About the Nature of Time

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Introduction

Classical physics is based on a number of fundamental philosophical assumptions known as classical realism – or common sense realism. In the beginning of the XXth century, classical physics was superseded by Relativity and Quantum Mechanics. But classical realism remained up to now our main interpretative frame. Yet if it is consistent with classical physics, it is likely that it is not with Relativity and Quantum Mechanics. But this point went generally unnoticed - and this is probably the main reason why "nobody understands Quantum Mechanics".

If we want to adress properly the question of "The Nature of Time", we must then question classical realism in the first place – i.e. we must revisit our most basic assumptions about reality.

Part I. Perception, Space and Time

I.1.Perception

The founding postulate of any realism is that there is an observer-independent reality.

As part of reality, the observer is in a continuous physical relation with it. But he also perceives this relation, i.e. he abstracts it and creates a picture of it in his mind. The purpose of perception is to provide the observer with information about his macroscopic environment, so that he can act upon it. His perception must therefore be as reliable as possible – hence the classical realist view according to which what is perceived is what exists. Yet this assumption is not precise enough : what is perceived is the result of the observer's physical relation with reality, i.e. *reality as it appears to him in this relation and not reality as it is independently of it*.

When the observer sees an object, for example, what he sees is not the object itself, but the flow of photons bouncing off it – and more precisely, that part of the flow that hits his retina cells. The picture he creates does not represent the object as it is independently of him, but as it appears to him given his visual system's properties and limits : it is the result of an encounter between a certain object and a certain biological organism. What is created then is a *subjective interpretation of the outlying reality,* constructed by the observer from what he can grasp of it – a mental picture which corresponds more or less to what it represents.

Einstein once asked if the moon exists when nobody is looking at it. The answer is not so obvious as it seems. What exists independently of us is the element of reality with which we interact and of which we create a picture in our mind. But we cannot know what this element is outside this interaction. We know it only through our picture of it ("the moon"), which does not exist independently of us. The said element of reality does exist independently of us, but when no one is watching it, no one creates a picture of it - "the moon" does not exist.

This distinction may seem minor, but we shall see that it is essential.

I.2. Discontinuity of perception

Our sensory apparatus consists of multiple independent receptors, each one acting separately. Besides, each of them acts only intermittently : after interacting with the environment, it must regenerate its energy potential and is out of action for a Time : our perception is a discontinuous process.

It is also discontinuous because of the way each act is performed. In the case of vision, light interacts with the retina cell. Only when this interaction is completed can the cell send its result to the cortex. What is sent is then a fixed information about a quasi-instantaneous state of reality. It is transmitted through a chain of modified molecules inside the cell, then a chain of electric impulses inside the optic nerve. The material vectors conveying it thus undergo several transformations, but the information itself remains unchanged. When it reaches the cortex, it is decoded and associated with other informations to form a visual picture. Being a sum of discrete, fixed informations, this visual picture is itself a discrete and fixed information, representing a certain determinate, quasi-instantaneous state of the outside world.

In order to adapt to the changing outer reality, the visual apparatus must constantly renew this fixed visual picture, by constantly replacing it with a new one. As a result, visual perception is a discrete (cinematographic) succession of motionless determinate pictures. The observer perceives his continuous physical relation with reality in a discontinuous way.

I.3. Space

The observer's mental picture of outer reality consists of a number of forms which are in certain topological relations with each other - and with the observer's own perceived form. This system of topological relations between perceived forms (or objects) is what we call *Space*.

If Space is determined by perceived (observer-created) forms, there is no empty Space, independent from the forms that structure it. All that which is perceived is present in Space and Space is present in all that which is perceived : one can say that Space is the general mode in which we give form to (we inform) outer reality. As far as we are aware of reality only through perceived, observer-created forms, *what we call Space belongs to our perception of reality and not to reality, i.e. Space is not observer-*

independent (2). Granted that we perceive only that which exists, it is sensible to suppose that what observers subjectively perceive in terms of Space corresponds to something existing objectively in independent reality – but which is not knowable directly, as it is. Therefore, to avoid confusions, we save the word "Space" for that which is perceived.

Classical realism considers on the contrary that Space belongs to observer-independent reality.

This assumption implies that if Space is observer-independent, it must be the same everywhere and common for all observers – but it can be perceived differently by each of them, according to his position (perspective effect).

In Special Relativity, an observer looking at a system uniformly moving relatively to him sees the lenghts of this system contracted in the direction of movement. For another observer placed in this system it is the first observer who is moving and whose lenghts are contracted. All reference frames being equivalent, both are equally right– but their perceptions are mutually exclusive.

If the two observers were in a common Space - the all-encompassing, observer-independent Space of classical physics - this could be called a perspective effect. But then, only one of them would objectively be at rest relatively to this Space and only one moving. If both observers are at rest and moving, they must be in two different Spaces. Consequently, the length contraction is no perspective effect : it is the way each observer appears in the other's Space. There is no objective, observer-independent Space where one of them is right and the other wrong.

Moreover, if Space belonged to reality we would have two different realities, one for each observer : reality would be what each observer perceives, we would be in a solipsist world.

Realism implies that what we call Space does not belong to observer-independent reality, but to its subjective perception (there can be as many Spaces as there are observers). This means that, contrary to the universally admitted opinion inherited from classical physics, we are not "in Space", Space is in us : what is "in Space" is the representation we create of ourselves, the form in which we perceive our own physical presence.

(2) Kant was the first to assume that Space and Time belong to "the a priori categories of our sensibility" (Critique of Pure Reason, Transcendental Aesthetics)

I.4. Time

An arrow is flying towards a target. We perceive it through a series of fixed, determinate pictures (I.2.) : we see it at rest for, let us say 1/50th of a second, in spatial position A, then in spatial position B, etc. As far as these spatial positions are the result of performed acts of perception, we call them *actual positions*.

We don't perceive the arrow *between* A and B. Although A and B are separated by some distance, in our perception the arrow jumps instantly from A to B, after 1/50th of a second. It is present to us only in its actual positions A and B : its perceived presence is discontinuous. But its real presence is continuous : while we are perceiving it at rest in A, it moves on towards B - but it does so unperceived.

If we assume that what we see is what really is, we suppose that if the arrow is always perceived in a determinate actual position, between A and B it also is in a series of intermediary determinate positions. But each of these, being determinate, must itself be separated from the others by a series of determinate positions, and so on, *ad infinitum* : A and B are separated by an infinite series of determinate positions. But we don't perceive them : we just logically suppose they exist. They are not actual positions, but since they can be perceived (with the help of a movie camera for instance), we shall call them *potential positions*.

We have then two different sorts of positions of the arrow : its *actual positions* (which are perceived, which correspond to performed observations) and its *potential positions* (which correspond to possible observations, but are not perceived). In other words, *it is only when the arrow is in actual positions A and B that it is in our Space*. When it is between A and B, it is in reality, but it is unperceived, *it is not in our Space*.

If the two actual spatial positions A and B are distinct, it is because they are separated by what we suppose is an infinite succession of unperceived potential spatial positions. If not, A and B would not be distinct, they would form only one spatial position. In this case, the arrow would be *simultaneously* in A and B. In other words, if A and B were separated by no potential Space, they would be separated *by no Time interval*. In other words, *our infinite succession of potential positions between A and B is a Time interval*. *What we call Time is potential Space.*

I.5. Twin paradox : is Time observer-independent ?

Does Time belong to reality or to our representation of it ? Let us consider the famous twin paradox.

One of two twins remains on Earth, the second one leaves for a cosmic trip toward a faraway star. A, the stay-at-home twin considers that he is at rest and that B is moving : B's Time appears to him slowed down : B becomes younger. B notices the opposite.

When B comes back to Earth, some years later, either they are the same age again, either they are of different ages.

If both were the same age again, this would mean that they share a common, universal, observer-independent Time and that the slowing down of B's Time is only a perspective effect, an illusion that would disappear when the twins meet again, as Henri Bergson argued against Einstein in 1921 (3) – this was experimentally disproven in 1971 by Hafele and Keating's (4) with airliners carrying atomic clocks.

If they are not the same age, the slowing down of B's Time is not a perspective effect : B is now in A's reference frame, where his Time has been slowed down and where he is younger. Each one was in his own Time and not in an universal, observer-independent Time : *Time does not belong to reality but to its perception by an observer*. Like Space, it is observer-created and there can be as many Times as there are observers.

(3) Henri Bergson, *Durée et simultanéité*, PUF Paris, 1968

(4) J.C. Hafele and R.E. Keating, *Science* 177, 166 (1972).

I.6. Time and motion

When the arrow is in A or B, it is in our Space. When it is in between, it is not, *it is in our Time*.

In our Space, the arrow is always at rest in an actual determinate position. This position is separated from the others by a Time interval, consisting of a supposed infinite series of potential positions - in each of which the arrow is supposed at rest.

But the arrow can be said at rest in one position only if it travels zero distance. In an infinitely divisible Time interval there is no zero distance. Thus, when travelling from A to B, *the arrow is never at rest, it is never in a determinate position*. *In our Space, the arrow is always at rest, in our Time it never is.*

This means that *movement does not take place in Space, but in Time* - where we cannot perceive it. When the arrow is betweeen A and B, it is moving : we cannot perceive it (to perceive it, we must stop it and spatialize it). Contrary to what is assumed in classical physics, the arrow is not "at every instant in a determinate position". It is in such a position *only in our spatial perception (description) of reality – in our Space*. In Time, it is moving *continuously*.

Saying that in Time the arrow is moving continuously amounts to say that *Time is never identical to itself* – whereas every spatial perception is always identical to itself as long as it lasts. Because we can represent reality only in terms of Space, i.e. in fixed, determinate representations, we cannot perceive movement directly – only through a succession of fixed, motionless representations (movement takes place outside them).

I.7. SpaceTime

While in an actual (determinate) position in Space, the arrow is in a supposed infinite series of successive potential positions in Time. This infinite succession of potential positions is our description of its continuous unperceived movement (6), which manifests itself as the transient duration of the arrow's actual position – what is commonly called *the passing of Time*.

Each actual (spatial) position has a beginning (when the arrow appears in this position) and an end (when it appears in the next one). If its beginning and end were simultaneous, they would annihilate each other : every spatial position of the arrow necessarily corresponds to an interval of Time, it necessarily has a duration. On the other hand, a duration connects two actual positions : without them, there would be no duration. *There is no Space without Time and no Time without Space.*

Space and Time exist only relatively to each other : they exist only jointly, as *Spacetime*, each element of which can be transformed into the other – by actualizing potential Space or potentializing actual Space (which is possible because they belong to the observer's perception of reality). Such unity is the result of their being created by the observer in a single act of perception.

Consequently, if Time does not exist independently of Space and if Space is observer-created, Time is also observer-created : as seen previously, Time belongs to our representation of reality, and varies according to our physical relation with it. This is why two observers uniformly moving relatively to each other have different Times as well as different Spaces. And the observer is not in Time - what is in Time is the spatial representation he creates of himself.

In order to follow the changing of reality, the observer must create a succession of fixed spatial views, each of which is present to him for a certain duration. So, the spatial dimension of his perception gives him a figurative perception of reality - but a static one – while its temporal dimension gives him a dynamic – but unfigurative - perception. Each dimension cannot be without the other because it has what the other has not : to be efficient, perception must be spatiotemporal.

(6) One can notice here again that a continuous process is impossible to express adequately in discontinuous terms.

I.8. Irreversibility

During the Time interval between actual position A and actual position B, the arrow moves continuously : we represent it as an infinite series of successive potential positions, one at a time. But it can be in a new position only if it is no more in the previous one – i.e. *if the previous one ceases to be*.

In other words, the continuous renewal of reality expressed by the passing of Time is achieved by continuously replacing "that which is" – i.e. *by its continuous disappeareance.* So, Time can flow only in one direction : replacing "that which is no more" by "that which is" – Time reversion would mean replacing "that which is" by "that which is no more", by nothingness.

In reality itself, what is "present"(7) continuously arises by continuously erasing what was before. *There is no past in reality* - only in the observer's consciousness. Reality is always in the "present" moment of its continuum, as "that which is". "That which is no more" is definitely no more and is no part of "that which is".

Reality can be continuously appearing only if it continuously disappearing, if it is continuously renewing itself. Then the flow of Time – the "arrow of Time" – is necessarily irreversible : the continuous renewal of reality of which it is the expression can take place only in the positive direction, as replacement of "something" by "something else" and not by what has just disappeared, by “nothing” : in this perspective, Time reversion would simply mean the disappearance of reality. *Time irreversibility expresses the fundamental ontological dynamics of reality, its continuous renewal, the only way in which it can exist.*

(7) If the term “present” means a fixed state, it is not relevant to reality, since reality is changing continuously and knows of no fixed state. In this context, the term “present” is ambiguous and can be applied to reality only in a metaphorical sense.

Part II. Space, Time and Quantum mechanics

II.1. Wave-particle duality and collapse of the wavefunction

When a quantum object is observed – i.e. when it physically interacts with the physicist’s observing device – it appears as a determinate particle, in a determinate location and a determinate state. When it is not observed, the object appears as a probability wave, in all its possible locations and states. This strange ambivalence known as wave-particle duality aroused many commentaries and interpretations.

Let us compare this with the macroscopic example of the arrow (I.4.). The observer perceives the arrow only when he physically interacts with it (when the flow of photons bouncing off it hits his retina cells). He creates a picture of it *at rest* for a split second in a determinate spatial position, then in another, etc. He never creates a picture of it *moving* from one position to the next one. Between two actual positions, the arrow is in Time, where *it has no determinate position*.

In the subatomic world too, we perceive only that with which we physically interact. When a quantum object interacts with his observing device, the physicist creates a picture of it as a determinate particle in a determinate state and a determinate position. The particle is in *his Space*.

When the object does not interact with the observing device, the physicist creates no picture : the object is not in his Space – but it nevertheless exists in reality. A classical realist will think that if what is real is what is perceived, the object which appears to him as a particle when he observes it is still one when he does not. Yet he notices that when not observed this supposed particle behaves in a strange way : it is spread out in a multiplicity of more or less probable positions and in a superposition of all its possible states. The quantum object has no actual, observed, spatial position, corresponding to a performed observation, but an array of possible positions, described by its wavefunction, corresponding to observations that could be performed : it is outside the observer’s actual reality, in his potential reality, it is outside the observer’s Space, *it is in his Time.*

When the quantum object interacts with the observer, it is in his Space, where it appears as a determinate particle in a determinate state and position. When it does not, it is in his Time, where it has no determinate form, is in no determinate state and position, but in all of them, with a certain probability. The collapse of the wavefunction can then be interpreted as *the crossing of the object from Time into Space*.

The difference with the macroscopic arrow is that, when not observed, the arrow remains an arrow. In the quantum world, we are sure that the quantum object is a particle only when we interact with it. When we don't, we don't know exactly what it is : *it has no definite form*. We call it a potential particle because we can describe it only in the terms of our interaction with it. But as far as it is spread out over a relatively large area, there is reason to think that it is non local, that it is not the same object as in Space.

In other words, the intriguing wave/particle duality is not a mysterious property of subatomic reality : *it can be ascribed to the limits of our own spatio-temporal mode of perceiving it*.

II.2. Schrödinger's cat and observer-created reality

As long as it does not interact with another object, a quantum object is in a superposition of states and positions. But when it interacts with something – for example with the physicist's observing device - it is found in a single state and position. For classical realism, this means that observing the object modifies it – modifies reality.

Because he was deeply disturbed by this idea, Erwin Schrödinger imagined the following thought experiment. A cat is locked in a box (where it cannot be observed). In the box a random quantum process can trigger a lethal system which will kill the cat. In an hour's Time, this can happen with a 50% probability. Accordingly, after an hour, the cat has as many chances to be alive as to be dead.

As long as the box is not opened, the quantum system is in a superposition of states of equal probability : the cat is also in a superposition of states - alive and dead. Only when the box is unlocked is the system found in a determinate state : the cat is then either alive or dead. Consequently for classical realism, the act of observation collapsed the quantum system's wavefunction and brought it into a determinate state : observing reality modified it.

The problem stems once more from a loose definition of reality. For classical realism, what I perceive is reality : since I perceive the cat, the box, etc, they are real. Now, when I don't perceive the cat, it is in two different states, when I perceive it, is is in one state. Conclusion : my observing reality changes it.

But if reality is what I perceive, what I don't perceive is not reality : observing reality does not modify it, *it creates it*. Then, there is no more observer-independent reality. Classical realism ends up in solipsism.

In the new perspective presented here, what I see (the cat) is not reality, it is the spatial representation I create of a certain element of reality. This representation does not exist outside my consciousness (what exists independently of me is the element of reality it corresponds to). When the cat is in the closed box, I cannot create an actual representation of it : I cannot know wether the cat is alive or dead, I can only calculate the probability of its being alive or dead. The two being equal, my conclusion is that the cat is in both states at the same time. But these states don't correspond to two really performed observations : they correspond to two *possible* observations. That is *they are not actual, but potential representations of the cat : the cat is not in my actual but in my potential Space, in my Time*.

When I open the box, I collapse the system's wavefunction : I bring the cat from my potential Space into my actual Space, from my Time into my Space. There the superposition disappears : the cat is now in one determinate state, as every decent cat must be in Space. *My opening of the box did not change reality, it changed my physical relation with reality and hence, my spatial representation of it : there is no such thing as observer-created reality.*

II.3. Double slit experiment

More disturbing yet for common sense and classical realism is the Double slit experiment. Particles are fired at a panel containing two slits. Beyond the panel is a screen. The particles can be fired individually.

When only one slit is open, the particles behave in a classical manner : they go through the slit and hit the screen in a diffraction pattern. When both slits are open, particles form an interference pattern on the screen : they behave as waves. This happens even when the particles are fired one by one – which means that each particle passed through both slits at the same time and interfered with itself.

We are sure it is a particle only at its starting point and at its arriving point, when we can create a spatial picture of it : it is in an actual position, *it is in our Space*. In between, we cannot observe it, it is outside our Space, *in our Time*, where it is spread out over a multiplicity of possible positions and trajectories distributed along a probability wave, and can go through both slits at the same time.

Now the same experiment is performed again, but with a particle detector on each slit : on the screen the interference pattern disappears. The reason is simply that when one of the quantum objects interacts with one of the detectors it is spatialized in one determinate point, as a determinate particle : it is now a classical (spatial) object, with only one trajectory, it can no more go through both slits. In other words, *when detected, it enters the observer's Space*. *When not detected, it is in his Time,* where it follows all possible trajectories.

II.4. EPR effect+Relativity

It is now generally accepted that two entangled particles can communicate instantaneously whatever the distance between them (EPR effect).

Observing (physically interacting with) the first one results in its being found in one determinate state. Then the second one is always found in the orthogonal state. As incredible as it may be, the second one must instantaneously “know” in what state the first is.

In 2002 a strange experiment was performed at Geneva University (8) : it was the same EPR experiment with two entangled particles, but here the detectors, instead of being motionless, were moving at great speed relatively to each other so that, in accordance with Special Relativity, they were in two different reference frames. The result is that in reference frame 1, particle A was detected before particle B, and in reference frame 2, B was detected before A.

An entangled particle can “inform” its twin about its determinate state only if it is detected first. But here *we have two different reference frames, in each of which each particle is detected before the other, so that there is no “second” particle to be informed.* Nevertheless, the two particles are always found in orthogonal states, as Quantum Mechanics predicts. If there is some sort of communication between them, it is established not only outside Space, but also outside Time.

Causality itself is restricted to each reference frame : in reference frame 1, A is supposed to be the cause of B, and the opposite in reference frame 2. In each reference frame, there is a causal relation between A and B – but only in this reference frame. The two causal relations are mutually exclusive. There is no common causality. If the result of the observation is independent reality, whe have two different and incompatible independent realities : once again, the world is solipsist. If the world is realist, this means that we cannot know what happens in observer-independent reality itself : we can only know the point of view of each separate observer - his representation of independent reality.

Causality relations are temporal (A before B, B before A). Then temporal relations too exist only in each reference frame : there is no common Time for both. This confirms that there is no Time outside a reference frame, i.e. outside an observer : as said in (I.5), Time does not belong to reality but to its representation, there is no universal, observer-independent Time.

(8) *Experimental Test of Nonlocal Quantum Correlations in Relativistic Configurations*, H.Zbinden, J.Brendel, N.Gisiin, W Tittel, Physics Review A.63.022111. 2001.

Conclusion

Replacing the common conception of reality inherited from classical physics by a more precise one opens on a new understanding of Space and Time which, in turn, allows to construct an interpretation of Quantum Mechanics free of some of its alleged “oddities” - such an interpretation being only an extension of Copenhagen Interpretation.