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SPACE AND TIME ONTOLOGY: NEW MODELS FOR NEW PHYSICS

SARA LUMBRERAS SANCHO

In one of professor Nickel's papers [NICKEL 2006], he proposes a model for movement – and in general, for change – in which each instant in time (characterized as the set of real numbers) is assigned to one point in a configuration space. As much as this model seems to intuitively fit to our experience, it implies a number of assumptions about the nature of space and time that are interesting to explore. During the debate session I mentioned the timeless physics developed by Julian Barbour [BARBOUR 1999] as an example of a different perspective. This paper reviews not only this concept but also other similarly provocative ideas that might prove useful for improving our understanding of the universe. Prior to this, the relevance of the philosophy of space and time will be briefly outlined and its history reviewed to provide some background for the discussed models. Finally, an approach where space and time are only defined by convention will be considered.

THE RIDDLE AND A NEW RENAISSANCE

Space and time are such fundamental notions that they seem to resist any attempt to define them in a sensible manner (as in the celebrated quote from St. Augustine, *"What then is time? If no one asks me, I know. If I wish to explain it to one that asked, I do not know"*). Their ultimate reality is beyond the scope of science yet the whole building of physics is based upon them. These concepts have evolved with science: absolute space and time were essential for the development of Newtonian mechanics; a space-time which depends on the observer and is conformed by matter was at the core of the revolution of General Relativity.

It is precisely General Relativity, together with Quantum Field Theory, what poses an intriguing riddle to science at the moment. Quantum Mechanics has already inspired non-local interpretations of the universe [BOHM 1952]. Quantum gravity would accomplish the final step of a unification process started by Maxwell and his Electromagnetism laws. However, after decades of effort and many promising lines of research (such as string theory); such unified theory has not yet been found. It is in the mind of many that the next scientific revolution will come with a change of paradigm that will reconcile the two different theories with a new understanding of space and time.

As expressed in [MAJID 2008], *"There are elements of some kind of new Renaissance centered on our understanding of space and time"*. It seems clear that Science is now in need of deep philosophical input and that it is indispensable to identify and challenge our latent assumptions. The old questions should be revisited with new eyes. What is the reality of space and time? Are they continuous or discrete? (This question might have a different answer for time and space respectively). Are they independent of consciousness? Is empty space or time without change possible? In what ways do they interact with matter? Can two things be at the same place at the same time? Philosophy has reflected on these issues for millennia: returning to its insights can provide a starting point for the current considerations.

BRIEF HISTORY OF THE PHILOSOPHY OF TIME AND SPACE

Not surprisingly, it is in Greece where we find the two first well-known examples of philosophers of time. Heraclitus defended that everything in reality is in a state of constant flux and change. On the contrary, for Parmenides change is an illusion as it is logically impossible. Parmenides' disciple Zeno formulated the paradoxes that made him famous, in which he tried to prove that movement was impossible because it was an addition of an infinity of sub movements. As naïve as paradoxes such as *Achilles and the Tortoise* might seem today (now that we understand the concept of limit), they clearly show that Zeno and Parmenides assumed continuity in space and time. This was actually the case for all well-known Greek natural philosophers, including Democritus (for whom only matter was quantized, but not the infinite space in which it moved). Only in relatively recent times have we seen proposals of discrete space time.

Plato proposed three different kinds of existence: that which comes to be (matter), that in which things come to be (this would be space), and that after which it comes to be (that would be the model, the form). So for him space actually existed but not in the same way as matter.

Aristotle stated that the existence of space is "*held to be obvious from the fact of mutual replacement*". He even proposed a definition: "*The space occupied by an object is* *the innermost motionless boundary of what contains it*". However, time does not have a real existence, as the past does not exist any more and the future does not exist yet. Nonetheless he gave time a definition: "*Time is number of change with respect to before and after*". Interestingly, time exists only in relation to mind as "*it is a kind of number, and only the soul can count*".

Medieval theologists held that God does not exist in time but in eternity, understood as an existence without time rather than time without beginning or end. As stated by Boethius: *"Eternity is the entire and perfect possession of endless life at a single instant"*. It is interesting to note that for medieval masters such as St. Augustine or Boethius this divine all-at-once eye did not pose a threat to free will. God's knowledge of the future is not equivalent to a humane knowledge of what is to come, as for Him every moment in history is the same. It is useful to keep these considerations in mind when examining timeless cosmologies such as Barbour's.

Kant interpreted space and time as a priori notions that are not abstracted from experience but rather frame it. In order to have any experience at all, it must be bounded by these forms.

Newton created precise descriptions of the concepts of motion, space and time. For him time flows in perfect uniformity completely undisturbed. Space is absolute, much like a limitless transparent container that stretches to infinity. He agreed that one could only observe relative motions, but nevertheless stated that the absolute movements could be deduced.

Leibniz opposed this view, defending a relative view of space where only relative distances and speeds had a real physical meaning. His correspondence with Newton's spokesman Clarke has been very much studied. The final argument in the discussions was an experiment where a bucket of water is set to rotate. The curvature that appears in the surface of the liquid does not respond to the relative movement of the water and the walls of the bucket but very clearly to its absolute rotation. The discussion was deemed to be closed in favour of Newton's view.

It was not until the 19th century that Mach, brilliant scientist and deeply convinced empiricist, raised suspicions about the invisible notion of absolute space. He argued that the linear or angular momentum of an object exists as a consequence of its relative motion with respect to all the other objects in the universe. This is what Einstein called *"Mach's principle"*. Inertia will be then necessarily a concept that involves the whole universe rather than just the studied object.

Einstein was inspired by Maxwell's laws (that determine the speed of light without specifying with respect to which reference) to postulate that it was the same for them all. Actually, all experiments trying to measure differences in the speed of light due to relative motions with respect to the ether (like Michelson Morley's experiment) had failed. From this starting point he derived a new paradigm where all the laws of Physics are the same independently of the observer. Space and time are completely intertwined in one space-time, and they are not immutable any more but conformed by the matter they contain. It is their geometry what will define inertia now, as inertial reference frames will be the ones following geodesic paths in this new landscape.

Relativity has very probably been the deepest transformation in our understanding of space and time, and has pushed ahead our knowledge of Physics. Now the question is whether a further change in the interpretation of space and time can bring us the next revolution. Perhaps its seeds are already in one of the evocative models discussed below.

BARBOUR'S TIMELESS UNIVERSE AND OTHER SUGGESTIVE PARADIGMS

In this section we will review some interesting perspectives which differ from the mainstream interpretation and which could potentially trigger the next scientific revolution. Barbour's idea of an eternal universe will be exposed, together with other provocative speculations by other renowned current scientists.

The End of time

Julian Barbour was admittedly fascinated by Mach: "*It is utterly beyond our power to measure the changes of things by time. Quite the contrary, time is an abstraction, at which we arrive by means of the changes of things*". He reflects that when we measure time we are actually measuring distance, using the length covered by the clock's hand to infer the time elapsed. Solar time is the distance the sun has moved in the sky. Sidereal time, the distance the stars have moved. Atomic time, the oscillations of a cesium atom. Actually, it is possible to build the simplest clock by analyzing the relative movements of just three bodies moving inertially. This inertial clock was firstly introduced by Neumann, and then developed by Tait. With three particles, one can assume one of them is at rest. We can use the second one as the hand of the clock, dividing in intervals the distance it covers. If we assume it moves with unit speed, it is immediate to deduct the speed of the third particle. Actually, it is enough to count with three snapshots of an inertial system to completely define it in these terms, and be able to calculate all the future and past relative positions of its components. It is important to note that these snapshots come alone, i.e. without any additional data specifying the moment when they were taken. The possibility of fully describing a (very simple) system without time inspired Barbour for his search of a model for a timeless universe.

He proposes that the ultimate arena for the universe is the space of all its possible configurations. As these configurations are eternal he gives this space the name of *Platonia*. All *Platonias* have a distinguished state of minimum size and complexity which he calls *Alpha*.

There is however no *Omega* as there is no limitation to the size or complexity of what can exist. If we trace a curve in *Platonia* we will have a history for the universe. Again, there is no need for time; as in Tait's construction, having the relative positions of the elements is enough to define a history (and nothing stops us from checking the relative position of the hand of our clock for each point in the curve).

We can define distances in *Platonia* as we wish and, using them, trace minimum length curves or geodesics across its landscape. Some definitions of distance are particularly interesting as Barbour seems to be able to derive from them histories that are consistent with Newton's Laws or, with a more sophisticated definition, even Relativity. Therefore it seems to be possible to re-formulate mechanics as a whole in a timeless fashion.

However, our experience still speaks for the existence of time. Barbour tries to explain the origin of this persistent illusion. In *Platonia* all the possible configurations of the universe exist eternally. However, these configurations appear with different intensity. He describes a *mist* that concentrates around the best solutions for the equation of the universe, in a way that resembles the probabilities from Quantum Mechanics. The solutions that resonate best are the ones that seem to be the most internally consistent. This internal consistency manifests in creating what he defines as *time capsules*. A *time capsule* is any fixed pattern that creates or encodes the appearance of motion, change or history. Thus our impression of time and movement is just due to the tracks they leave, which are actually timeless, and to the memories of them in our consciousness which are indeed timeless patterns too.

He even speculates that the universe probably has a tendency to find more suitable those solutions which are more structured. This will make the universes containing consciousness the most appealing. This could explain the fact that the reality we observe is highly complex and structured and yet this is a statistically highly improbable state.

Non-commutative geometry, foams, fractals and holograms

Barbour's is not the only timeless cosmology. In causal networks, as in Penrose and Sorkin's work, space-time is described by a discrete set of events for which it is merely specified what elements causally precede others. Penrose reflected as well on the values that were given to angular momentum in Quantum Mechanics. *"Why should we say an electron has spin up or down rather than left or right?"* [PENROSE 1971] We only know that one electron can take two different values for its spin: ½ or -½. The directions of space are meaningless. When we build a structure of elementary particles, we can find its total angular momentum. If we move one electron from one structure to another, we can find the probability of the second structure increasing or decreasing its total angular momentum by ½. This probability is interpreted by Penrose as the cosine of the angle that the two structures form. If an electron which is contributing with a positive momentum has 100% probability of contributing with positive momentum when transferred, then the two structures are exactly parallel. If it always contributes with opposite sign then they would be anti-parallel. Intermediate values of probability would give intermediate angles. These probabilities are discrete but as the structures become more complex they can take more values and in the limit they would give origin to a continuum of directions. Spin networks do not consider time, but Penrose generalized them to a four-dimensional space-time in Twistor Theory. In this framework the basic units are rays of light, in that a photon exists simultaneously in all the points it crosses due to relativistic time dilation.

In all the models presented above it is assumed that the distance from point A to B is necessarily the same as the one from B to A. Non-commutative geometry tries to relax this condition and apply non-commutative algebra to space. Alain Connes, a French mathematician, works in exploring the possibilities of this conception of space [CONNES 2008]. In a way which is reminiscent of Democritus and his atoms with different shapes he even proposes that matter might be a manifestation of the deep structure of space-time.

It has been mentioned above that the assumption of continuous space-time can be the root of the Quantum Gravity problem. We know from Quantum Mechanics that distances below Planck's length are physically meaningless. Space-time could be based on a *foam* (as expressed by John Wheeler), where there would be some fuzziness at the fundamental scale. Physicists like Shahn Majid [MAJID 2008] study the consequences of such a description of reality. In particular, Majid's theory predicts that the speed of light would vary slightly with frequency. There are already experiments in place to detect these minimum variations in the light emitted by distant supernovae using the LISA telescope.

Tim Palmer proposed a new interpretation of Quantum Mechanics where the probabilities arise as a consequence of the intrinsic complexity of the structure of space [PALMER 2009]. For him the deep reality should be described as a fractal. His main idea can be exemplified by the analogy of receiving the coordinates of a point on a very intricate coastline. Certainly we would not be able to know exactly whether the point belongs to the land or to the sea but rather a probability. Palmer holds that the probabilities we find in Quantum Mechanics are derived from a similar phenomenon.

It has also been proposed that all the information contained in the universe is encoded in its boundary. This ultimate hologram would encode in the two dimensional boundary surface the whole of the three-dimensional reality. If space is discrete, it would mean that for the surface to be able to store all the information, the inside should be much fuzzier. Craig Hogan from Fermilab believes this fuzziness can be behind the unexplained noise that is disrupting the GEO600 experiment in Hannover, designed to detect gravitational waves [HOGAN 2008].

AN INTRIGUING POSSIBILITY

According to Barbour, we can depict our reality without time and this as an evidence of time's illusory nature. However, even if this description was perfectly consistent with observation, it would not prove that time does not exist. It only proves that it is possible to mathematically produce physics without time, which is not quite the same thing. As we already do science using the concept of time, this would mean that we have two different possible models which might work equally well. Interestingly Quantum Field Theory has provided with another example where the two different theories formulated with different space-time backgrounds (AdS/CFT and T-duality) give equivalent results. Could it be the case that contradicting descriptions of space and time gave us equally good predictions?

Poincaré [POINCARE 1905] highlighted the fact that our senses could not apprehend the geometry of space directly: geometric space, the true framework for our experiences, is different from the representative space which we infer from our senses. For a start, the experience of vision is a purely two dimensional phenomenon. However, we take the information from our retinas, our perceptions of touch and how these change with movement and combine them to form the three-dimensional representative space. As a result,"*It is also just as impossible for us to represent to ourselves external objects in geometrical space, as it is impossible for a painter to paint on a flat surface objects with their three dimensions. Representative space is only an image of geometrical space, an image deformed by a kind of perspective, and we can only represent to ourselves objects by making them obey the laws of this perspective.*"

Poincaré proposes a mental experiment where we consider a world contained in a sphere where all the objects have the same linear coefficient of dilatation, so the length of any body is proportional to its absolute temperature. The temperature in this world decreases with the distance to the center with the formula $R^2 - r^2$, so in the boundary the temperature is absolute zero. Even though this universe would be finite, to their inhabitants it would be in fact infinite, as they would became smaller and smaller as they approach the boundary. These imaginary people would study the physics of such a world completely unaware of the thermal dilatations. When they move, they would experiment a contraction of their limbs in the direction of the boundary. However, this deformation would be considered a kind of perspective, and so their senses would adjust to correct it.

Poincaré points that "*It would be a mistake to conclude from that that geometry is, even in part, an experimental science. If it were experimental, it would only be approximate and provisory. And what a rough approximation it would be! Geometry would be only the study of the movements of solid bodies; but, in reality, it is not concerned with natural solids: its object is certain ideal solids*" He finally argues that experiment can guide us but it does not impose any choice of geometry neither can reveal what is the truest, the most appropriate geometry.

It is impossible to measure any distance without a measuring rod or without the possibility of moving the rod, as we can only compare distances when they are next to each other. We assume that the rod will remain the same in the process. These assumptions are the ones actually shaping the geometry that we find. We might find a different solution if we take another hypothesis. For instance, if instead of assuming that the rods are not distorted we assume that the speed of light is always the same we find relativistic geometry.

A conventionalist approach to space and time where their nature is only agreed by convention is plausible. It seems like we could get equally good theories based on very different assumptions. This might mean that their fundamental ontology does not exist independently of the experience that already assumes them, in a sort of unavoidable circularity. It could also be the case that it cannot be ultimately expressed mathematically, and we can only find different approximations to their true structure. Or finally, it could simply mean that their reality can be expressed with mathematics in more than one way. The different models that prove to work should be understood as descriptions of the same reality beyond their mathematical differences. The final aim of this paper is to motivate discussion on the latter possibility, with one single nature and multiple descriptions. A perspective on the history of the Philosophy of space and time, as well as some overview on the more recent developments as given above can be seen as pointing in that direction.

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