Visualisation and Interpretation in Theories with and without a Spacetime

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Abstract

The debate over the indispensability of representing physical systems in space and time is an old one. Descartes already took extension to be one of the defining properties of matter, sharply contrasting the properties of the thinking substance. Theories of modern physics, especially quantum mechanics, have become increasingly abstract: and so, they are more difficult to visualise and to interpret. During the inception of quantum mechanics, there was an influential debate (cf. for example De Regt (2001)) about the *Anschaulichkeit* of the theory (its visualisability, and its intuitive-visual appeal): with Heisenberg's matrix mechanics being criticised for its lack of *Anschaulichkeit.* Schrödinger argued that his own wave mechanics was superior, because it allowed for spatial and temporal representations, which are necessary for grasping the phenomena.

Current theories of quantum gravity attempt to unify quantum mechanics with general relativity. In these theories, space and time may not be fundamental: for it is claimed that space and time are not part of the basic variables of the theory. If true, this form of a lack of *Anschaulichkeit* is more radical, compared to the earlier discussions. For the claim of the new theories of quantum gravity is that spacetime itself ceases to be a fundamental entity. This raises interpretative and philosophical questions, which have only started to be addressed in the literature. In particular:

(1) Can physical theories, in which space and time are fundamentally absent, be understood using conventional methods: as physical theories, but lacking a spacetime?
(2) How is spacetime reconstructed, and what epistemic role does its visualisation play in understanding the theory?

In this talk, I will briefly address the first question, and I will mostly focus on the second. I will argue that spacetime and visualisation, though not necessary to interpret such theories, are very important tools (they are 'contingently dominant' tools).

I will discuss how visualisation can be had, in theories which do not contain a spacetime at the basic level. I will also discuss how visualisation is used by physicists to interpret their theories. This is done through the derivation of 'effective spacetimes', namely spacetimes which do not appear in the theory at the basic level, but which can be derived in special limits of interest (De Haro and De Regt (2018)).

There are then two ways in which physicists use these effective spacetimes to interpret their theories:

(i) They develop a hermeneutic circle, of which the first step is to build an initial visual interpretation using the effective spacetime. In a second step, this initial interpretation is stripped of its spacetime connotations, to build a new interpretation.
(ii) The effective spacetimes can also be used to directly build novel spacetime interpretations, which provide a complete new level of understanding of the theory, and

thus are very helpful in calculation and reasoning that would be almost impossible without the visual methods.

Here I will concentrate on the second method. I will discuss three case studies that illustrate two different uses of visualisation: in the first example, physicists use 'Feynman' diagrams, in quantum field theory, to visualise a transition from one spacetime to another, thus making possible calculations and reasonings that were inaccessible without the visualisation of the new spacetime.

The second example will be random matrix models, which are purely algebraic models consisting of matrices. These models develop a curved space in a certain limit (the so-called ''t Hooft limit'). The visualisation in spacetime is then again used to give a new interpretation to the theory, which can be used for computation.

The third example will be the holographic principle for gravity theories (for an introduction, see Bekenstein (2007)). Here we have a case of theoretical equivalence between two theories:

(i) A gravitational theory in a curved spacetime, which is formulated using the tools of geometry.
(ii) A non-gravitational theory in a flat spacetime of one fewer dimension (hence the name 'holographic').

The claim that physicists make is that these two theories are equivalent because they 'contain the same information'.

The question is then how the hologram encodes the geometric information about the extra dimension, and how the hologram can be used for calculations and reasonings that are otherwise almost impossible to perform. I will discuss how such a hologram can encode non-trivial geometric information, and the sense in which these theories are theoretically equivalent. Namely, the two theories are equivalent representations of a single common core of quantum information (De Haro (2016)). This would suggest that quantum information is the more fundamental concept, and that visualisation is part of the interpretation of that information.

References

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