Leibniz space-times

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More often than not, Lee Smolin's essays are engaging and thought provoking. I specially appreciate his willingness to tackle conceptual issues, often dismissed as philosophical or uninteresting by a great deal of the physics community (which, in my opinion, should know better). Also of note are his efforts to convey to non-specialists the key ideas and problems faced by modern physics, without unduly over-simplifications or dishonest hype.

A case in point is his recent essay The Case for Background Independence, where the meaning, virtues and drawbacks of relationist theories of quantum gravity are explored in detail. More concretely, Smolin describes the close relationship between three key issues in fundamental physics, to wit:

- Must a quantum theory of gravity be background independent, or can there can be a sensible and successful background dependent approach?
- How are the parameters of the standard models of physics and cosmology to be determined?
- Can a cosmological theory be formulated in the same language we use for descriptions of subsystems of the universe, or does the extension of physics from local to cosmological require new principles or a new formulation of quantum theory?

The article begins with a brief historical review of relationism, as understood by Leibniz and summarized in his principles of sufficient reason (there's always a rational cause for Nature's choices) and the identity of the indiscernible (entities with exactly the same properties are to be considered the same) [1]. These principles rule out absolute space-times (like Newton's) or a fixed Minkowskian background (like perturbative string theory), since they single out a preferred structure 'without reason', as do theories posing any number of free parameters (think of the much debated *landscape*) [2]. As is well known, Newton won the day back in the seventeenth century, until Mach's sharp criticism marked the resurgence of relationist ideas. Mach rejected Newtonian absolute space-time, favouring a purely relational definition of inertia [3], which ultimately would inspire Einstein in his quest for the general theory of relativity [4].

Smolin's article continues with a careful definition, in modern terms, of relational space and time, and follows with a discussion of some current theories featuring background independence: general relativity, causal sets, loop quantum gravity, causal dynamical triangulation models and background independent approaches (by Smolin himself) to M-theory. In a nutshell, it is argued that any self-respecting relational theory should comply to three principles:

- There is no background.
- The fundamental properties of the elementary entities consist entirely in relationships between those elementary entities.
- The relationships are not fixed, but evolve according to law. Time is nothing but changes in the relationships, and consists of nothing but their ordering.

None of the theories above passes without problems this litmus test of pure relationsm. Take for instance general relativity. To begin with the dimension, topology and differential structure of space-time are givens, and thus play the role of a background. And, on the other hand, only when we apply GR to a compact universe without boundary can we aspire to a relational view, since otherwise we would have arbitrary boundary conditions (partially) determining the structure of space-time. Once you abide to these preconditions, a proper interpretation of general covariance (in which you identify space-times related by arbitrary coordinate transformations) provides a relational description of space-time (for an in-depth discussion of the subtle interplay between gauge invariance and relationsm, see also this excellent article by Lusanna and Pari, and references therein). As a second example, loop quantum gravity is also background dependent: in this case, the topological space containing the spin-networks of the theory. Other than that, loops are an almost paradigmatic case of a relational description in terms of graphs, with nodes being the *entities* and edges representing their relationships.

After his review of quantum gravity theories, Smolin takes issue with string theory. His subsequent train of thought heavily relies on the fact that relationism, or, more concretely, Leibniz's principle of the indiscernible, rules out space-times with global symmetries. For if we cannot distinguish this universe from one moved 10 feet to the left, we must identify the two situations, i.e., deny any meaning or reality to the underlying, symmetric structure. But, as is happens, the M-theory programme consists, broadly speaking, in maximizing the symmetry groups of the theories embodied in the desired unified description. More concretely, in background-dependent theories, the properties of elemental entities are described in terms of representations of symmetries of the background's vacuum state. Each of the five string theories embodied by M-string (should it exist!) has its own vacuum, related with each other via duality transformations (basically, compactifying spatial dimensions one way or the other one is able to jump from one string theory to the next). Thus, M-theory should be background independent (i.e., encompass different backgrounds), but, on the other hand, one expects that the unique unified theory will have the largest possible symmetry group consistent with the basic principles of physics, such as quantum theory and relativity. Smolin discusses some possible solutions this contradiction (which a lack, er, background to comment intelligently), including some sort of (as yet unknown) dynamical mechanism for spontaneous symmetry breaking (which would result in a Leibniz-compliant explanation for the actual properties–such as masses and coupling constants–that we find in our universe).

After all the fuss, there is disappointingly little to be said about relationist unified theories [5]. Invoking again the principle of the indiscernible, Smolin rules out symmetries that would make (unified) identities undistinguishable (if two entities have the same relationships with the rest, they are the same entity). By the same token, a universe in thermal equilibrium is out of the question. Reassuringly, our universe is not, and the negative specific heat of gravitationally bound systems precludes its evolution to such an state. The case is then made (after casting evolution theory as a relationist one, which is OK by me) for Smolin's peculiar idea of cosmological *natural selection*. To my view, it is an overly speculative idea, if only for the fact that it depends on black holes giving rise to new universes when they collapse [6]. If that were the case, and provided that each new universe is created with random values for the free parameters of our theories, one would expect that a process similar to natural selection would lead to universes with its parameters tuned to favour a higher and higher number of black-holes (which seems to be the case in our universe). Nice as the idea is, i think we're a little far from real physics here.

The article closes with a short section on the cosmological constant problem (with the interesting observation than only casual set theory has predicted so far a realistic value) and relational approaches to (cosmological) quantum theory. Again, the author adheres to non-orthodox ideas. This time, to recent proposals (see here and here) of hidden-variable theories, albeit they have far better grounds than the reproducing universes idea. The possibility of a relational hidden-variable theory is argued for with a simple and somewhat compelling line of thought. In classical physics, the phase space of a system of N particles is described by a 6N variables, while a quantum mechanical state vector would depend on 3N variables. On the other hand, in a purely relational theory one would need to use N^2 variables, as these are the number of possible relations between N particles. These would be the hidden-variables completely (and non-locally) describing our particles, which would need statistical laws when using just 3N parameters.

An amazing journey, by all accounts.

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[1] See here for excellent (and free) editions of all relevant Leibniz works, including his Monadology, and here for commented excerpts of the Leibniz-Clarke correspondence.

[2] See also here for an interesting take on Leibniz's principle under the light of Gödel's and Turing's incompleteness theorems as further developed by Gregory Chaitin.

[3] Julian Barbour's "The Discovery of Dynamics: A Study from a Machian Point of View of the Discovery and the Structure of Dynamical Theories" is the definitive reference to know more about the history of the absolute/relative divide. (Another amazing book by Barbour on these issues is "The End of Time : The Next Revolution in Physics", thoroughly reviewed by Soshichi Uchii here. Smolin himself has many an interesting thing to say about Barbour's timeless Platonia.)

[4] Barbour argues in his book that Einstein seems to have misunderstood Mach's discussions on the concept of inertia, taking it for the dynamical quantity entering Newton's second law instead of the inertial motion *caused* by

space-time according to Newton's *first* law.

[5] I'm also a bit surprised by Smolin's uncritical acceptance of reductionism, which he simply considers, "to a certain degree", as common-sense.

[6] Tellingly, the only reference where this *theory* is developed is Smolin's popular science book "The Life of the Cosmos".
