Is Reality Analog or Digital?

by Alfonso Treviño

The world which we perceive through our senses in our everyday life seems to us a continuous world. Solid matter seems undisputable solid to us, we cannot appreciate empty spaces through which we can squeeze our fingers. Time feels likewise; although clocks divide time in hours, minutes and seconds, we are aware of the existence of shorter periods of time, as when we measured the time it takes a runner to complete a 100 meters race. We can fathom the existence of shorter units, but we feel time flowing smoothly, with no stops or leaps from one time unit or the next.

What was described above was what most scientists accepted as the true nature of our universe until the coming of quantum mechanics and the theory of relativity, which changed the ideas about the essence of the universe. Both theories are regarded as the greatest scientific achievements of the 20th century, and both had been—and continue to be—tested, obtaining results that matched these theories' predictions.

Of the two of them, quantum mechanics has proved to be the hardest to comprehend by laymen. One of its assertions is that energy comes in packets or quanta, therefor establishing a unit for energy and rendering energy as discrete, by adding a new constant, *the Planck constant (h)* to the set of constants scientist work with. Add *c*, the speed of light, and *G*, Newton's gravitational constant, and you have the three war horses scientists use to mathematically study the nature of reality.

As I stated above, combining these three constants, Planck concluded that there was a lower limit for the amount of energy that could be emitted or absorbed in any given interaction. Extrapolating from that, scientists have calculated the lower limits for other aspects of reality, such as temperature, mass, length and time.

Having lower limits for time and length make us conclude that the nature of reality is digital, or discrete. How can we perceive our surroundings and the passage of time as analog, or continuous?

The key issue is the way we see the universe as a whole. The universe is like an immense computer, so let's see what a computer really is. In 1936, Alan Turing set the foundations for what now is known computational theory. Computational theory defines a computer as a system that can process a *finite language* affecting the state of the machine based upon the previous state. A finite language is any set of finite values that can interrelate through a number of finite operations. A human language—i. e. English—is a finite language as it is based on 26 values—the letters of the alphabet—and a set of operations for the combinations of those values—the valid words in English and the grammar rules. A machine for processing English sentences will analyzed each letter until it finds a space; at this state the machine will check if the word formed with the previous letters is valid and if so, it will expect the first letter of the next word. When a punctuation sign is reached, the computer will analyze the whole sentence to validate if it's grammatically correct.

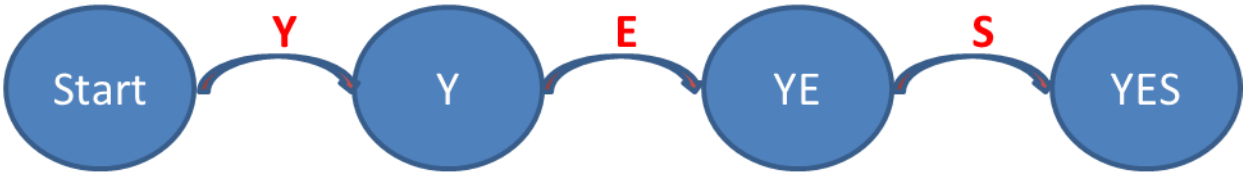

Fig 1. Diagram for a finite state machine that validates English words. Each circle represents the state in the process of recognizing a word.

According to quantum mechanics, every particles in any given time has a set of properties—position, energy, velocity, etc.—whose values are known collectively as its *quantum state*. .Some properties are inherent to the particle nature, so we can say they are fixed, as is the case with an electron charge or mass. Other properties, such as position, present values that aren't fixed, instead they are determined by a probability function from which we can only say that the value of property *x* is in a certain range. When a measurement is taken for the value of a non-fixed property, its value gets fixed. Why? This is sometimes called *quantum weirdness*, but there´s nothing weird about it. It's just the result of imagining the subatomic world in terms of our own macroscopic world. We tend to visualize particles as spheres or marbles, when their nature is entirely different. Particle/Wave Duality and String Theory present us with alternatives of what the nature of elementary particles, but they are beyond the scope of this essay. I'll return to quantum states and the universe as a computer after briefly introducing GUTs.

String Theory is just one of the GUTs (Grand Unification Theory) that tries to formulate a unified view of the cosmos, in which the four fundamental forces—gravity, electromagnetism, strong nuclear force and weak nuclear force—derive from a single force and the large zoo of elementary particles is reduced to a small number or really elementary particles. Its main contender is Loop Quantum Gravity Theory.

LQG postulates the existence of the length and time units exposed earlier and, although it does not lack of problems, it's viewed as a stronger theory than its contender—String Theory—which requires additional dimensions, while LQG incorporates relativity without the need of any additional aspect.

The fabric of space-time is, therefore, constructed from tiny building blocks of Planck dimensions. How is it that we cannot perceive space-time as discrete? Let's take back the idea of a computer. Imagine we have a special quantum camera that takes snapshots of quantum states of all particles in the whole universe at a given moment. The quantum states themselves are the letters of the finite language the universe analyzes, while the interactions between particles are the operations to be computed. Let me use t_h as a short name for Planck time and t_i for the time of any interaction between particles. As t_h is the shortest time possible, and any interaction will take any integer multiple of t_h, we have that for any interaction t_i. is greater or equal than t_h, hence for the universe to change from one state to the next it will take at least the fastest t_i, whereas every snapshot is taken every t_h. In other words, because events take at least the Planck time to occur—but some will take longer—and, complexity arises when moving to larger scales—molecules, cells, rocks, humans, stars—meaningful events take longer and longer, as they are built upon combinations of lesser events, the discreteness is lost and a sense of continuity appears.

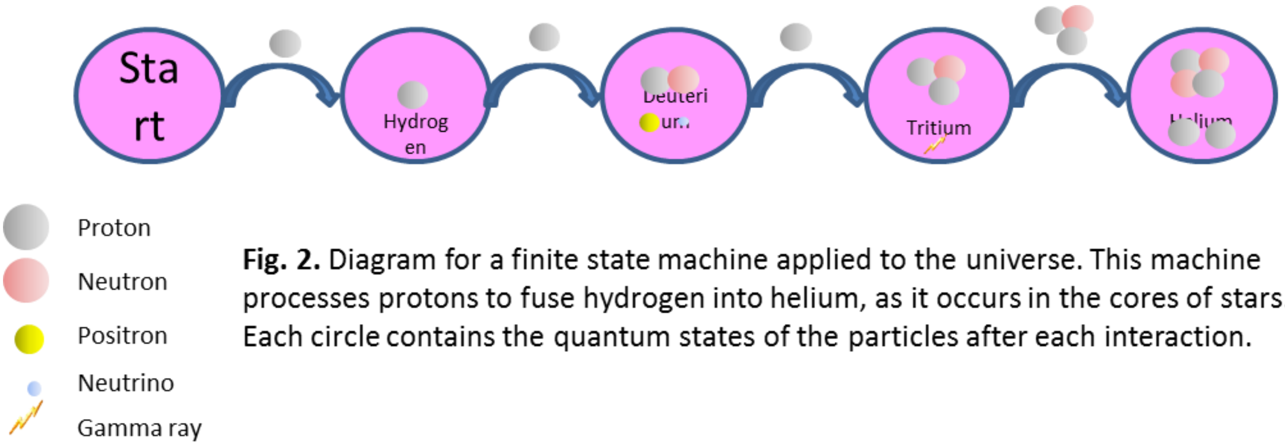

Fig. 2. Diagram for a finite state machine applied to the universe. This machine processes protons to fuse hydrogen into helium, as it occurs in the cores of stars. Each circle contains the quantum states of the particles after each interaction.

We can find an everyday analogy in movies. Movies consist of a series of discrete frames presented so rapidly that the time between frames is shorter than the time the brain requires to realize there's a gap in there, so we have a sense of continuity.

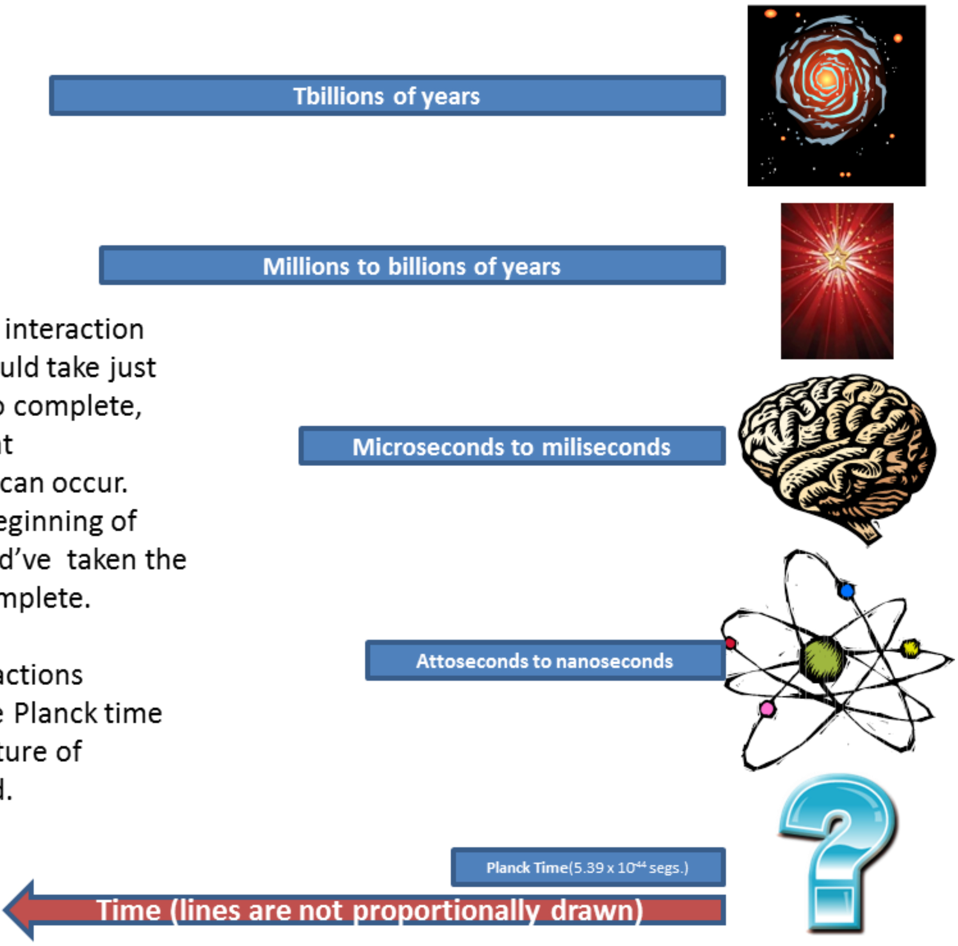

Fig. 3. The fastest interaction in the universe could take just the Planck time to complete, but at the moment there's none that can occur. Inflation, at the beginning of The Big Bang could've taken the Planck time to complete. With complexity, meaningful interactions take longer, hence Planck time and the digital nature of time go unnoticed.

Units:
1 milisecond = 1×10^{-3}
1 microsecond = 1×10^{-6}
1 nanosecond = 1×10^{-9}
1 attosecond = 1×10^{-18}

Something similar happens with space. The shortest distance a particle can move is the Planck length. The minimum distance a particle can move during an interaction is the quantum length, l_i, so the shortest distance a particle moves during an interaction, l_i, is equal or greater than l_i. As we go to larger scales, meaningful interactions comprise larger types of particles, causing the Planck distance to be irrelevant and non-evident from a macroscopic perception. Is like first seeing the grains of sand and then taking a picture of the beach from high above, no grains of sand can be resolved, what we see is just a sheet of sand.

Fig. 4. Planck length is so small that it goes unnoticed when the shortest distance a body moves is large, like the grains of sand cannot be seen when watching the beach from a distance.

Because our senses and our instruments are based upon macroscopic structures, they cannot and will not be able ever to detect the digital nature of reality.

But, is the universe really discrete? Is it necessary for the laws of physics a digital universe? If we take for granted the premise of quantum mechanics that energy is quantized, so there's a lower limit for the amount of energy a quantum can have. Let's call it q_n In any interaction, the emission or absorption of q_n won't take less than a certain time and the minimum distance it can cover during that time cannot be less than some quantity. As there's no quantum with less energy than q_n we can deduce that there cannot be time intervals or lengths lower than the ones stated above—t_n and l_n.

The answer to the second question requires a visit to the computer analogy. For a computer to go from one state to the next all it requires is an operation to be performed. A computer can stay a second in a given state, provided an operation is performed, or a million years. Times intervals are of no relevance, so the computer does not care if time runs smoothly or in leaps. And the same can be said about distance: the computer doesn't care if the operation involves a series of steps or if it is performed fluently; the computer only cares about the change of state.

To finish this discussion, I would like to emphasize that, being the universe a type of finite state machine—or computer—it doesn't care about the true nature of reality. Causality and the expansion of the universe are not affected by continuous or discrete space-time.

Expansion can be modeled as a machine that goes from one state to the next by performing operations that involved ordinary matter, dark matter, dark energy and space-time as characters of a universal finite language.

Causality requires us to go back to the original universal computer I presented, the one in which the particles go from one state to the next, changing their quantum states. Add one more character to the language, *entropy*, and you can model causality as we find it in everyday life, with the arrow of time pointing from the past to the future.

As a conclusion of this essay I can say that no matter if reality is analog or digital, the universe will operate the same. Which one of these alternatives is correct? As long as contending theories to explain reality are not sufficiently proved to get the status of laws, we can only bet in favor of those that have been more tested and have more predictions agreeing with what scientists observe. Quantum mechanics is a mature field involving mature theories. If we accept quantum mechanics, then we will eventually conclude that reality is digital.

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