respective time scales. This range covers a vast domain, from the *zitterbewegung* of elementary particles (like $\tau_e \approx 10^{-22}$ sec for an electron) to the rotation periods of large galaxies with averages of the order of hundreds of millions of years (i.e., something like $t_G \approx 10^{16}$ sec). The time scales, where life and all the “interesting” processes of computations (in nervous systems, or in computers) occur, lie somewhere in between these extremes, with a marked concentration of molecular reaction times or cyclic processes in organisms somewhere between 10^{-9} sec (binding rate of molecules in water, collisions of intracellular proteins, etc. [4]) and 10^{8} sec (recurrence of seasons, i.e., years), or the typical GHz domain of present-day CPU clock rates, i.e., $\tau_{CPU} \approx 10^{-9}$ sec, as compared to the firing rates of *individual* neurons, typically within periods of seconds or less.

The first point to observe here is that, throughout the history of the universe, more and more cycles have emerged, with an additional tendency of their interlocking via hierarchies of feedback networks. Whereas the cycles (frequencies) at the far ends of the time scale (i.e., for elementary particles, and for proto-galaxies) have remained largely the same from early onwards, the intermediate ones have gradually emerged, like, e.g., planets’ cycles of their respective years and days, the latter leading, in earth’s case, to the circadian rhythms of simple organisms, and so on.

The second point to be stressed is the fact that throughout the more recent history of life on this planet, as well as of humans’ cultural and technological achievements, said interlockings of cycles, characteristic interaction times, etc., have shown the tendency to encompass ever more zones on the time/frequency scale (viz., for example, the ever increasing “resolutions” of the objects of natural science, as well as their historical records.) So, there is a tendency of increased data collection along with increased data processing rates. Interestingly, this seemingly “technological” feature is already visible in biological evolution. This does not only refer to improvements in cognitive resolutions during biological evolution, but goes much further. For, throughout the last decades, a number of surprising regularities, valid for practically all living organisms on the planet, have been found. One of the oldest is Kleiber’s scaling law [5], which states that all vertebrates are subject to the same relation between body size and metabolic rate. The corresponding power law is represented, as usual, in doubly-logarithmic plots, by a straight line with a slope of $3/4$. In more recent years, the validity of Kleiber’s law has been found to extend over more than 21 orders of magnitude, i.e., from microbes (with masses around 10^{-13} g to whales (10^{8} g). What is even more important: West *et al.* [6] were able to *explain* Kleiber’s law (and similar ones), primarily on the basis of the *physical* boundary conditions of the organisms. The exponent of $3/4$ (as well as others, in other types of power laws) can be derived from their theory, which needs only a small number of parameters, such as the Euclidean surface and a biologically relevant "effective" surface, and the requirement that the effective surfaces are "maximally fractal", i.e., volume filling.

Another important power law has been found relating the size of an organism to the time it takes for its development from the unicellular stage onward. (Considering organisms as UTMs, their sizes would relate to Chaitin's ("algorithmic") complexity measure, whereas the maturing time would decisively relate to Bennett's "logical depth".) One can thus view organisms also as embodied life cycles, as John T. Bonner has proposed [7], such that biological evolution concerns the evolution of life cycles themselves, and not just of matured organisms. The developmental phase, then, is the actually decisive "unit" which by natural selection is changed throughout time. For it is clear that the only possibility to substantially change the characteristics of mature organisms is by changing their development. So, we recognize the importance of the developmental *process* for the evolution of the species. It is thus a requirement for a new "step" in the evolution of species that niches occur (or: "self-organize") where over larger-than-average times development may happen unhindered. In a more abstract language this means that corresponding niches in some "fitness space" are a prerequisite for the occurrence of bit strings of increased logical depth throughout evolutionary times.

To summarize, we have started this Chapter with the observation that there exists a wide range of material cycles or average interaction time constants in the universe, with a tendency a) to interlock, and b) to extend the interlocked domains to ever wider ones, thus encompassing ever more micro- and macro-processes. This goes hand in hand with a process where complex systems tend to exist on, or in an ordered regime near, the "edge of chaos", as Stuart Kauffman and others call it, because co-evolution takes them there. [8] For the present Essay it is important to note that such tendencies, firmly rooted in the "material world", manifest themselves also in the dynamics of living organisms as well as in the evolution of human-made computing machines. In other words, by focusing on these interlocked processes, we are still doing physics, and it is therefore justified to speak of an abstract "evolutionary mechanics", as Jim Crutchfield does [9], as well as of the physics of computation, in the context of our present discussion.

A common theme of these domains, as well as of others, is the theme of *emergence*. Other areas of physics, where emergence becomes of importance, cover practically all orders of magnitude, i.e., from emergent large-scale structures in the universe as a whole to attempts at understanding "quantum theory as an emergent phenomenon" [10], or to an approach in a similar spirit, with an *exact* derivation of the Schrödinger equation from a suitably re-interpreted classical physics, i.e., modern non-equilibrium thermodynamics [11].

2. The “Evolution of Evolution” Project

The aim of research projects such as Crutchfield’s *evolutionary mechanics*, as a complement to the study of chemical, prebiotic, or biological evolution, is to distill the corresponding abstract procedures of information processing into a kind of “computational evolution”. In making use of an agent-based modelling of the environment, diverse “substrates” (e.g., physical, macromolecular, or metabolic ones) represent the available resources as well as the constraints with respect to information processing or model construction. Crutchfield’s has been an early proptotype of research programs which can be generally described like this: “The intention is to expunge as much disciplinary semantic content as possible so that if novel structure emerges, it does so neither by overt design nor interpretation but (i) via the dynamics of interaction and induction and (ii) according to the basic constraints of information processing.” [9] Ever since computers have become available on a broad scale, very different computational tools have been developed which are of possible use for such types of projects. Among them are cellular automata [12], or their quantum versions [13], or coupled map lattices (CML) [14].

Our group (AINS) has implemented the latter to develop a toy model for the “evolution of evolution” [15], which was originally guided by considering fundamentals of biological macroevolution. One of our model’s essential interfaces with the domain of empirical data is the so-called “punctuated equilibrium”, i.e., a well-documented extension of Darwinian evolutionary theory. [16] On a population level, it has recently been observed in the laboratory. On the species level, some of the qualitative features of punctuated equilibrium were successfully simulated by Bak and Sneppen [17] in a toy model on a lattice of sites, with each site representing a species, thereby drawing on earlier work on “self-organized criticality” (SOC), a systemic phenomenon similar to, but not identical with, the “order on the edge of chaos” mentioned above [18].

However, there exists one important question which is hardly touched upon by SOC and similar models, namely how evolution produces entities of increased complexity. In particular, it has been proposed by Kauffman and co-workers that the Darwinian process of mutation and environmental selection would have to be complemented by self-organizing processes in order to eventually decouple the strict link between mutation and selection. In fact, our simple toy-model of evolution has turned out general enough to be compatible with SOC models of punctuated equilibrium, but in essential ways goes beyond them to encompass evolution towards higher complexity. For, if one considers the Bak-Sneppen model and its more recent versions, one is led to conclude that the SOC state is always a "quasi - steady state", i.e., "the evolution process always self-organizes into the same critical steady state having, as a consequence, the same appearance" [19]. In other words, the analogy to the well-known sandpile model suggests that SOC describes evolution via punctuated avalanches of high mutation rates over a wide range of sizes, with long intermittent periods of stability, but without any (long term) time dependence of the avalanche sizes, the equilibrium periods, or their relative changes, respectively. As an alternative, we (i) aim at a meta-macroevolutionary model in the sense that we disregard questions on the concrete evolutionary substrate, thereby (ii) concentrating on relative changes with respect to previous evolutions. In other words, we are mainly interested in simulating the "evolution of evolution".

As is usual in this type of models, one assumes at each lattice site of a 1-dimensional CML (i.e., representing a “species” in a food-chain, for example) a value between zero and one to represent the individual species' fitness at a particular time step relative to the others. This is done in such a manner that the total fitness for the whole array is given by a normalization constant. In other words, one assumes local interaction between the nearest neighbored species to affect relative fitness. However, as opposed to the Bak-Sneppen model, we are not interested in implementing a very specific and thus extremely model-dependent mechanism of eliminating least fit species, or the like. Rather, we intend to study the *relative frequency of deviations from some average evolution*, the details of which are not supposed to matter. To do so, we need to have an explicit evolution rule for nearest-neighbor interactions, upon which certain constraints can be imposed, such that some kind of statistically controllable but individually contingent deviation can be implemented.

With regard to this, a phenomenon is at hand which has been discovered and studied by us in some detail, called *fractal evolution* [20]. It is a universal dynamic property shown for one-dimensional CMLs with (i) one or more temporal feedback operations (involving some memory of the system's states) boosting certain sites to values far above the average ones, and (ii) a normalization procedure after each time step. Fractal evolution is then characterized by a power-law behavior of the system's order parameter with regard to a resolution-like parameter which controls the deviation from an undisturbed (i.e., feedback-less) system's evolution and provides a dynamically invariant measure for the emerging spatiotemporal patterns. It must be strictly distinguished from the phenomenon of fractal growth, which describes the accumulation of micro-patterns into a static structure with (self-similar or other scale invariant) fractal features. In contrast, fractal evolution is characterized by the fact that the *dynamics* of the evolution itself is *scale invariant*: instead of generating a "frozen" fractal object, the *generation mechanism* itself is "fractal", i.e. the chosen resolution itself finally generates the observed fractal properties. We have shown that the phenomenon is very robust with respect to variation of all the system's variables. For our models, we mainly chose temporal feedback loops, because, in general terms, they introduce a quality of self-reference for the whole system. As a concrete motivation for doing so, however, we consider a certain periodicity of constraining conditions for the whole evolutionary landscape. Again, the details are not supposed to matter, i.e., the periodicity may refer to relatively short-term cycles of constraints enforcing functional couplings within individual species, or externally, in the ecology or the like.

In a "normal" evolution of our fitness landscape that were unaffected by such cycles, the relative fitness values would gradually become adjusted to each other, thus gradually reaching an ever more smeared-out pattern representing stasis or equilibrium. However, if a species' fitness value after such a cycle happens to be the same again as before it, within a certain degree of accuracy $1/\varepsilon$, then, even if the relative fitness value is low, some reproductive isolation must have been achieved (for example, via economic functional couplings) that amounts to an acquisition of a relative survival rate far above the average. In fact, the reported "molecular cognition" within genomic dynamics already suggests a certain cognitive ability for each individual site in that it can monitor its own "fitness" within that of its environment with a resolution $1/\varepsilon$. Maintaining constancy in fitness space within cycle periods with a constraining and eventually destructive potential, while most of the environment produces decreasing fitness values, means that an ecological niche has been found whose fitness potential can be consumed. In these cases, then, the species' site is a particularly favorable niche and therefore enhanced to some boost value, thus providing a fragmented overall pattern emerging in fitness space with particular elevated zones of highest survival rates and, consequentially, also of fitness. (Fig. 1)

The main result with regard to *fractal evolution* is the following. Firstly, the mean lifetime $\overline{\tau}$ of the patterns is an emergent order parameter of the system. It is given by the arithmetic mean of the maximal temporal extension of all fragments for a chosen intrinsic parameter ε, the so-called "relative interval width", i.e., the error tolerance of fulfilling the required feedback condition, upon which boosts may be implemented. Secondly, $\overline{\tau}$ scales according to $\overline{\tau} = a\ \varepsilon^{b}$, practically irrespective of variations of the systems variables or the initial conditions. This power-law behavior of the system's order parameter $\overline{\tau}$ with regard to the resolution-like parameter $1/\varepsilon$ provides a dynamically invariant measure for the emerging spatiotemporal patterns given by the fractal evolution exponent b.

However, let us remind ourselves now that our main intention was not in just finding an abstract machine that would produce a power law within our modelling restrictions. Rather, what is required is a system of this kind, where manipulations are possible of relations "within" the domains of the power law: we are looking for an extension of our machine in terms of a dynamics that would enable us, figuratively speaking, to wander up and down along the straight line representing the power law in log-log plots. For, our aim still is to find a tendency for the establishment of longer lasting niches, which is not merely the trivial consequence of some (external) input, but which should emerge intrinsically, i.e., as an intra-systemic necessity. In fact, the relation between ε and $\overline{\tau}$ to accomplish this turned out to be a circular one: ε and $\overline{\tau}$ had to be implemented via mutually operative feedback loops: Introducing a suitable time interval, which can be argued for as a systemically necessary "local time window" of the sites, one calculates for this time interval the actual mean lifetime $\overline{\tau}_{lok}$, and the latter will typically fluctuate stronger than the mean lifetime $\overline{\tau}$ obtained from averaging over much longer times. With this operation, one can implement a mechanism that we denote as "noisy recursion": recursions with unbiased fluctuations around means, i.e., with equally weighted amounts of increases and decreases of the fluctuating quantities. As a first result of their implementation, we could reproduce the signature of the devil's staircase function, i.e., of *punctuated equilibrium* behavior.

As a main result, however, we obtain a progressive alteration of ε, or of the resolution $1/\varepsilon$, respectively, within the system's evolution, a phenomenon which we denote as *hierarchically emergent fractal evolution* (HEFE). In effect, HEFE constitutes a fluctuation driven and adaptive mechanism for the gradual increase of the mean lifetimes of the emerging patterns, i.e. for the expansions of regions of high fitness in the fitness landscape. In Figure 2, three examples of temporal evolutions of the mean lifetime per "generation" are shown according to three different time spans of each generation during which the mean lifetime is determined. Although fluctuations are allowed with equal opportunity for decreasing and increasing lifetimes, respectively, a long-term increase of the mean lifetimes is observed practically in all cases and has its origin in the functional property of the power-law of *fractal evolution*: one obtains altogether a clear tendency towards decreasing relative interval widths ε, leading to an average increase of the mean lifetime $\overline{\tau}$ per generation. [15]

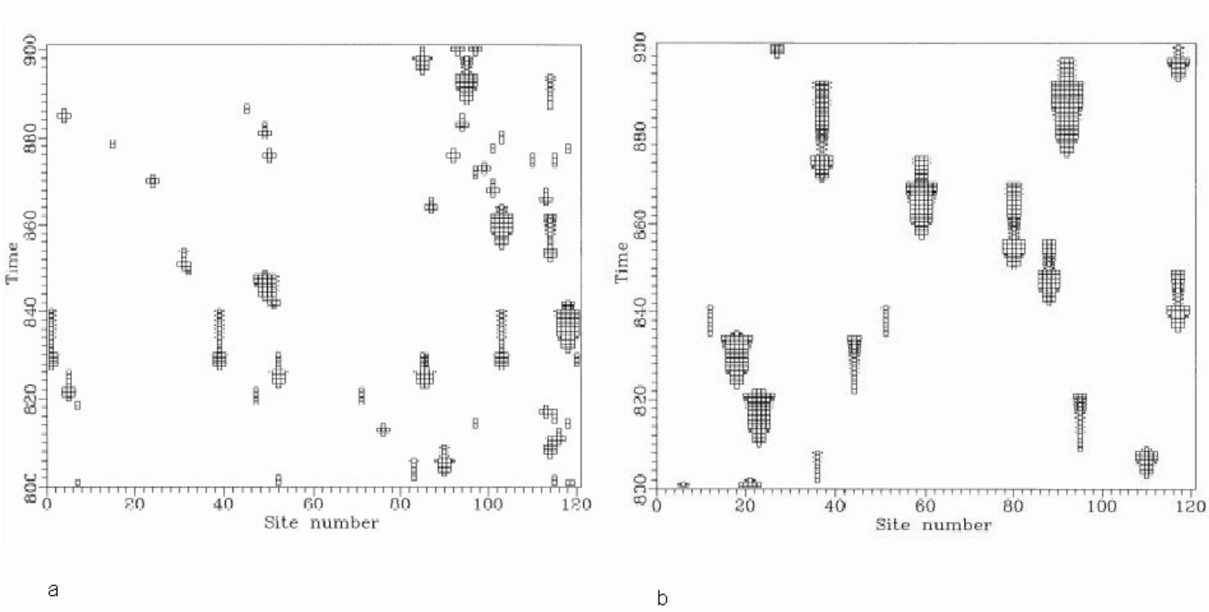

Fig. 1: Distribution of "evolutionary niches" in a coupled map lattice (CML) with feedback loop: The relative interval width, or error tolerance, ε is 25% in (a) and 4.1% in (b). Plotting various values of ε versus average lifetimes $\overline{\tau}$, respectively, on a log-log scale, one obtains the straight line of a power law, i.e., *fractal evolution*. [20]

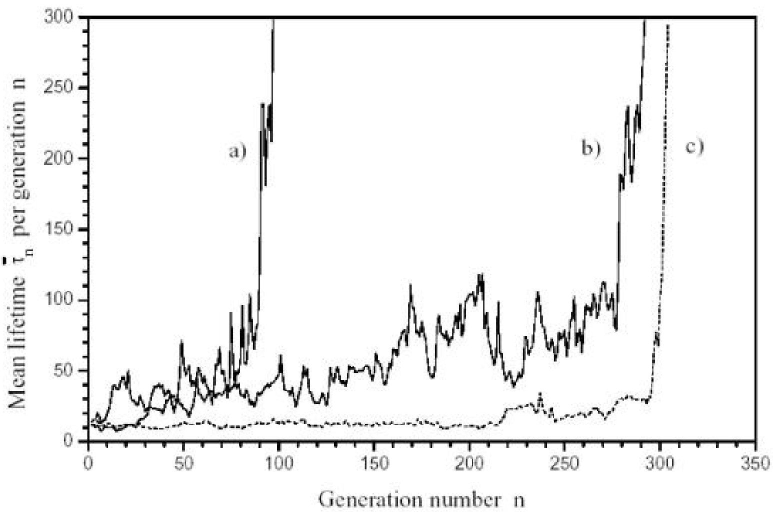

Fig. 2: Hierarchically emergent fractal evolution (HEFE) for three different values of time spans of data taking with particular ε ("generations"). The time span for each generation is given by 2000 time steps for curve a), 5000 for curve b), and 10000 for curve c). The starting value for all curves is ε = 10%. Note also the characteristic stepwise increases as well as decreases of the mean lifetimes per generation, thus indicating two opposing trends in the short-term dynamics. In the long run, however, the mean lifetime is bound to increase. (From [15].)

To summarize, we have seen that, by implementing a "meta-feedback condition" via *noisy recursions*, the mere functional property of *fractal evolution* of the fitness landscape is transformed into a dynamical process. One thus obtains an intrinsic (as opposed to a merely extrinsically imposed) emergence of growing potential niches, enabling the increase of complexity for the species involved at the respective sites. Having avoided a definition of complexity, we have instead focused on the potential of temporal niche extensions, independent of the detailed underlying biological mechanisms. The main result of our simple computer model lies in the observation that, even when implementing only time-symmetric fluctuations around averages, in the long run a time-asymmetric behavior can be observed, i.e., the niches are bound to increase. Considering that the nucleus of our model contains just two mechanisms, we can thus formulate the following two propositions:

> **Proposition 1:** The minimal abstract machine designed to map the emergent dynamics of evolutionary systems consists of two abstract machines with counter-running recursive dynamics, each characterized by their own periodicity, respectively.

> **Proposition 2**: The first of these two machines (i.e., feedback via a global periodicity) results in a universal power law (*fractal evolution*), and the concatenation with the second machine (i.e., feedback via the periodicity of *noisy recursions*) necessarily leads to the irreversibility of evolutionary processes (*hierarchically emergent fractal evolution*).

Among other features, the model thus reproduces also the "Red Queen effect". The individual species evolve within the whole system, which due to purely intrinsic dynamics shows a tendency toward enabling higher complexity. Although individual species have such a tendency, too, it is the total system that optimizes all complexity levels in such a way that the dynamics of its individual "cells" is subject to the intrinsically emergent global development.

As a final step, one can now try to substitute "species" by a more abstract entity, and consider the co-evolution of an array of UTMs (the cells of the CML) in their quest for a more and more detailed comprehension of the world. Then, of course, the whole "evolution of evolution" project discussed so far can only function as a metaphor for further ponderings: one would be ill advised to take the "simple model" too seriously, too literally. Still, however, as a metaphor it can provide us with a valuable insight, once we accept the following adaptations: Keeping in mind our previous observation about the tendency that ever more material processes (cycles, etc.) become interlocked, one certainly has to discard the one-dimensionality, together with the periodic boundary conditions, of our CML model in favour of a large-scale multi-dimensional and practically infinite grid, say, of UTMs or Bernoulli TMs, or the like. What our model seems to indicate, then, is something that could act as a challenge for future model building with regard to evolving architectures of (physical or other) knowledge:

Proposition 3: As it has been shown that the interlockings of a very simple set of feedback mechanisms can create irreversible complex behavior, the latter can entail a universal tendency towards ever greater logical depth. Eventually, then, the whole grid may reach a level with sufficient logical depths at each of its "cells" that would provide a maximally detailed map of the world, i.e., ultimately, of itself.

Epilogue

Here, then, is where the scientific method of today reaches its limits, and speculation remains the only guide. Of course, ideas have been presented in the science fiction literature as to how one could imagine such an all-pervasive "ultimate" machine, which may be identical with "the world". Still, the vastness of the universe and the depths of not-knowing that await us there may very easily render all our musings negligible. Moreover, facing the all-too-real challenges of the 21st century here on earth may even shed a completely different light on an "end of physics", considering the potential of our self-destruction. [21]

How should we imagine the "ultimate" machine to create the "meaning of the universe" from itself, without simply ending up with an answer such as "42"? George Steiner has put forward the warning that "unless we are very careful in our terminology, 'meaning' will carry a stubborn implication of transferability, of equivalence in another form. It is only when we apprehend the 'meaning of meaning', the expressive totality integral to a given set of verbal, syntactic, language-specific units, that we understand fully." [22] However, this can be no problem of principle for our machine, which thus also acquires the quality of being a poetical machine. In all cases, then, its "meaning" would indeed be worth knowing.

And if there was anything that we individuals, infinitely far away from such universal capacities, may experience as – if only remotely – similar, I would suggest *contemplation*, in the form that John Gray has paraphrased it; that is, "not the willed stillness of the mystics but a willing surrender to never-returning moments." [21] Or else...?

Perhaps we are all [*]

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