Title: On the reality of time and the evolution of laws

Date: Oct 02, 2008 11:45 AM

URL: http://pirsa.org/08100049

Abstract: There are a number of arguments in the philosophical, physical and cosmological literatures for the thesis that time is not fundamental to the description of nature. According to this view, time should be only an approximate notion which emerges from a more fundamental, timeless description only in certain limiting approximations. My first task is to review these arguments and explain why they fail. I will then examine the opposite view, which is that time and change are fundamental and, indeed, are perhaps the only aspects of reality that are not emergent from a more fundamental, microscopic description. The argument involves several aspects of contemporary physics and cosmology including 1) the problem of the landscape of string theory, 2) cosmological inflation and the problem of initial conditions, 3) the interpretation of the â€œwavefunction of the universe,â€• and the problem of what is an observable in classical and quantum general relativity. It also involves issues in the foundations of mathematics and the issue of the proper understanding of the role of mathematics in physics. The view that time is real and not emergent is, I will argue, supported by considerations arising from all these issues It leads finally to a need for a notion of law in cosmology which replaces the freedom to choose initial conditions with a notion of laws evolving in time. The arguments presented here have been developed in collaboration with Roberto Mangabeira Unger .

The reality of time and the evolution of laws of nature

Lee Smolin
Perimeter Institute
Work in progress with Roberto Mangabeira Unger
October 2008

With thanks to Julian Barbour, Harvey Brown, Jim Brown, Stuart Kauffman, Jaron Lanier, Patricia Marino, Fotini Markopoulou, Steven Savitt, Neal Stephenson, Steve Weinstein

*To suppose universal laws of nature capable of being apprehended by the mind and
et having no reason for their special forms, but standing inexplicable and irrational,
: hardly a justifiable position. Uniformities are precisely the sort of facts that need to
e accounted for. Law is par excellence the thing that wants a reason. Now the only
ossible way of accounting for the laws of nature, and for uniformity in general, is to
ıppose them results of evolution."*

Charles Sanders Peirce (1893):

Roberto Mangabeira Unger:

You can trace properties of the present universe back to the properties it must have had at the beginning. But you cannot show that these are the only properties that the universe might have had…Earlier or later universes might have had entirely different laws…To state the laws of nature is not to describe or explain all possible histories of all possible universes. Only a relative distinction exists between law like explanation and narration of a one time historical sequence.

If you are asked what you mean by the necessity of the laws of nature (that is to say by the necessity of the most necessary relations), you can legitimately respond only by laying out the substance of your cosmological and other scientific ideas. People who appeal to fixed conceptions of necessity, contingency and possibility are simply confused.

from Politics: A Work in Constructive Social Theory, CUP , 1987, p 180

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The existence of an objective lapse of time … means (or, at least s equivalent to the fact) that reality consists of an infinity of ayers of 'now' which come into existence successively."

In my own work I have come full circle from embracing the notion of that time is emergent to belief in RSPM.

There are several arguments for the reality of time

From cosmology

From particle physics

From quantum gravity

From theoretical biology

We take the cosmological arguments first.

The view that RSPM is false is much older than quantum cosmology and is also older than the block universe interpretation of general relativity. It arises in any deterministic cosmological theory whether based on Newtonian mechanics, general relativity or quantum theory.

This is because the “present moment” has no role in these formulations of dynamics.

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.

Carnap, 1963

But Einstein thought that these scientific descriptions cannot possibly satisfy our human needs; that there is something essential about the Now which is just outside the realm of science.

We both agreed that this was not a question of a defect for which science could be blamed, as Bergson thought. I did not wish to press the point, because I wanted primarily to understand his personal attitude to the problem rather than to clarify the theoretical situation. But I definitely had the impression that Einstein's thinking on this point involved a lack of distinction between experience and knowledge. Since science in principle can say all that can be said, there is no unanswerable question left. But though there is no theoretical question left, there is still the common human emotional experience, which is sometimes disturbing for special psychological reasons.

Carnap, 1963

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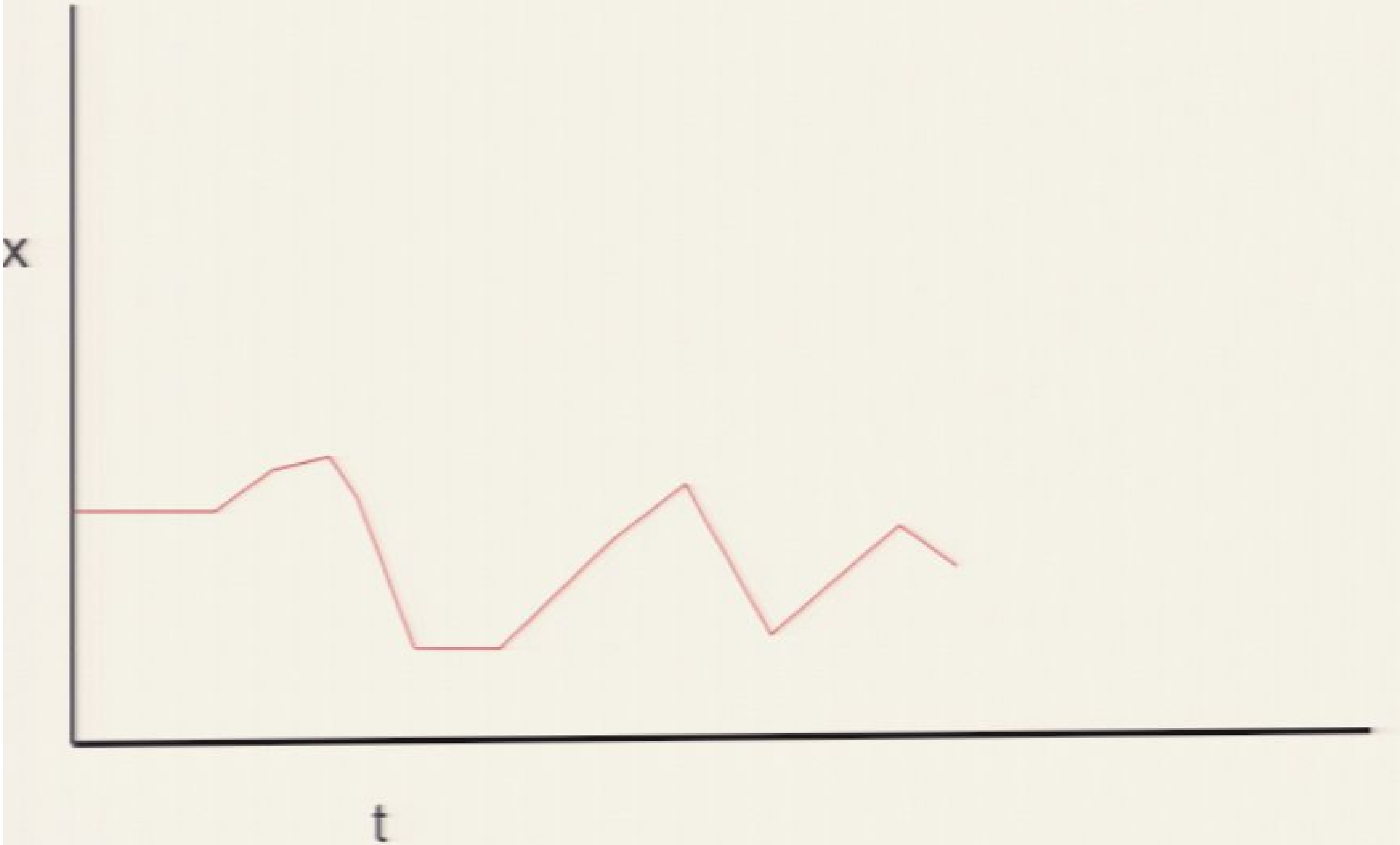
How does this happen?



The geometrization of time

The geometrization of time, and hence the erasure of the present moment, is perfectly appropriate when we are studying and modeling the physics of a subsystem of the universe.

Time is then reducible to a reading on a clock that is outside the subsystem being modeled.

The experience of the present moment is also not part of the subsystem being modeled.

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But the situation is not the same if we try to model the whole universe, because then all the clocks and all the experiences of the present moment are part of the universe we seek to model.

Let us look at how physics is modeled in mathematics, and the precise roles of laws and time in those models.

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The key is the separation of explanation into two parts:

Laws and initial conditions.

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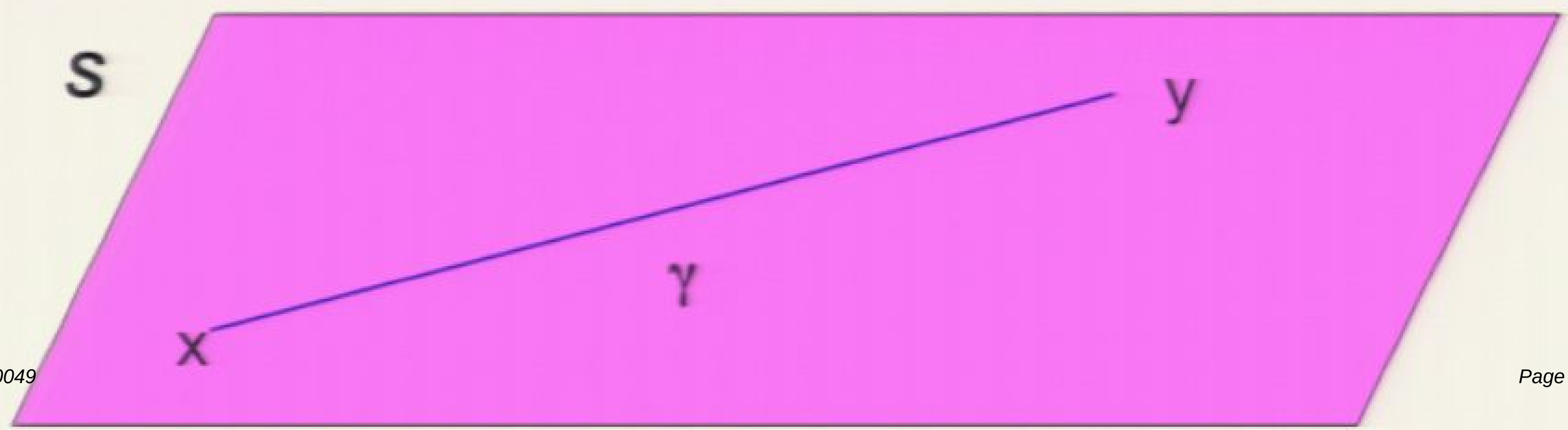
- The dynamics is specified by giving a rule to evolve the state on **S.** If the dynamics is continuous it gives a set of curves, γ, on **S**, which are allowed histories of the system. There is a unique curve through each **x** of **S**.



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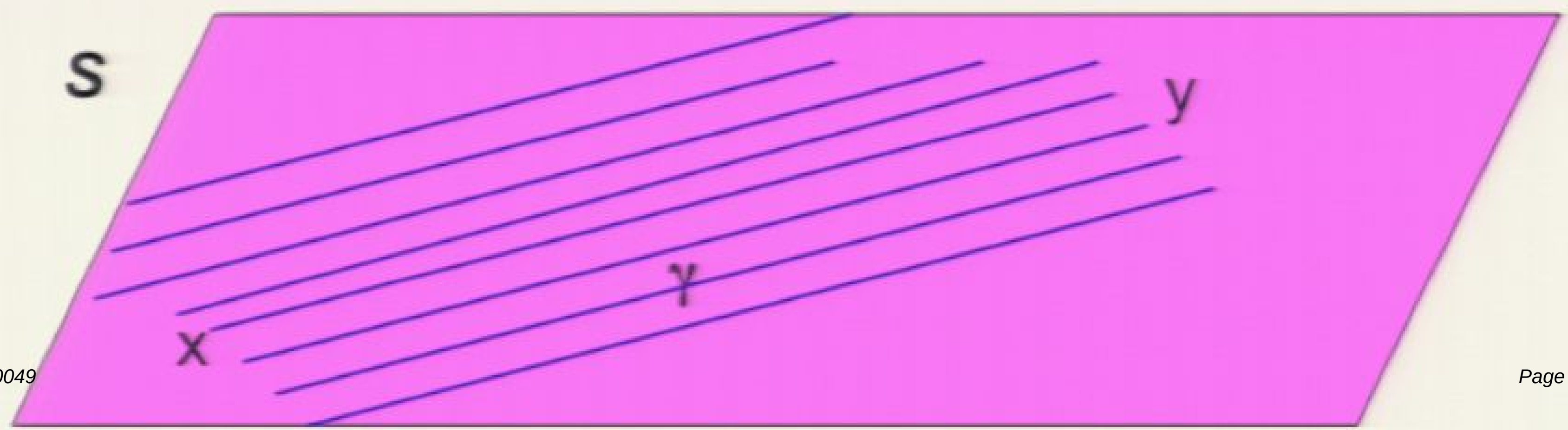
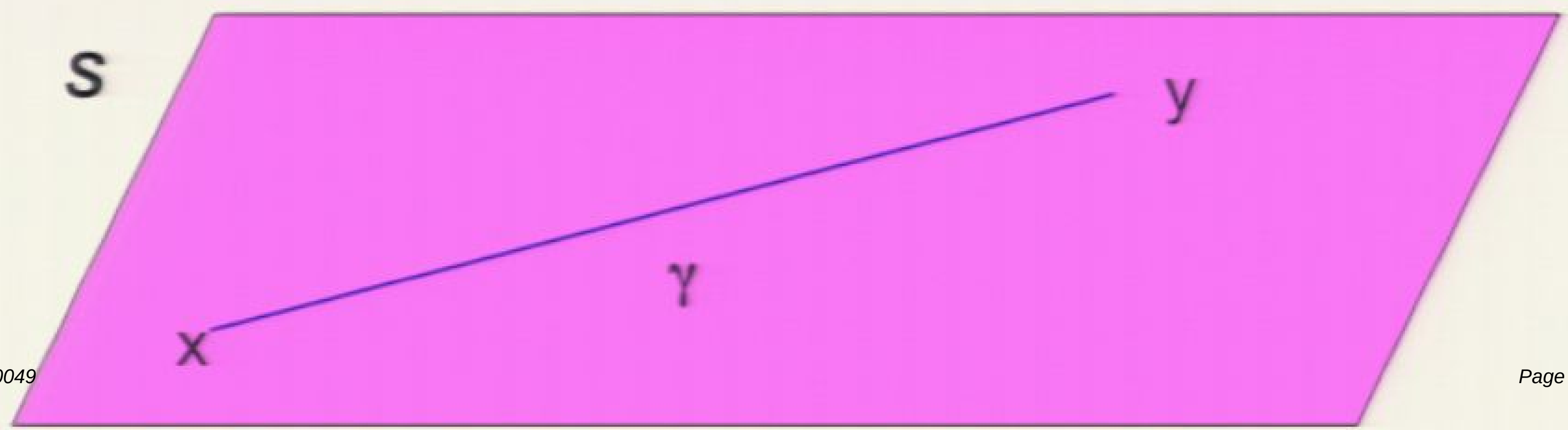


The Newtonian schema:

- To apply this schema to an experiment one prepares the system at an initial time, $\mathbf{t_1}$, in a state **x** of **S**. One then waits till a time $\mathbf{t_2}$ and observes what state, **y** of **S** the system is in. The clock by which time is measured is assumed to be external to the isolated system.



Time is eliminated in applications of the Newtonian schema:

- It is geometricized ie represented as if it were a dimension of space.
- Causal implications, played out in time, are represented by timeless logical implication.
- Observables at any time are reduced by use of the equations of motion to functions of the initial conditions.
- In thermodynamics time averaging is shown to be equivalent to ensemble averaging.

All successful applications of the Newtonian schema so far are either to subsystems of the universe or are gross approximations.

Those are always approximate because interactions between the subsystem and environment are neglected.

THESIS:

A truly fundamental theory must be a cosmological theory.

Any theory short of a cosmological theory is a truncation that neglects interactions between subsystems and the environment and is therefore approximate.

The key question: How do we construct a cosmological theory, that is a physical theory of the whole universe? Can we employ the Newtonian schema or must it be based on another schema?

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"*How were the initial conditions for the universe chosen?*"

"*What was time before the big bang?*"

"*How does an eternally true law apply to a universe that began only a short time ago?*"

"*What is the status of points in configuration space which are never realized in the one history of the universe?*"

"*What is the status of lawful trajectories in the state space, which are solutions of the theory not realized in nature?*"

"*How can we tell whether an observed fact is a consequence of a law or an initial condition if as in the case of the universe as a whole, there is only a single instance of the system?*"

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Without the Newtonian schema we do not:

- **Know what a law of physics should be.**
- **Have an argument against the reality of succession of present moments.**

Does it really make sense in cosmology to insist on the notion of a strict separation into eternally true laws and initial conditions?

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There is only one instance of the system.

We don't get to control the initial conditions.

In fact, there are good reasons to be skeptical about the proposition that the laws we observe presently hold eternally.

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For example, What could it possibly mean to say that the laws of physics are eternally true if the universe they apply to is less than 14 billion years old?

The singularity theorems themselves tell us that either other laws hold at early times or the present laws apply only to a finite domain in the past.

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- •A quantum gravity effect, present only at Planck densities, "bounces the universe so it goes back further in time.
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n each case, we have to believe in a law acting at very early times that e have no evidence for at any time since.

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It used to be believed that the geometry of space is part of the eternal laws of nature. Space is, always was and always would be Euclidean three dimensional space. This was a law!

In general relativity, the geometry of space becomes contingent and dynamical. It evolves according to law just like all the other fields and particles.

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Energy
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The eternally true laws of Newtonian mechanics are equivalent to the statement of conservation laws:

Energy	time
momentum	translations
angular momentum	rotations

Noether's theorem tells us these are just consequences of particular symmetries of space and time. But in general relativity these symmetries are contingent and consequences of dynamics and initial conditions. Hence they only hold approximately and only when the universe has expanded to the point it has these approximate symmetries.

Hence: Newton's laws are the result of dynamical evolution.

till more reasons to disbelieve physical laws are eternal:

The paradox of unification:

theory that unifies phenomena ***A*** and ***B*** has to explain why ***A*** and ***B*** in fact manifest themselves differently?

Hence, the properties of fundamental particles and forces become state dependent and hence subject to dynamical evolution.

This happened for the electromagnetic and weak interactions.
If a grand unified theory were true it would be true also for the strong interaction. If string theory is true it is true also for gravity.

Hence, it begins to look as if many, if not most properties of the elementary particles and basic forces that we would think are specified by laws are actually contingent and determined by a combination of initial conditions and environmental factors.

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

Peirce

Conclusions till this point:

Conclusions till this point: The arguments for the elimination of time in physics are strong so long as they are restricted to the study of subsystems of the universe.

This is sensible because the time, t, we use in the descriptions of subsystems is in fact the reading of a clock used by the experimenter outside the subsystem, so indeed, time in the subsytem is not represented, only the time of the observer.

But these arguments fail when applied to the universe as a whole, partly because they are based on assumptions like the applicability of the Newtonian schema that do not sensibly extend to the universe as a whole.

We also see that much of what we thought was law is in fact contingent and hence the result of dynamics.

Hence, a theory of the whole universe might incorporate time and evolution of laws in an essential way.

But there is in fact good reason to consider the possibility that laws of nature evolve in time.

But there is in fact good reason to consider the possibility that laws of nature evolve in time.

Because this is the only route to a falsifiable explanation for how the laws of nature have been selected.

Two kinds of landscape theories:

ime dependent

'osmological natural selection

'opulation evolves on the landscape

Iighly non-random population.

)ur universe is typical

'reation mechanism implies typical niverses have surprising features ot implied by our existence.

'enuine falsifiable predictions.

Upper mass limit of neutron

Static

Eternal inflation

Static probability distribution

Random, equilibrium populatio

Our universe is very untypical

Anthropic principle must be invoked, all other parameters random.

No falsifiable predictions

The only landscape theory which leads to falsifiable predictions features evolution in time.

Are there lessons?

Some objections to these conclusions

Don't these conclusions contradict the quantum theory of gravity, within which time is believed to be "emergent."

What is known about the emergence of spacetime in background independent quantum theories of gravity?

Theories where emergence of spacetime has not been shown:

Causal sets
Euclidean path integral approaches to quantum gravity
Spin foam models.

Theories where emergence has to some extent been shown:

Causal dynamical triangulations
Quantum graphity
BFFS model
AdS/CFT (ie Neil's talk yesterday)

What do the successful theories have in common?

A global notion of time, with respect to which there is standard hamiltonian evolution.

If space is emergent but time is not, is this not in danger of violating the relativity of simultaneity of special and general relativity?

Doesn't the RSPM in any case violate the relativity of simultaneity?

YES, but so what? In the fundamental theory there is no space, so no locality, all degrees of freedom are coupled to each other.

Locality is emergent as space is emergent.

Does this imply that at the quantum gravity level there may be a hidden absolute simultaneity?

Perhaps.

Isn't this view ruled out because the block universe is a consequence of the relativity of simultaneity of special and general relativity?

'he argument from the relativity of simultaneity is not convincing:

Seems unlikely that there are no limits to the validity of lorentz symmetry. Do we really want to believe in boosts that contract the Hubble scale to the Planck scale?

In nature there is a preferred time coordinate.

A preferred simultaneity may arise at a deeper level, ie in a deeper or hidden variable version of QFT or in quantum gravity.

In GR lorentz invariance is a symmetry of only one solution, hence in quantum gravity it can be a symmetry of at most one state.

In contemporary approaches to quantum gravity, space is emergent from a deeper level in which all degrees of freedom are interacting directly with each other. This implies that locality in classical spacetime is emergent, hence lorentz invariance is emergent and approximate.

Barbour's derivation of a preferred slicing from Jacobi's principle.

here is also an argument from biology: (Kauffman)

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Until recently, all successes of science were the result of studies and models of small subsystems of the universe.

Theories of a whole universe must be structurally different from theories of small subsystems.

In particular, there are conditions necessary for the successes of theories of subsystems that are not present when applying them to the whole universe.

The key difference between theories of subsystems and theories of the whole universe must be in their treatment of time.

In particular, time disappears in theories of subsystems, but cosmological laws may or must themselves evolve in time.

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Puzzling, but not irrational. Leads to falsifiable predictions from explanations of why these laws.

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Musn't there be a meta-law to govern the evolution of laws?

Wouldn't this then be an eternally true law?

Possible responses:

- Yes, but a new form of law that allows no choice of initial conditions
- Yes, but in a new form whose configuration space is constructed only as the universe evolves (Kauffman's adjacent possible.)
- Yes, but is universal, as in computation. arxiv/0803.2926.
- No, cosmology reduces to narration of natural history.