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Opinion

On the Striking Similarities Between Our Universe and a Simulated One

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Abstract - This article explores the potential parallels between our physical universe and a hypothetical simulated universe, drawing insights from both physics and computer science. The aim is to present plausible reinterpretations of fundamental physical concepts by considering the constraints and structures inherent in computational systems. From this perspective, it may be possible not only to infer how the universe operates but also to speculate on why it behaves the way it does.

Keywords - Simulation hypothesis; General Relativity; Computational complexity; Artificial General Intelligence; Hidden-variables theory.

1 Introduction

Richard Feynman once said: "What I cannot create, I do not understand". If we could create a Universe like our own, we would certainly be able to understand it completely. The only way we might be able to create a Universe like ours, is in a virtual computer simulation. Unfortunately, building an actual Universe-like computer simulation remains an impossible endeavor, for the moment. What we can do instead, is to, at least partially, imagine how we would design such a simulation, and see if this process can give us an insight on some important concepts of Physics.

2 Quantization matters

As a first argument, we could say that the biggest problem of any computer simulation is that computational resources are finite. You only have so many bits to represent information and to store it, and so many floating-point operations per second (FLOPS) at your disposal to execute your algorithms. No matter what you do, you will never be able to compute a simulated reality that is really continuous in the mathematical sense. In a computer simulated Universe there wouldn't exist neither infinitesimal nor infinite quantities, and every quantity would have to be finite. This entails that any complete and correct theory describing such simulated reality would have to be quantum. This insight is important because it tells us that, while continuous mathematical theories would be perfectly able to approximately model such a simulated universe even to a high degree of precision, they would fail to do so exactly at the scale where quantization becomes significant, which is also exactly the problem that today's Physics is experiencing right at the intersection between the Classical and the Quantum realms.

3 Finite speed of light

In a computer simulation, the information content describing its state, changes as the simulation is integrated forwards at discrete time intervals called "frames". When the simulation's state becomes bigger than a certain threshold, updating it all in the same frame becomes computationally infeasible. One strategy that is usually adopted in such scenario is to update only a part of the state at each frame, instead of the whole. With partial state updates, if a certain event happens in the simulation at a certain point in space and time, the effects of such event will not spread instantly (in one frame), but instead they will spread over multiple, potentially many, frames. The speed at which you can update the simulation state, usually called the update rate, is proportional to the size of the partial state update and the size of the partial state update is proportional to the available computational resources. Thus, the update rate of the simulation will be proportional to its available computational resources. Using the partial state update strategy will have visible consequences in the simulation: the most important being that information will not be able to transmit instantaneously (in one frame), but only over multiple, potentially many, frames, and, since the update rate is fixed, also the speed at which information is transmitted will be fixed. Consequently, in a simulated universe we will observe a constant upper bound for the speed at which information is transmitted. This characteristic property becomes in fact the speed of light of the simulation. It is striking how we observe the same thing happening in our Universe.

4 Algorithmic optimizations

If you were to use multiple fixed-size discrete grids to simulate a universe (as in finite element analysis), one problem that would immediately arise is that you wouldn't find an optimal resolution: what you would find out pretty quickly, instead, is that, in order to increase the size of the simulation, you would have to give up on the resolution, and vice-versa. This problem always appears when trying to create a computerized particle simulation, and, as a matter of fact, it has already presented to those creating vast computerized cosmological simulations, e.g. the Bolshoi cosmological simulation. One method used to attack this problem is called Adaptive Mesh Refinement and was pioneered by Marsha Berger, Joseph Oliger, and Phillip Colella [1]. One interesting variation of Adaptive Mesh Refinement is the Adaptive Moving Mesh Method [2] developed by Huang Weizhang and Russell Robert, that uses a r-adaptive strategy (relocation adaptive, where the r-adaptive strategy moves cells instead of subdividing them) to achieve the same result as Adaptive Mesh Refinement. If you think about it, an r-adaptive strategy that is based on the local energy density as a parameter might resemble how curved space-time works in our Universe. Conceivably, a more advanced cosmological simulation could make use of a more advanced version of the Adaptive Moving Mesh Method algorithm, that both moves the space grid cells and changes the local delta time for each cell. By moving cells from regions of lower energy density to regions of higher energy density at the speed of light of the system, and scaling the local delta time accordingly, the resulting grid would look and behave similarly to curved space-time in General Relativity (If energy density is used as the parameter, instead of mass density, the system will account for relativistic effects of speed, too). Furthermore, updating the grid at the speed of light, instead of updating it all at the same time (as per the partial update strategy), would allow to spread out the computation over multiple time frames. In this scenario, gravity would spontaneously arise from the grid mesh distortion caused by the cell relocation strategy, much like it arises from space-time curvature in our Universe. Similarly, time dilation would result from scaling the delta-time of each cell proportionally to its size, thus effectively slowing time down for smaller cells or speeding it up for bigger cells.

Furthermore, since changes to the grid are made at a finite speed rather than instantaneously, they would propagate like waves in a medium, ultimately forming gravitational waves. Another important aspect to consider is that, if each particle in the simulation had an infinite range of interaction for gravity, with every movement it would trigger a state update that would take an infinite amount of frames to end. Consequently, the gravity range of interaction of each particle in the simulation, although big, would still have to be finite in size. This agrees with a recent theory, that states that the Hubble tension's variability over the Universe's age can be explained by attributing to gravity a finite range of interaction [3].

5 Intractable problems

The existence of Quantum Computing tells us that our Universe is able to perform computations that can render tractable, at least, some of the problems that are intractable to the classical algorithms. For this reason it seems that, behind the scenes, our Universe might actually be a computational construct of some kind that has the power to, at least partially, solve intractable problems efficiently. It may be plausible that somehow this one-of-a-kind algorithm is possible only for particle simulations through Quantum Physics, and that the problem one wants to solve would then have to be encoded in the behavior of the particles. If this is true, then it follows that our Universe might be an instance of this construct that is trying to solve a specific problem. And what might this problem be? The answer could be deceptively simple. In fact, the only thing we know for sure about our Universe is that it is capable of creating life (we are ourselves proof of it), and that's exactly the problem it could be trying to solve. As a matter of fact, if we were to build a Universe-like computer simulation, just by the sheer size of the simulation itself, there would be a high chance that we would end up with life springing on one or more planets orbiting somewhere around their own stars. From this point of view, the emergence of life itself seems linked to its originating environment in an indissoluble and profound way, almost as if it was an intractable problem that one could only solve through a special algorithm that has the power of rendering it tractable. For this reason, it is very likely that, to succeed in creating synthetic conscious life, the only feasible way might be creating a simulated environment that possesses the correct characteristics for life to emerge from. This would require either to invent an algorithm that renders the problem of simulating such environment tractable, or to harness Quantum Computing to do just that for us, effectively hacking into the Universe's algorithm itself. This fact has important implications in the field of Artificial Intelligence, where the pursuit of creating the so called Artificial General Intelligence might depend on it.

6 Playing dice with the Universe

To compute probabilistic processes in a Universe-like simulation, one would have to use random noise and this has important consequences. To understand them we are going to address them from two points of view: that of an hypothetical external observer and that of an internal observer (which is itself part of the simulation and is as real as the reality in which he lives). If the external observer is given the current simulation state and asked to retrieve the previous simulation state, given that he recorded the random values used to compute the current state from the previous, he will always be able to recover the previous state from the current. The same cannot be said for an internal observer, who doesn't have access to the random noise values and will never be able to recover the previous simulation state from the current. Moreover, if you ask the external observer to compute the next state from the current, he will be able to do so by using new values obtained from the random noise source. Instead, for the internal observer things are a bit different and, given that he has already developed a so called "Theory of Everything", he will be able to compute some next state form the current, but the state that he will compute will quickly diverge from the one computed by the external observer, because he will inevitably use a different random noise source. Furthermore, if you consider a process inside the simulation that is an extreme scrambling process where noise is prominent, and let that process transform a system from a certain physical state to another, and then ask the internal observer to recover the initial physical state of that system given its final transformed state, he will not be able to do so, because he has no access to the random noise values used in the transformation. On the contrary, if you ask the external observer, he will be able to do so, because he has access to that values, and no information will ever be lost to him. In conclusion, in a simulated Universe, an hypothetical external observer might be able to rewind time but still has to compute the future, and can always recover information scrambled by an internal stochastic process. On the other hand, an internal observer is not able to rewind time, can only compute possible futures without being able to predict the ground truth future, and can loose information scrambled by a stochastic process. In this scenario, randomness becomes relative to the frame of reference and, while Einstein's God doesn't actually play dice, because to him the noise is in fact pseudo-random and just adds variability to the solution of the computation, for us that noise represents the maximum measurable entropy and, since we cannot recover the noise's seed, we will never be able to predict the computation's outcomes, nor invert the arrow of time.

7 Quantum speculations

This view of our Universe is able to spark some ideas about Quantum Mechanics that, although speculative, might still be insightful. These ideas have not been expanded much by the author and are reported in the following list in the hope they might stimulate and inspire the reader:

1. Quantum Mechanics is an alternate and more optimized way of representing and evolving reality in a wave-like probabilistic representation, that is equivalent to a classical particle representation up to a certain interaction threshold and is essentially an algorithmic optimization, that renders the many-body problem tractable, capability that Quantum Computing has been shown to have by a new quantum algorithm that was uncovered in December 2023 that is exponentially faster than any known classical algorithm at simulating the classical dynamics of 2^n coupled oscillators and can do so in polynomial time in n [4]. This equivalence is perceived as the wave-particle duality.

2. When interactions stronger than a certain threshold occur, the system has to revert to classical mechanics, either fully or partially, because otherwise the wave-particle equivalence would not hold. This concept seems to be close to the Penrose's interpretation of quantum mechanics [5]. To get in and out of this alternate representation you need an encoding process and a decoding process.

3. Superposition and Entanglement are encoding processes that encode one or multiple observables to an equivalent quantum system.

4. An interaction that is strong enough triggers the decoding process, that in turn decodes the quantum system either partially or fully. When the system is fully decoded it is called a collapse, otherwise it is called decoherence. Measurements are interactions that trigger a collapse.

5. The quantum decoding process is an actual computational process, and can be used to carry out computations as demonstrated by Quantum Computing. It is also a one-way function, because, if you don't have access to the random noise source used to carry out the computation, you will not be able to recover the input from the output.

6. For this quantum optimization algorithm to be effective, the parts of reality computed with it must outnumber the parts that are not, and the ratio between the two should

remain above a certain threshold. This would not be possible due to stars and black holes, where the interactions are high in number and magnitude. For this reason, the threshold at which an interaction is able to trigger the quantum decoding process should be a function of space-time curvature, which is also a concept close to Penrose's interpretation of quantum mechanics [5]. If this isn't the case, then the other option is that most low-curvature space has to be evolved as a quantum system, which implies that empty space might not behave like we expect.

7. Since the particle representation is more computationally expensive, a "measured" photon that appears as a dot in the slit experiment will revert to its quantum representation as soon as it can and thus, if you put the slit and the screen at a further distance from the measurement, the interference pattern would reappear. The distance threshold at which this happens might be quite large due to the high speed of light.

8 Conclusions

This view of the Universe and its accompanying way of thinking put things in a new perspective. From this perspective we were able to formulate many interesting ideas. For instance, we were able to think of a possible cause for the finiteness of the speed of light. Also, we were able to gain a different point of view on General Relativity and come up with the fact that it might actually describe an optimization algorithm. Additionally, we thought of the Universe as an instance of a computational construct of some kind, capable of partially solving intractable problems, whose specific purpose might be finding a way of creating life. On top of that, we understood that we might be able to create synthetic conscious life in a computer simulated environment, and that Quantum Computing might be the key to succeed in doing that. Finally, we were able to think of the possibility that, even knowing the "Theory of Everything", our future could still be unpredictable to us, and that there are situations were scrambled information could be unrecoverable to us.

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