CONSTRUCTOR THEORY (https://www.constructortheory.org)

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Frequently Asked Questions

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Q1. How can one test constructor theory?

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Constructor theory is a ‘theory of principles’. A principle in this sense is a law about laws, not directly about physical objects. Familiar examples in current physics are the principle of equivalence in relativity, the principle of locality, and the principle of conservation of mass in pre-relativistic physics.

Testing a theory always needs there to be at least one rival theory, otherwise the best explanation for the failure of a test is simply ‘experimental error’ etc. When there are rival theories making different predictions about measurable quantities, a crucial test can be performed and the ones making false predictions can be tentatively discarded.

Testing a principle is similar, but at one step removed: again at least two rival principles are needed. The way one tests them is to first deduce predictions from *rival* laws conforming to each of them. Then, one tests that prediction. For example: the principle of energy conservation has important implications for models describing a skier sliding down a mountain slope. One can then take two models that describe the skier’s motion: one, e.g. Newton’s laws, obeys the principle of conservation of energy. The other, does not: for instance, it predicts that the skier ends up having more kinetic energy at the bottom of the slope than it had potential energy at the top. Then, one performs an experiment with an actual skier, to test one model against the other. So far, all experiments testing models that predict spontaneous creation of energy have been refuted.

Principles in constructor theory are tested in the same way. For instance: the principle of *interoperability of information* requires that the composite system of two information media is also an information medium. This implies that certain transformations are possible on the composite system, irrespective of the details of their dynamical laws. As in the previous example, for the test we need two rival models describing the composite system of two information media. One model could predict that the principle is not obeyed, for instance because the two systems can only imperfectly interact with each other, in a way that for example perfect copy-like operations are not allowed. Confirming the prediction of one or the other model would test the interoperability principle of information. The same holds for the other constructor-theoretic principles.

Q2. Is constructor theory 'anthropomorphic' (meaning, it refers to machines that look all too humans) or 'anthropocentric' (meaning, it appears to give humans a privileged position in physics explanations)?

No – and there are a number of reasons. The main one is that (despite the name) constructor theory's laws are NOT about constructors. They are about stating what tasks are *possible* and what are *impossible*. A task is impossible if it cannot be performed to arbitrarily high accuracy, with no other side-effects; it is possible otherwise. These are counterfactual statements – about what could or could not be made to happen on a physical system.

So when is the idea of a constructor needed? We need to appeal to a 'constructor' in order to explain what it means for a task to be *possible*, *in the traditional conception*. An approximate constructor for the task T to be performed to accuracy epsilon refers to the part of the environment of a given physical system that is necessary and sufficient for the task to be performed to that accuracy. When the task is possible, one can find approximate constructors for any arbitrarily high accuracy. In the limit of perfect accuracy, or zero errors, the constructor works in a perfect cycle: it delivers the task and retains the ability to cause it again. It is important to say that constructors are not necessarily machines made by humans: chemical catalysts and enzymes are examples of constructors as much as heat engines and computers are. But, as we said, constructor theory isn't about describing the behaviours of these entities.

The logic to formulate the laws in constructor theory is the same as in thermodynamics: for instance, the law of conservation of energy states that certain constructors are impossible (e.g. specifically: perpetual motion machines of the first kind). Out of this statement one can then derive a number of predictions, *without* ever referring to any specific perpetual motion machine. Likewise, in constructor theory we don't need to specify the details of the constructors that are associated with a possible task. We only state that the task is possible (or impossible) and derive consequences from that statement. So in that sense constructors are not at all at the foundations of the laws, not any more than they are in quantum computation or in thermodynamics. Constructor theory, however, aims at generalising the logic of these two branches of physics to other fields, at the same time also improving on the laws in those two fields themselves.

An unexpected bonus of switching to counterfactuals is that in constructor theory we can talk objectively about *additional* entities (such as knowledge or information) that traditionally are considered anthropocentric or subjective. This is because for example information is defined implicitly by the concept of information medium – a system with a set of states on which all permutations and also the copy-like task are *possible*. Likewise, knowledge is information that is capable of remaining embodied in physical systems. Nothing in these definitions appeals to an observer or a knowing subject. In this sense, constructor theory is superior to the traditional conception of physics because it can handle these concepts on objective grounds, while the traditional conception cannot.

Q3. How does Constructor Theory differ from the framework of Resource Theories?

Constructor theory and the resource theories framework differ in *motivations* and *content*. A resource theory expresses the content (or part of the content) of existing theories, such as thermodynamics, classical or quantum computation, etc., in terms of three kinds of thing: (i) the *free operations* – that is, operations which can be used without limitations; (ii) the *resources*, i.e. the remaining operations, considered expensive; and (iii) the *free states*, or non-resources.

The aim is to extract, and conveniently to systematise, *implications* of the theory to address *operational issues* such as: According to that theory, which resources can be converted into which others by the free operations? What are the ways in which a given conversion can be accomplished? Can these conversions happen under various constraints, e.g.: deterministically, stochastically or when a catalyst (i.e. a resource which is not consumed in the process) is present? What are suitable measures of the quality of a resource? For instance, the resource theory of *asymmetry* in quantum theory (where the resources are quantum states and operations violating the symmetry) can categorise constraints arising from symmetries, such as selection rules in atomic physics, Noether's theorem, etc.

A general, category-theory based formalism for resource theories has recently been proposed encompassing the existing resource theories (of *athermality*, of *asymmetry*, of *non-uniformity*, etc. [1] (https://www.constructortheory.org/info-FAQ.html#fn1)). This formalism could be called 'resource theory' itself, as distinct from theories of particular resources under particular existing theories.

Thus resource theory, and resource theories, derive their entire content about the physical world from the existing theories that they are resource theories of. They have no pretentions (as Lovelace would say) to originate anything. They have neither eyes to see nor tongue to speak (as Lenthall would say) except as those theories are pleased to direct them.

Constructor theory does. It not only intends to reformulate existing theories (in terms of possible/impossible tasks only); it contradicts some existing theories (such as non-local variants of quantum theory) and also makes assertions about the physical world in *addition* to those implied by existing theories. For example, the constructor-theoretic expression of the First Law of Thermodynamics implies that the energy of a constructor is bounded below and above. Also, constructor theory demands a *local, deterministic* structure in physical theories – while resource theory is agnostic about this issue. Indeed, while in resource theories there are many notions of 'performable transformation' (including stochastic ones) in constructor theory a task being *possible task* can only mean that a constructor for it can be built, with arbitrary accuracy and reliability.

Thus, while the *resource theory of athermality* takes notions such as thermal states, heat baths, temperature and equilibrium as they are defined in thermodynamics, the *constructor theory of thermodynamics* (forthcoming), aims at explaining what 'temperature', 'thermal states', 'work', etc. mean *physically*, in terms of regularities of the underlying laws, expressed *exclusively via possible/impossible tasks*; and at improving on the existing formulations of thermodynamics, making them exact, and not approximate.

Similarly, *a quantum resource theory* takes as given the entities such as 'observables', 'distinguishability', 'information', etc, as they are defined in quantum theory. The *constructor theory of information* instead is about formulating what tasks the laws of physics must permit or forbid (i.e., make possible or impossible) for those entities to exist; and it contains *new principles* about those that do not follow from quantum theory, but are conjectured new laws. They precisely describe entities and processes in nature (such as information and computation, measurement and distinguishability) that in the prevailing conception can only be understood as emergent phenomena, or in vague, informal ways. Fundamental theories formulated in the prevailing conception do not (and cannot) refer to those entities at all; nor can reformulations of them, such as resource theories – no matter how general they are. Constructor theory accommodates those entities exactly, and explains them.

1. "A mathematical theory of resources", B. Coecke, T. Fritz, and R. Spekkens, http://arxiv.org/abs/1409.5531 (https://www.constructortheory.org/%E2%80%9D%E2%80%9D))

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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.

Contact Us

Wolfson College
OX2 6UD
University of Oxford

contact@constructortheory.org
(mailto:contact@constructortheory.org)

(http://www.ox.ac.uk/)

(http://www.templetonworldcharity.org

(https://eutopiafoundation.org/)

(https://fqxi.org/)