Towards Computers of Generation Omega – Non-Equilibrium Thermodynamics, Granularity, and Acausal Processes: A Brief Survey

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ABSTRACT

Nowadays, we are using mainly computer of fourth generation, and we are designing fifth-generation computers. It is reasonable to ask: what is the perspective? What will the computers of generation omega look like?

- As the speed of data processing increases, we face a natural limitation of *causality*, according to which the speed of all processes is limited by the speed of light.

- Lately, a new area of *acausal* (causality violating) processes has entered mainstream physics.

This area has important astrophysical applications. In this paper, we show:

- how non-equilibrium thermodynamics makes these processes consistent,

- how these processes can be used in computations, and

- how the very possibility of these processes lead to the *granularity* of the physical world.

KEYWORDS: computer generations, granularity, non-equilibrium thermodynamics, quantum computing, acausal processes

1. GENERATIONS OF COMPUTERS: WE NEED FASTER AND FASTER COMPUTERS

No matter how fast modern computers are, there are still problems that take too much computational time and, thus, cannot yet be handled by modern computers. To solve these problems, we must design *faster* and faster computers. So far, the speed of the computers has been doubling every few years. Can we keep up with this increase?

According to special relativity, all velocities are bounded by the speed of light; thus, to make computer elements faster, designers try to decrease the *size* of these elements. Every hardware technology eventually reaches its limit, i.e., the smallest element size that this technology can achieve; after that, to decrease the size further, we need to invent a *new* technology. Computers that use this new technology are usually called computers of a *new generation*.

The existing 4th generation computers are based on VLSI technology. At the current speed-up rate, this technology will soon exhaust its potential. Physicists and engineers are therefore working on new technologies for fifth, sixth, etc., generations of computers. Vague ideas are proposed for technologies suitable for even further generations. (The further generation, the more vague the ideas.)

It is therefore desirable to get a clear view of the computers of the very distant future generations. We will call these computers *generation omega* after the notation "omega" (ω) for the first infinite ordinal number proposed by Cantor, the founder of set theory (the first consistent theory of infinite objects).

2. COMPUTER GENERATIONS AND QUANTUM PHYSICS: GENERAL DESCRIPTION

To get faster computers, we must decrease the size of the elementary processing elements.

As the size of an object decreases, *quantum effects* become more and more essential in its description:

- for *macro-size* objects, quantum effects are rare (e.g., in lasers), small, and difficult to measure;

- in *chemistry* (which studies *molecules*) quantum effects are often important;

- for *elementary particles*, quantum effects are so overwhelming that their non-quantum description is practically impossible.

Therefore, as the size of the computer elements decreases, we need to take quantum effects into consideration to a larger and larger extent.

To take these effects into consideration, we must use quantum physics. In general, a physical theory describes how particles and fields interact in space-time. Therefore, in the ideal quantum physical theory, particles, fields, and space-time structures must be considered from the quantum viewpoint. In practice, the effects of their quantization is different, so, some of these quantum effects can often be neglected:

- the largest quantum effects are related to objects that have been known and analyzed for the longest time, i.e., particles;

- the next quantum effects are related to newer objects: fields;

- and finally, the smallest quantum effects are due to quantization of space-time physics, physics whose experimental effects are still on the edge of modern observation abilities.

The smaller the objects, the more effects we need to consider. At first, we have to use traditional quantum mechanics (also called *first quantization*), in which fields (and space-time structures) are described by non-quantum formulas, but the particles' quantum behavior is taken into consideration. This quantum mechanics describes atoms, quantum chemistry, etc. Modern engineering research into *quantum dots* as computer units and modern theoretical research into quantum computing, with its exciting potential ability of solving such hard-to-solve problems as factoring large integers (see, e.g., [2,3,6,7,29,30]), is at this quantization level.

- From the *practical* viewpoint, quantum dots will have a huge potential of further miniaturizing computers, so, if this project is successful, we will not need to worry about it for at least a few decades.

- However, from the *fundamental* viewpoint of a more distant future, we need to look further.

To describe even smaller objects, we need to use *second quantization* (or quantum field theory (QFT)), in which both particles and fields are quantized, and the *fully quantized theory*, in which space-time is quantized as well.

3. ENTER ACAUSAL PROCESSES

In general (curved) space-time, the maximum possible communication speed (i.e., the speed of light c) is determined by the metric tensor field g_{ij}; see, e.g., [15].

- In *non-quantum* theories, this field is smoothly depending on coordinates and therefore, the corresponding maximal speed is slightly changing in space and time (and is practically constant for small areas).

- *Quantization* of space-time means, in particular, that the metric tensor field undergoes quantum fluctuations, and, as a result, the *actual* maximal speed at any given point is randomly larger or randomly smaller than c. Since the average deviation must be 0, this means, roughly speaking, that in half of the cases, the maximal possible speed is larger than c, and in half of the cases, it is $< c$.

An object of finite size is influenced by the "average" field in the area that this object occupies.

- If the object is *large* enough, then the random fluctuations "average out", and the object moves as if in a space where the maximal speed is the macro-world speed of light.

- However, if we consider much *smaller* objects, then these objects can actually feel the local fluctuations.

Therefore, if this tiny object moves (and transfers information) at a maximal local speed, and this local speed, due to a fluctuation, is larger than c, then we get a microobject that, without violating causality, is able to transfer information at a speed v that is *larger than the* macro-level *speed of light c*.

The smaller the object, the larger this potential speed v (it can be, actually, as large as possible).

As a result, we have an *unexpected additional boost in computer performance*:

- we considered *smaller* and smaller processing elements because the smaller these elements, the faster the computer;

- it turns out that if these elements are small enough to take into consideration full quantum theory, then not only their size gets smaller, but also the actual *speed* of communication transfer can be made *faster* than the macro-level speed of light; thus, computers become even faster.

4. ACAUSAL PROCESSES IN PHYSICS AND BIOLOGY: A BRIEF HISTORY

Traditional physics is *causal* in the sense that future events are determined by the past state of the Universe. This dependence can be deterministic (as in classical, pre-quantum physics), or stochastic (as in quantum physics). There have been for some time an idea of the possibility of *acausal* processes, in which the influence can go in the opposite direction: future can influence the past. Such processes are called *acausal*.

The idea that the speed of all particles cannot exceed the speed of light (and that, therefore, it is impossible to influence the past) was one of the main ideas of Einstein's Special Relativity Theory.

In *quantum mechanics*, due to its probabilistic character, many deterministic restrictions of pre-quantum physics become somewhat "blurred" in the sense that they are no longer prohibiting some events completely, but simply telling that these formerly prohibited events have small probability. For example, in classical physics, a particle cannot penetrate the potential barrier if the energy of this barrier exceeds the initial energy of the particle; in quantum physics, however, it is quite possible (although not highly probable) that a particle "tunnels" through this barrier and end up on the other side of it. This is not simply a theoretical conclusion, this "tunnel effect" is the basis of "tunnel diodes" that are extensive used in nowadays electronics.

Uncovered possibility that quantum mechanics can make pre-quantum restrictions "soft" lead to a possibility that causality may also be violated in quantum processes. Such violations were first discovered by Einstein, Podolsky, and Rosen in their famous paradox (physicists call it EPR paradox for the first letters of the authors' names; for details, see [32]). Einstein, who was not a great fan of quantum mechanics, proposed this paradox as a way of disproving this theory. (It is worth noticing at this point that all experiments so far seem to confirm quantum mechanics.) EPR paradox does not lead to a real time travel: it simply shows that in the resulting quantum formalism, the future state influences the past one; however, all attempts to extract a real time travel from it turned out to be futile because, crudely speaking, the resulting influence on the past is so small that, when we try to measure it, it "drowns" in the inevitable quantum uncertainty of measurements.

This fact does not mean that causality is true in quantum physics. In the last decade, several more sophisticated schemes have been proposed that, in principle, can lead to the actual time travel [33–35].

In addition to *physical* arguments in favor of possible causality violations, there exist *biological* motivations for such processes: Rosen [25] suggests that the living beings can use physical processes that influence the current events depending on the future ones (he calls such acausal processes *anticipatory*; see also [24–28].

Until 1988, acausal processes has been mainly considered as one the many possibilities, not the most probable possibility, and not part of the mainstream physics. In 1988, the physicists' attitude to acausal processes changed when Kip S. Thorne, the world's leading astrophysicist, published several papers in the leading physical journal *Physical Reviews* in which he showed that within the existing quantum physics and cosmology, acausal processes are highly probable; these publications lead to several other serious research results [1,9,17,18,20–22,31]. As a result of this research, three basic types of acausal processes have been discovered; these processes are summarizes in Thorne's monograph [32] (for more popular expositions, see, e.g., [4,5,12,13,19,23,36].

5. PARADOXES OF ACAUSALITY AND HOW NON-EQUILIBRIUM THERMO-DYNAMICS CAN SOLVE THEM

The idea of acausal processes was, for a long time, mainly part of science fiction, because this idea is paradoxical. The most well known *father* paradox is most convincingly described in terms of the actual *time travel* (travel to the past):

The time traveler paradox occurs when a time traveler goes to the past and shoots his own father to death before he himself was conceived. Then:

- On one hand, the time traveler *is* still *alive*, because he was alive before the killing, and he did not harm himself in any way.

- On the other hand, since his father has died, he could not have conceived the time traveler, and hence, the time traveler cannot be born. So, he is at the same time *not alive*.

A similar paradox occurs if we cannot actually *travel* to the past, only *influence* it; also, it occurs even if we have no human beings at all, simply physical processes. The reason why we (and other authors) present this paradox in its time-traveler form rather that in the form of differential equations of physics is that when we have a problem with differential equations, there can be many reasons for that (wrong equations, wrong method of solution, etc.), while the *time-traveler* paradox reveals the paradoxical character of acausal processes themselves.

For clarity of exposition, we will describe the current solution of the paradoxes of acausality on the same time-traveler example as we described the paradox itself. Of

course, similar to the fact that the paradox occurs even when there is no time traveler at all, the described solution is also applicable to the case of purely physical acausal processes. This solution is described in [8,10,11,14,16].

Since the time traveler is alive at the time when he starts the shooting, this means that he was conceived after all, and therefore, that his attempt to kill his father has failed. Why could it have failed? Well, the gun may have malfunctioned, or he might have missed, or a brick (or a meteorite) might have fallen on the time traveler's head at the very moment when he was ready to shoot, or a policeman of the past has stopped him, etc.

Some of these possibilities are quite realistic, some (like a meteorite) have an extremely low probability. The time traveler can prepare for some of these possibilities: he can check his gun before going to the past, use automatic weapons, wear a hard hat against falling bricks, a fake police uniform to prevent an interference of the past's police, etc. In principle, whatever possibility we describe, the time traveler can take care of it. However, he cannot take care of them all: for example, in principle, the gun can malfunction simply due to some unexpected (but probable) random Brownian motion of its molecules.

If the time traveler takes care of all possibilities with reasonable (sufficiently high) probability, this still leaves other possibilities, with extremely low probability, that normally do not occur, but that would have to occur because otherwise, we would have a paradox.

Summarizing: *if an acausal process is possible, then some events will take place, whose probability is normally extremely low to prevent this acausal influence from happening.* This conclusion is true not only for a time traveler, but for an arbitrary acausal process.

6. COMPUTERS THAT USE ACAUSAL PROCESSES

According to the above analysis, the very possibility of an acausal process leads to the implementation of highly improbable events. Let us assume that we have organized such an acausal process in such a way that if we switch it on, it will lead to an implementation of a highly unprobable event with a probability $p_0 \ll 1$.

Let us show how this device can be used to solve a typical hard-to-compute problem of *propositional satisfiability*: given a Boolean (propositional) formula $F(x_1, \ldots, x_n)$ with n Boolean variables $x_1, \ldots, x_n$, find the values (if any) for which the resulting formula is true. This problem can be easily solved by trying all 2^n possible combinations of n "true" and "false" values. Unfortunately, this *exhaustive search* becomes non-feasible even for $n \approx 300$, when the resulting computation time exceed the lifetime of the Universe. It is known that this problem is computationally hard (the precise term is *NP-hard*) in the sense that

if we can solve it in reasonable time (i.e., time bounded by a polynomial of n), then we would be able to solve *all* problems from a large class (called NP) in reasonable time, and this most computer scientists consider impossible.

To find the values x_i using *acausal processes*, we can set up n quantum random number generators that generate n random bits. Then, we check whether the results $x_1, \ldots, x_n$ of these bits satisfy a given formula. If they do, these values are the desired answer; if they do not, we switch the above-mentioned acausal process on. Nature has two choices:

- It can generate the desired solution in the random generators. If the formula has only one satisfying combination of variables (out of 2^n), the probability of this event is 2^{-n}.

- It can also generate a vector that *does not* satisfy the given formula. In this case, the switched-on acausal process makes the nature implement the highly unprobable event, with probability p_0.

Therefore if $p_0 \ll 2^{-n}$, it is much more probable that Nature will prefer the first alternative.

This idea was announced in [11,14] and described in detail in [10].

7. ACAUSAL PROCESSES LEAD TO GRANULARITY OF THE PHYSICAL WORLD

In the previous section, we applied the idea of acausal processes to computations. artificially designed *computations*. However, we can also apply it to nature itself.

- In traditional *causal* physics, whatever initial conditions $x(t_0)$ we set at the initial moment of time t_0, we can always integrate the equations and end up with the state of the Universe $x(t) = F(t, x(t_0))$ for all consequent moments of time $t > t_0$ (here, the function F describes the dynamics of the system). In this case, initial conditions are *arbitrary* and therefore, we have a *continuous* set of possible states.

- If there is an acausal process present, then the initial condition cannot be arbitrary: if, e.g., we have an acausal process that transforms a part $p(x(t))$ of a state at moment t into a moment of time $t' < t$, then, in addition to the dynamical equation that connects $x(t)$ and $x(t')$ with $x(t_0)$ must have an *additional* condition $p(x(t)) = p(x(t'))$. Therefore, the initial condition $x(t_0)$ must satisfy the additional equation $p(F(t, x(t_0))) = p(F(t', x(t_0)))$.

How does an additional equation restricts the set of all possible conditions? For the case of one variable, a *linear*

equation has a *single* solution, a *quadratic* equation has, in general, *two* solutions, etc. The more complicated the equations, the more *granular* is the set of its solutions. Since the dynamic equations are, usually, very complicated, we naturally expect that the additional equations caused by acausal processed lead to a *high granularity* of Universe.

8. ASTROPHYSICAL APPLICATIONS OF ACAUSALITY

A general idea of these applications. As we have mentioned, acausal processes lead to highly unprobable events. According to statistical physics, if Nature has a choice, it would rather prefer situations where these highly unprobable events do not occur. Therefore, if there is a random (statistical physics-type) process that can either lead to an acausal process or not, then, the *actual* probability of this process resulting in acausality is very low, *much lower* that it would have been if we did not take the possibility of acausal processes into consideration (practically, thermodynamically impossible).

In this paper, we only show this idea on one possible applications, whose description enables us to avoid technical details; other applications are also possible (see, e.g., [8,11]).

Example: The isotropization of the Universe. One of the main problems of modern cosmology (see, e.g., [32]) is that the Universe is too isotropic. On large scale, in all directions in which we look, we see the same statistical distribution of matter. The initial state of the Universe was, according to the modern physical viewpoint, *random*, and therefore, far from being isotropic. Hence, the observable isotropization is due to some physical processes. Many physical processes shuffle matter around and thus, contribute to the isotropization, but calculations show that during the lifetime of our Universe, these processes are not sufficient to explain the current isotropy; to be more precise, for *random* initial conditions, the probability of the initial conditions that lead to the observed isotropy is very low.

The explanation of this phenomenon in acausal physics is as follows: Anisotropy means that different distant areas of the Universe will have radically different matter densities. For acausal processes, there is no speed restriction; therefore, since there is an excess of matter in one area and abundance in another area, acausal processes will re-shuffle the matter from the dense area to the area where matter is scarce. Such a process is, as we have mentioned, thermodynamically unprobable and therefore, it is much more possible that the random initial conditions are chosen in such a way that prevents these acausal re-shufflings, i.e., that the initial conditions lead to the observable isotropic

Universe.

What this explanation does is shows that the probability of an initial state of the Universe leading to isotropization, the probability that is small if we do not take acausal processes into consideration, becomes much larger if we consider the possibility of acausal processes.

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