Internship proposal: Compositionality in the presence of symmetry in quantum physics, and quantum reference frames

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Background

Recent years have seen considerable progress in the reformulation of fundamental physical concepts in informational terms, building on the perspective and techniques of the field of quantum information [1, 2]. A recent development has been the introduction of *sectorial constraints*, that encode the fact that certain operations cannot connect between some sectors (i.e. orthogonal subspaces) of their input and output spaces. This typically happens in the presence of conservation laws (and therefore in the presence of symmetries). An extended informational framework, called 'routed quantum circuits' has recently been introduced to describe and analyse physical situations in which sectorial constraints come into play [3, 4, 5].

The project

For a given symmetry (say, translation-invariance), imposing it on two systems A and B individually is usually not the same thing as imposing it on the global system AB as a whole: this amounts to a *compositionality problem* in the theory of constrained systems, that forms the core root of a certain number of paradoxes and counter-intuitive effects. Due to its structural flavour, the framework of sectorial constraints and routed circuits might be the right tool to solve this issue by properly formalising how compositionality works in constrained systems.

A particularly promising area of application would be *quantum reference frames* [6, 7], a novel and active research area that asks the question of what it would mean to describe physics with respect to the reference frame of a (potentially superposed) quantum object (see Figure 1). This is achieved by imposing translation-invariance on these systems in a particular way. The goal is to move towards a more relational account of physics, that would pave the way towards quantum gravity. In this field, people are faced with a 'paradox of the third particle' [8, 9, 10]: adding new objects to the description leads to paradoxical effects. The paradox

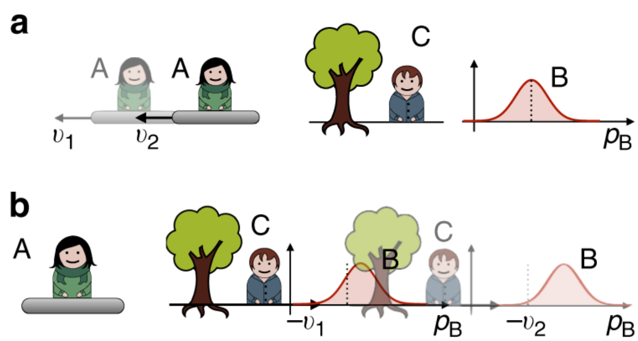

Figure 1: Illustration of the concept of descriptions relative to quantum reference frames (taken from [6]). In the first line, we see the description relative to C, in which A is in a superposition and B in a Gaussian state; in the second line, we see the description relative to A, in which the states of B and C appear entangled.

of the third particle is one avatar of the tension between symmetry (in this case, translation-invariance) and compositionality. Resolving the latter would thus provide a clarification of the significance of this paradox. Other potential areas of application include the recently proposed del Santo-Dakić protocol [11] (related to particle number conservation), and the Aharonov-Bohm protocol [12] (related to charge conservation).

The aim of the project is therefore to build a framework that would formalise compositionality for quantum systems in the presence of symmetries, using routed quantum circuits, and to apply it to the study of these concrete cases. This will typically start with considering simple situations, before building up to a general framework. The specifics of the project will be determined in conjunction with the intern, so please reach out if you are interested.

Location

The internship will take place at Télécom Paris in the Quriosity team, supervised by Augustin Vanrietvelde. Quriosity brings together physicists and computer scientists to explore the fundamental informational aspects of quantum theory.

References

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