Title: Does Time Emerge from Timeless Laws, or do Laws of Nature Emerge in Time?

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Abstract: The history of physics, from Galileo's spatialization of time to Einstein's block universe, and on to Julian Barbour's timeless quantum cosmology, tells a story by which time is demoted from a fundamental aspect of experience to an emergent illusion in a world held to be fundamentally timeless. The question I would like to address is, is this correct, or will the next stage in the development of physics require a rediscovery of time as a primary aspect of nature? One reason to bet on the reality of time is the strength of the argument of Pierce that laws of nature require explanation and that laws must evolve to be explained. This implies that time is prior to law, which means time cannot emerge from timeless law. This however raises a problem: is the evolution of law lawful? Are all laws effective and approximate? Is there a metalaw which governs the evolution of laws? If so, what selects the metalaw? One approach to this meta-laws dilemma is that the distinction between dynamical laws and the states they act on, which is absolute in most physical theories, is emergent. I present a simple model to illustrate this approach. This talk is partly based on joint work with Roberto Mangabeira Unger.

Some talks at this workshop assume that emergent phenomena emerge from non-emergent, exact, laws of physics. They seem to assume an absolute distinction between emergent and fundamental laws.

- Emergent phenomena:
  - Novel, surprising, contingent, robust, protected, at large scales. Common in several systems with different microphysics.
  - Cannot be derived from fundamental theory or described in the language of a fundamental theory.

- Emergent law: A law which applies only to an emergent phenomena.

- Fundamental law: timeless, completely general law applicable to the elementary particles and forces.

But is the distinction between fundamental and emergent laws absolute?

My motivation is that I am interested in what is not explained when we know what the fundamental laws are.

- The problem is that once you have posited the fundamental laws you still have not answered some of the most interesting questions that can be posed about nature:
  - Why these laws?
  - Why these initial conditions?

Reductionism works to reduce properties of composite systems to fundamental particles. But it is of no help when we ask for an explanation of the properties of the fundamental particles themselves.

The why these laws problem arises from the Newtonian paradigm for physical theories:

- Define a system, S, generally a subsystem of the universe.
- There is a timeless state space, C, containing the possible states of S.
- A timeless law, H, acts on C to define the evolution of states.
- There is an absolute distinction between states and laws.
- This reflects the operational distinction between general laws and initial conditions which is realized by doing experiments repeatedly with different initial conditions.

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If the Newtonian paradigm applies to cosmology then time is emergent from law.

- The block universe of general relativity (GR): what is real is not the present moment or the passage of time but the entire history of the universe. Our experience of the present moment and the passage of time is an illusion.

- Any physical observable in GR can be written as a function of the initial conditions.

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Once Einstein said that the problem of the Now worried him seriously. He explained that the experience of the Now means something special for man, something essentially different from the past and the future, but that this important difference does not and cannot occur within physics. That this experience cannot be grasped by science seemed to him a matter of painful but inevitable resignation.

I remarked that all that occurs objectively can be described in science; on the one hand the temporal sequence of events is described in physics; and, on the other hand, the peculiarities of man's experiences with respect to time, including his different attitude towards past, present, and future, can be described and (in principle) explained in psychology.

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However the Newtonian paradigm cannot be applied to cosmology without giving up the demand for explanation of the choice of laws and initial conditions.

- The choice of laws and initial conditions are input to the Newtonian paradigm. Hence, they cannot be output.

- The operational distinction between laws and initial conditions breaks down when applied to cosmology because there is only one system with one history.

- GR has an infinite number of solutions. At most one applies to our universe. Hence GR extravagantly over performs the job of being a cosmological theory as it makes predictions for an infinite number of cases that are never realized.

How can we have a scientific (ie falsifiable or strongly verifiable) solution of the why these laws problem?

To suppose universal laws of nature capable of being apprehended by the mind and yet having no reason for their special forms, but standing inexplicable and irrational, is hardly a justifiable position.

Uniformities are precisely the sort of facts that need to be accounted for. Law is par excellence the thing that wants a reason.

Now the only possible way of accounting for the laws of nature, and for uniformity in general, is to suppose them results of evolution.

C. S Pierce, 1892

The metalaw dilemma:

- Pierce says laws must evolve to be explained. The sufficient reason for a law cannot be logical so it must be dynamical and historical.

- But what governs the evolution of laws?

- Either the evolution of laws is governed by a law in which case we have to ask, Why this meta-law? So we still lack sufficient reason for laws.

- Or the evolution of laws is lawless, in which case we again lack sufficient reason for laws.

Towards a resolution of the metalaw dilemma.

• Metalaw universality: the metalaw satisfies some simple criteria and any metalaw satisfying those criteria generates an equivalent evolution of laws.

•Breakdown of the distinction between law and state. There is just a single metastate, from which state and law both emerge for limited times.

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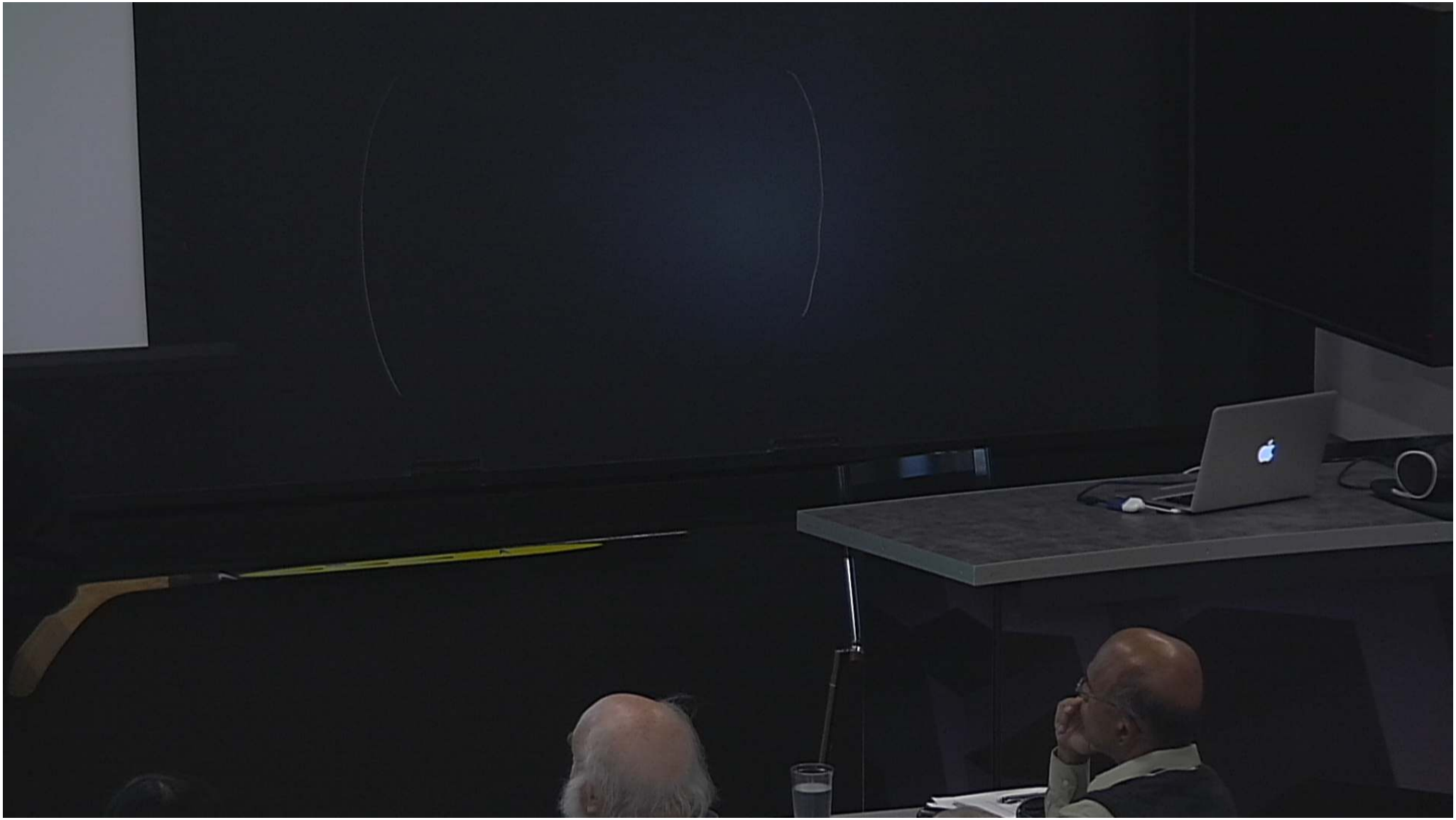
A toy model to study the emergence of the separation between law and state.

- The meta state is a large antisymmetric matrix of integers.

$$(X_n)_{ab} = -(X_n)_{ba}$$

It could be the adjacency matrix of a directed labeled graph.

- The metalaw is simple update rule.



Criteria for the update rule.

- Second order. $X_n = \mathcal{F}(X_{n-1}, X_{n-2})$
- Stability. $X = \mathcal{F}(X, X)$
- Non-linear, but minimally so, because non-linear equations can always be reduced to quadratic by inventing auxiliary degrees of freedom.
- The linear part is time reversal invariant.

These lead to a unique update rule:

$$X_n = 2X_{n-1} - X_{n-2} + [X_{n-1}, X_{n-2}]$$

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Quasi hamiltonian evolution.

- Define the "hamiltonian" at time n by

$$H_n = X_{n-2}$$

- Define the "state" at time n by

$$\rho_n = X_n - X_{n-1}$$

- The rate of change of the "state" is

$$\Delta\rho_n = \rho_n - \rho_{n-1} = \Delta^2 X_n$$

- The evolution rule can then be written as:

$$\Delta\rho_n = [\rho_{n-1}, H_n]$$

- **Consider the "Mathematical Universe Hypothesis" of Tegmark.**

There is a mathematical object O isomorphic to the history of the universe in the sense that every true property of the universe has a corresponding true statement about that mathematical object. This implies that every true property of the universe is deducible by logical implication from the definition of O.

O plus the isomorphism map is the fundamental theory. Therefor there can be no phenomena in nature not derivable from the fundamental theory.

- **Does the existence of emergent phenomena described only by emergent laws contradict the hypothesis that the universe is isomorphic to a mathematical object? Does the existence of biology disprove Tegmark's hypothesis?**