Features, not waves!

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Classically, the main ontological attempts at understanding quantum mechanics focus on the corpuscular behavior of these systems and especially on detection events, since these are the most classical phenomena that we have in such a context (indeed, they also require the presence of a classical apparatus). The main trend has been to consider wave-like aspects as deprived of ontological substrate and as reflecting rather the mathematical abstract formalism of the theory. The few attempts that have been done in order to assign some form of ontological reference to wave-like aspects have tried to interpreted this in terms of classical waves and have been disproved across the last 30 years (see Auletta & Tarozzi, 2004b; Auletta & Torcal, 2011).

It is perhaps time to try a different approach, by renouncing any attempt at a classical ontology and by taking seriously into account the non-local aspects of the theory (which are mostly associated with wave-like phenomena). When we consider things in this perspective, we shall discover that all non-local phenomena in quantum mechanics, although different, have something in common: they all rely on non-local interdependencies among possible events or measurement outcomes (see Auletta, 2011). This is true for all interference phenomena for isolated systems, this is true for entangled systems, this is true for the Aharonov-Bohm effect, and so on. What is sad is that we do not have until now a name for denoting this mysterious reality. It is indeed mysterious, since we cannot directly measure it. There is in fact no way to have a direct experimental evidence of it. In most cases we can only reconstruct the interference profile after many experimental runs, a circumstance that has led many scientists to discard any ontological attribution to wave-like phenomena. However, a proposed

Gennaro Auletta, "Features, not waves!", in Isabella Tassani (a cura di), *Oltre la fisica normale. Interpretazioni alternative e teorie non standard nella fisica moderna*, pp. 19-23.

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experiment (Auletta & Tarozzi, 2004a) shows that this is not necessarily the case.

Nevertheless, although very mysterious, these interdependencies display certain effects. Let us consider the following example: suppose that the state of two particles is a singlet state (an instance of entanglement: see Auletta *et al*., 2009, Ch. 16). In such a case, they show a spin-correlation such that when one of the two particles is found to be in a spin-up state along an experimentally chosen direction, the other one will be necessarily in a spin-down state along the same direction or vice versa (that is, if the former is found in a spin-down state, the other one will be in a spin-up state). In other words, we expect to obtain either up-down or down-up but never up-up or down-down. If the world consisted of random events only, we would expect to obtain one of these four possible outcomes with equiprobability. The fact that we can obtain only two (either up-down or down-up) out of four cases represents a reduction of the space of possible events. In other words, quantum-mechanical correlations act as constraints limiting the space of the events that we can obtain (and therefore also the space of possible measurement outcomes). Now, it is bizarre to admit that something can have such effect without being somehow a reality.

Since a specific term for denoting this kind of reality does not exist (but neither a satisfactory theory) I shall use the term *features* (Auletta & Torcal, 2011) meaning two different things simultaneously:

- These factors are characters of quantum state that have noticeable and experimental consequences. Although they cannot be ascertained in themselves, we can be sure of their presence when for instance we compare the statistics of the systems in entanglement. If the results show the kind of reduction of the space of possible events that I have mentioned, we can infer that they are in fact present.
- However, I avoid the term *property* since properties are by definition local, while I have stressed that features manifest themselves precisely in non-local phenomena.

However, we need also to take seriously in account that we cannot do a direct experience with these features. It is a little like for the Kantian noumenon. If I am allowed to draw this analogy further, I can say that a correct ontology can only be a kind of phenomenal one, that, is an ontology that is always interpreted in the framework of a certain theory. On the contrary, the primary reality is in itself a piece of *uninterpreted* ontology. This might be true of features, but what is the situation for events? They seem to be much more real so that such a distinction between an interpreted and uninterpreted ontology seems not very insightful for dealing with our problem. I will certainly not deny that there is indeed an ontological difference between events (which by definition are localized in space and time) and features (which by definition are delocalized). However, there is a commonality that is much stronger than this difference.

We take for granted that detection events mean property-attribution to quantum systems. In fact, if a detector clicks, we can say e.g. that a particle is located in a certain region of the space. However, what we forget here is that we are allowed to make such an attribution only because the measured system has previously interacted with an apparatus (the so-called premeasurement: see Auletta *et al.*, 2009, Ch. 9) in such a way that, if a detector clicks, the established connection between object system and apparatus allows us to infer which property we may assign to the system in this experimental set up. Moreover, we can do this only because there is a theory (namely quantum mechanics) that describes this dynamics and therefore provides us with the formal or mathematical means to perform such an inference. In other words, we assign a property only in the framework of both an experimental context and a theory. Therefore, a property is a piece of interpreted ontology: one of the major worries about classical mechanics is to have misunderstood this point and to have taken properties as primary ontology beyond any interpretation. However, an event is a piece of uninterpreted ontology: an event only happens or occurs and tells nothing about anything else. In order to do this, we need the mentioned framework.

Therefore both events and features are pieces of uninterpreted ontology. However, events have properties as interpreted counterpart. Which is the interpreted counterpart of features? Only this would fully justify our parallelism between events and features. I must admit that it is not so straight to find an interpreted counterpart to features (here, their specificity is manifest). However, I have mentioned the necessity of an experimental context in order to be able to assign properties. If we analyze such a process with more care, we shall see that it has three main fundamental stages:

1) We *prepare* a system in a certain state. A preparation can be understood as a *determination* of the state of a single system. It is the procedure through which only systems in a certain (previously theoretically defined) state are selected and delivered for further procedures, that is, allowed to undergo subsequent operations (premeasurement and measurement). States are equivalence classes of preparations.

2) Then we select a certain observable (like position or energy) to be measured. This step is called *premeasurement*. It consists in an interrogation of a quantum system relative to a specific degree of freedom. Indeed, not all experimental contexts are adequate to measure a certain observable, and this allows us to define an observable as an equivalence class of premeasurements.

3) Finally, a *detection* or measurement in a strict sense is an answer to our interrogation of the object system. Therefore, we can say that a property is an equivalence class of detections (many different detections can lead to the same property attribution).

Events occur in the third step, whilst features are constitutive of the state as it is prepared in the first step. The second step is somehow the dynamical bridge initial and final procedure (it us indeed in this stage that system and apparatus interact). Then, we can say that properties are attributed thanks to *detection* events, that is, to events that happen in a specific experimental framework. On the other hand, features are inferred thanks to the *effects* that a system in a certain state has on the subsequent steps. Therefore, the whole of the experimental procedure (consisting in preparation, premeasurement and detection) is a sort of *operational* bridge between uninterpreted and interpreted ontology (it is here that the Kantian framework is no longer helpful but we need to shift to a operationalist philosophy). It is what ensures this distinction but also the connection between these two ontologies (and therefore also justifies the term *uninterpreted* ontology). In this way, events and features on the one hand, and detections and preparations on the other can be taken to really be part of the two mentioned ontologies.

References

The aim of the following list is to provide the reader with some original texts in which primary literature is also quoted.

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