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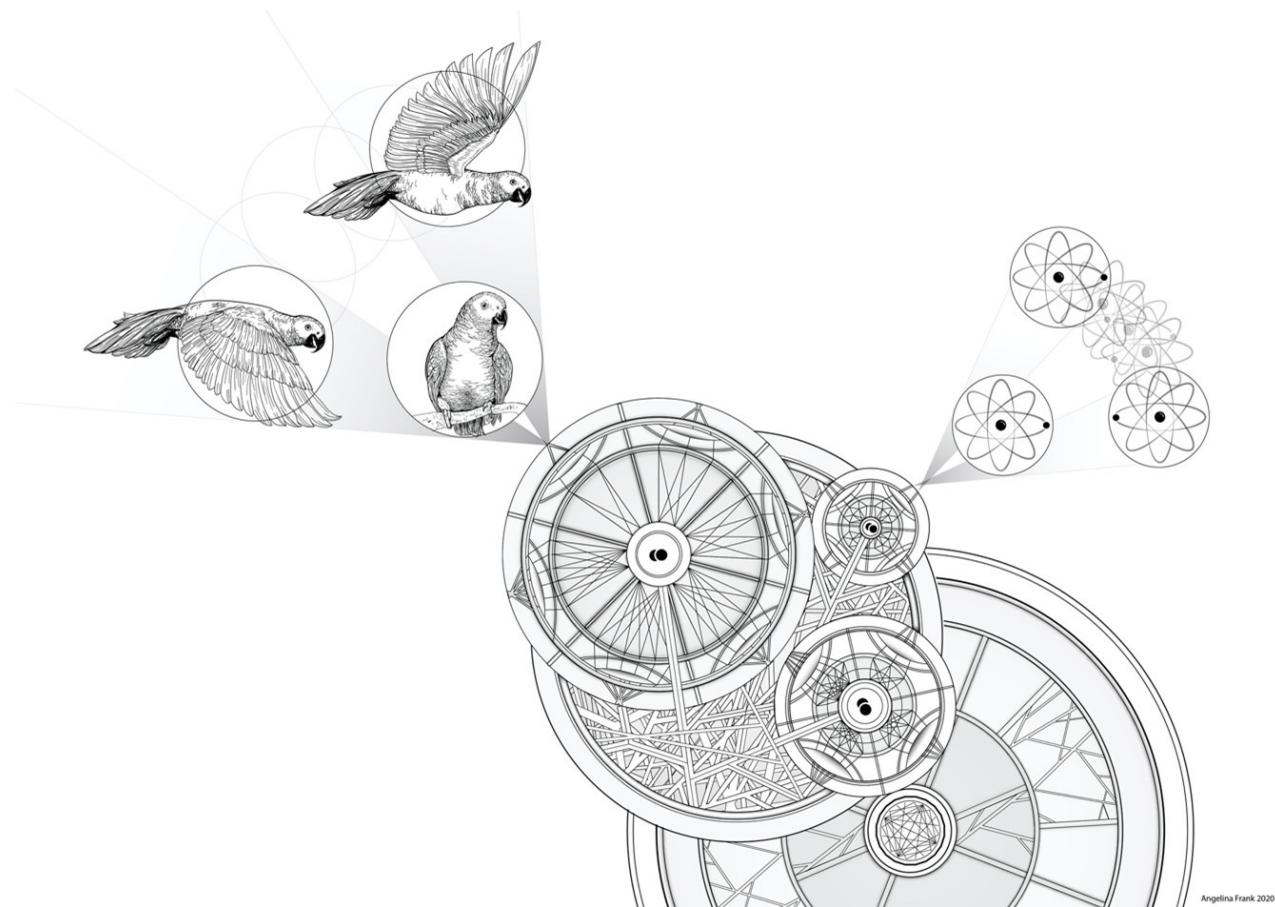
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## A pervasive issue in contemporary physics : hybrid systems.

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In the traditional conception of physics, we usually rely on dynamical laws to make predictions: specific dynamical constraints that tell us what *happens* in the universe in space and time. But there are domains where the current laws are expected to break down.



An important case is that of **hybrid systems**: where a quantum system (for instance, a qubit) interacts with another system that may not fully obey quantum theory, or whose dynamical trajectories are so complicated that they cannot be computed exactly. A notorious example of the former case is **gravity**: we have several inequivalent formulations of a quantum theory of gravity, but the best theory of gravity that we possess at present is still Einstein's general relativity, which is not quantum at all. General relativity says that spacetime curves according to where a mass is; but if a mass is quantum, it can be in two locations at the same time, and this breaks the structure of general relativity. This is why we are uncertain about how to treat a hybrid system made of a quantum mass in a superposition of different locations with a univocal dynamical law. And constructor theory can help with this problem.

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Another example (of the second kind of hybrid systems) is a **macroscopic system** with lots of degrees of freedom (e.g. a living cell or even a cat!) interacting with a small qubit. Such systems have been key to thought experiments like Schrödinger cat, but their dynamics may be intractable.

So how do we make predictions in these cases?

Theories of principles, such as constructor theory, come to the rescue. This is because they do not rely on specific laws of motion, but they are more general than them: they constrain laws of motion, those that are known and those that are yet to be known.

Hybrid systems have been occasionally treated in the past with a principle-driven approach: if you are in for some physics details, you can look up Wheeler and Bondi's derivation of gravitational red-shift from the equivalence of mass and energy; DeWitt's and Feynman's arguments for quantising gravity; Einstein's well-known derivations in the theory of relativity; Hawking's and Bekenstein's thermodynamic analysis of black holes.

In fact, the logic of principles underlies the branch of physics called thermodynamics. In existing thermodynamics, the principles only hold at a macroscopic scale. The laws of thermodynamics can be derived from microscopic dynamics using statistical mechanics, but this leads to approximate, probabilistic laws that remain inadequate to describe microscopic systems. Constructor theory can solve this problem as its principles are scale-independent: they hold at all scales, not just at the microscopic or at the macroscopic scale. These principles can describe the thermodynamic laws of qubits, macroscopic objects, and systems where the two interact. We therefore expect constructor-theoretic principles to be formidable tools to deal with hybrid systems.

## Principles in constructor theory

## Interoperability of information

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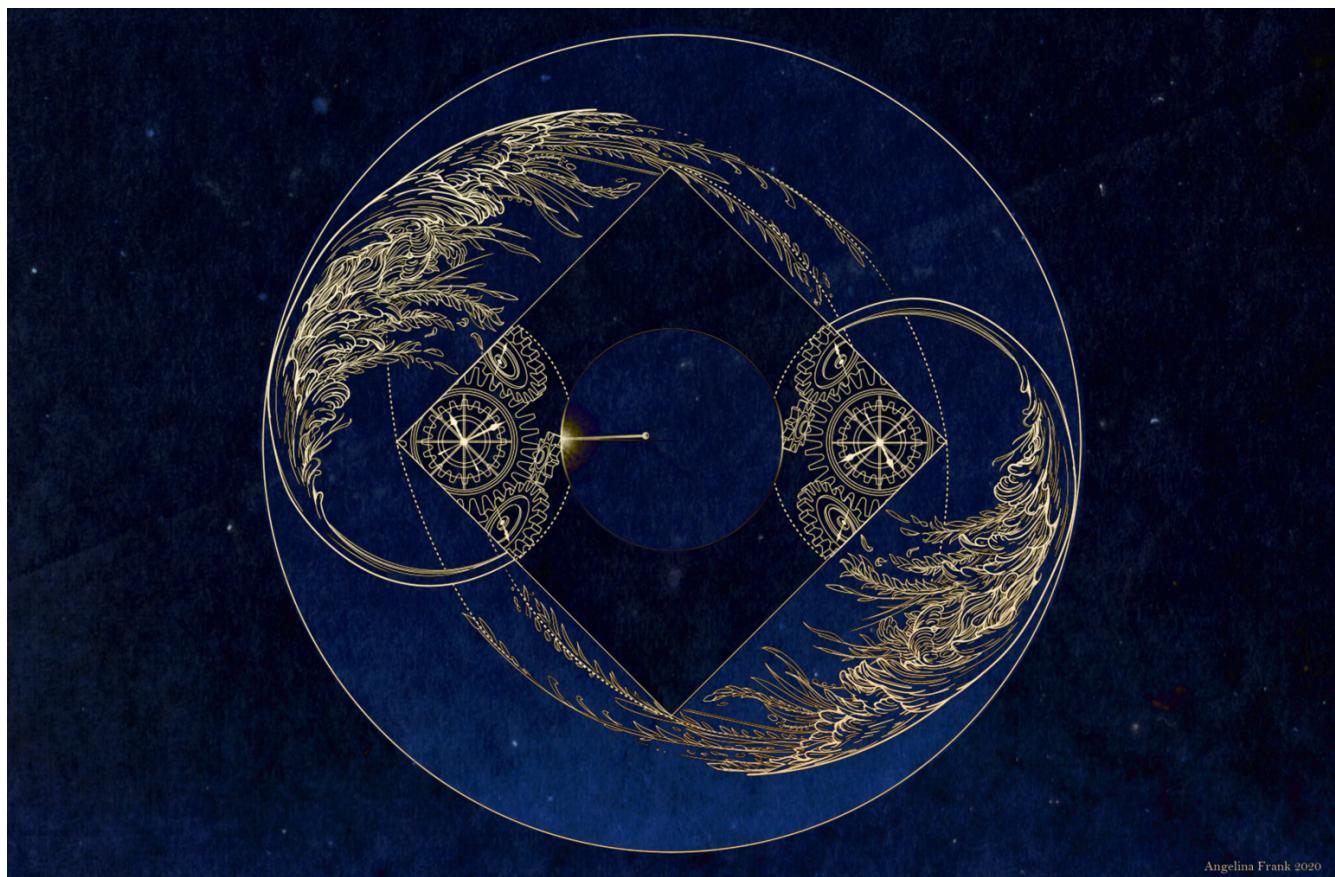
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Two systems that each can behave like an information medium with a given capacity (say, each is a bit), and when considered jointly still behave like an information medium, of larger capacity (two bits worth of information).

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*Important feature:* to formulate the principle you don't need to assume any specific dynamical framework or a specific scale. The principle is **scale**- and **dynamics**-independent. Compare this with the case of the no-cloning theorem in quantum information, where you need to assume quantum theory's laws of motion in order to prove it; or for example the second law of thermodynamics in one of the traditional formulations, where it is necessary to assume a macroscopic scale for it to be applicable.



**Principle of locality (or no action at a distance)**





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Given a partition into subsystems A and B, a transformation that acts on A *only* cannot change B.

*Important note:* The principle of locality is a pillar of both of our fundamental theories of physics: general relativity and quantum theory. Note the misleading, unfortunate terminology related to "Bell-type non-locality", which is used to indicate particular kinds of correlations that arise in entangled systems. Despite prevalent misconceptions, these quantum correlations perfectly satisfy (<https://doi.org/10.1098/rspa.2000.0585>) the principle of locality!

A remarkable application (<https://doi.org/10.1103/PhysRevLett.119.240402>) of these two principles is a recently proposed (<https://journals.aps.org/prd/abstract/10.1103/PhysRevD.102.086012>) **witness of non-classicality** to check if a hybrid system (which may or may not obey quantum theory) has itself some quantum features<sup>1</sup> (<https://www.constructortheory.org/applications.html#fn1>). It is based on the fact that if the principles of locality and interoperability hold, then one can conclude the following: if a system M can entangle two quantum systems Q and Q', then M must be itself non-classical.

This means it must have one of the basic features of quantum systems. Namely, the Heisenberg CONSTRUCTOR THEORY [\(https://www.constructortheory.org/\)](https://www.constructortheory.org/) principle is based on two of its variables, which must behave just like position (<https://www.constructortheory.org/>) and energy (<https://www.constructortheory.org/>) for an electron (<https://www.constructortheory.org/>). You can determine one with certainty, you cannot determine the other, and vice-versa. This is an exciting application of constructor theory, which underlies a recently proposed experiment to test quantum effects in gravity. This test also Research (<https://www.constructortheory.org/research/>) indirectly tests constructor theory's interoperability principle, because it is based on it. For example, if you could create entanglement despite having a classical object as a mediator, it would mean that either the interoperability law or locality are falsified. About Us (<https://www.constructortheory.org/about-us/>)



1. For further information about the tests to witness non-classicality in gravity, see: Marletto and Vedral (2017) (<https://doi.org/10.1103/PhysRevLett.119.240402>) Bose et al. (2017) (<https://doi.org/10.1103/PhysRevLett.119.240401>) Contact (<https://www.constructortheory.org/contact>) Illustrations by Angelina Frank (2020)

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## Constructor Theory

Constructor Theory is a new approach to formulating fundamental physics. This research is being conducted with support from the Templeton World Charity Foundation, the John Templeton Foundation, the FQXi, and the Eutopia Foundation.

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