Mathematics, Metaphysics and the Multiverse
Two Fundamental Issues -

How does science represent and establish control over information about the Universe

How does the Universe itself exercise control over its own development ... or more feasible:

☐ How can we reflect that control via our scientific and mathematical representations
1. The World as Mathematics
Causality - a Useful but Vague Notion

... the most venerable of all the philosophical definitions [of determinism] holds that the world is deterministic just in case every event has a cause. The most immediate objection to this approach is that it seeks to explain a vague concept - determinism - in terms of a truly obscure one - causation.

Physics Gets Computational

- Newton onwards - overarching aim of science became the extraction of the computable causal content of the world ... theories which computably predict, capturing truth via proofs ...

- Einstein [p.54, `Out of My Later Years', 1950]: "When we say that we understand a group of natural phenomena, we mean that we have found a constructive theory which embraces them."

while ...
Computation is Disembodied ...

- 1936 - Turing's machines ... a model of computational natural processes within structures which are countably presented

- Hardware trivial, Actions simple

- Computing power in the program ...

Universality, and Program as Data Paradigm
There's no logical reason why a disembodied fanatical mathematical researcher should not be created all ready to go: as long as it has the right architecture to support the process. (Whether any architecture implemented in a digital computer could suffice, or some Penrose-type quantum gravity machine is required is a separate question which I'll ignore for now.)
Successful reduction of “natural” examples to the Turing model - e.g. quantum computation (David Deutsch)

I am sure we will have [conscious computers], I expect they will be purely classical, and I expect that it will be a long time in the future. Significant advances in our philosophical understanding of what consciousness is, will be needed.

Question and Answers with David Deutsch, on New.Scientist.com News Service, December, 2006
Physicality Returns as Information ... 

- 1939 - Turing’s oracle Turing machines ...

- Provide a model of computable content of structures, based on p.c. functionals over the reals

- A model within which Newtonian computability etc comfortably fit ...
Physicallity Returns as Information ...

- 1939 - Turing’s oracle Turing machines
- Provide a model of computable content of structures, based on p.c. functionals over the reals
- 1944 - Post defines the degrees of unsolvability as a classification of reals in terms of their relative computability
- Giving a landscape with a rich structure
Fundamental problem: Characterise the Turing invariant relations

- **Intuition:** These are key to pinning down how basic laws and entities emerge as mathematical constraints on causal structure.

- **Notice:** The richness of Turing structure discovered so far becomes the raw material for a multitude of non-trivially invariant relations.
Bi-interpretability

Conjecture (Harrington): The Turing definable relations are exactly those with information content describable in second-order arithmetic

- Notice: Conjecture rules out there being non-trivial Turing automorphisms ...

- Partial results: Rigidity above $\emptyset''$
2. Problems with Physics ...
By 1973, physicists had in place what was to become a fantastically successful theory of fundamental particles and their interactions, a theory that was soon to acquire the name of the ‘standard model’. Since that time, the overwhelming triumph of the standard model has been matched by a similarly overwhelming failure to find any way to make further progress on fundamental questions.

Introduction to Peter Woit: “Not Even Wrong - The Failure of String Theory and the Continuing Challenge to Unify the Laws of Physics”, Jonathan Cape, 2006
Causality Beyond Computation?

If the creation of the universe can be described as a quantum process, we would be left with one deep mystery of existence: What is it that determined the laws of physics?

One way of thinking about what is unsatisfactory about the standard model is that it leaves seventeen non-trivial numbers still to be explained, ....

Peter Woit: Not Even Wrong - The Failure of String Theory and the Continuing Challenge to Unify the Laws of Physics, Jonathan Cape, 2006
... I would like to state a theorem which at present can not be based upon anything more than upon a faith in the simplicity, i.e. intelligibility, of nature ... nature is so constituted that it is possible logically to lay down such strongly determined laws that within these laws only rationally completely determined constants occur (not constants, therefore, whose numerical value could be changed without destroying the theory) ...
[According to Strong Determinism] ... all the complication, variety and apparent randomness that we see all about us, as well as the precise physical laws, are all exact and unambiguous consequences of one single coherent mathematical structure.

Strong Determinism

For computability theoretic ramifications:


The state of physics today is like it was when we were mystified by radioactivity ... They were missing something absolutely fundamental. We are missing perhaps something as profound as they were back then.
String Theory - the only game in town?

The longstanding crisis of string theory is its complete failure to explain or predict any large distance physics. ... String theory is incapable of determining the dimension, geometry, particle spectrum and coupling constants of macroscopic spacetime. ... The reliability of string theory cannot be evaluated, much less established. String theory has no credibility as a candidate theory of physics.

3. Many Worlds and Multiverses
Schrödinger’s Vanishing Worlds

Processes for change of wave equation describing quantum state of a physical system:

- Deterministic continuous evolution via Schrödinger’s equation - involves superpositions of basis states

- Probabilistic non-local discontinuous change due to measurement - ‘random’ jump to a single basis state

Interpretation?? (where do the other states go)
Real Randomness in Physics?

- Quantum randomness is a familiar experimental and theoretical phenomenon.

  It passes all reasonable statistical properties of randomness.

- Calude, Svozil: It is Turing incomputable (assuming ...)

Open question: How random is quantum randomness?
Many Worlds Interpretation

- Proposes many alternative histories of the universe
- All treated alike except for their different probabilities
Many Worlds Interpretation

- Proposes many alternative histories of the universe
- All treated alike except for their different probabilities
- Later development by many people, including Murray Gell-Mann, Jim Hartle, Roland Omnes, Wojciech Zurek ...
- ... theoretical elaboration of decoherence, entanglement, multiverse, our 'quasi-classical domain', ...
Many Worlds Interpretation

Hugh Everett III
(Nov. 11, 1930 - July 19, 1982)

Mark Oliver Everett - lead singer/guitarist of EELS

John Wheeler

Bryce DeWitt
Many Worlds Interpretation

Such decoherence mechanisms make possible the existence of the quasiclassical domain that includes ordinary experience. That domain consists of decoherent coarse-grained histories, which can be envisaged as forming a tree-like structure. ....

The structure first branches into alternative possibilities right at, or just after, the beginning of the expansion of the universe. Each branch then splits again a short time later into further alternatives, and so on for all time. At each branching, there are well-defined probabilities for the alternatives. There is no quantum interference between them.

... understanding the multiverse is a precondition for understanding reality as best we can. Nor is this said in a spirit of grim determination to seek the truth no matter how unpalatable it may be ... It is, on the contrary, because the resulting world-view is so much more integrated, and makes more sense in so many ways, than any previous world-view, and certainly more than the cynical pragmatism which too often nowadays serves as surrogate for a world-view amongst scientists.

The issue of what is to be regarded as an ensemble of ‘all possible’ universes is unclear, it can be manipulated to produce any result you want ... The argument that this infinite ensemble actually exists can be claimed to have a certain explanatory economy (Tegmark 1993), although others would claim that Occam’s razor has been completely abandoned in favour of a profligate excess of existential multiplicity, extravagantly hypothesized in order to explain the one universe that we do know exists.

“Causality is fundamental”

- Early champions of the role of causality - Roger Penrose, Rafael Sorkin, Fay Dowker, and Fotini Markopoulou

It is not only the case that the spacetime geometry determines what the causal relations are. This can be turned around: Causal relations can determine determine the spacetime geometry ...

It’s easy to talk about space or spacetime emerging from something more fundamental, but those who have tried to develop the idea have found it difficult to realize in practice. ... We now believe they failed because they ignored the role that causality plays in spacetime. These days, many of us working on quantum gravity believe that causality itself is fundamental - and is thus meaningful even at a level where the notion of space has disappeared.

Lee Smolin, The Trouble With Physics, p.241
4. Definability as Embodied Computation
How can the Universe constrain existence?

- Intuition - entities exist because of, and according to, mathematical laws. In the words of Leibniz [1714] -

  ‘The Monadology’, sections 31, 32:
  “... there can be found no fact that is true or existent, or any true proposition, without there being a sufficient reason for its being so and not otherwise, although we cannot know these reasons in most cases.”
Definability the key concept

☐ That is - Natural phenomena not only generate descriptions, but arise and derive form from them ...

☐ ... so connecting with a useful abstraction - the concept of mathematical definability ...

☐ ... formalising describability in a mathematical structure

☐ Giving precision to our conception of possible worlds - a possible world involves relationships which are definable
Connects with how Nature Computes
Definability as Higher Order Computation Embodied ...

- Can describe global relations in terms of local structure ...

- ... so capturing the emergence of large-scale formations ...

- **Mathematically** - formalised as definability or as **INVARIANC**E under automorphisms - over structure based on Turing functionals

- Or ... as higher order computability
Lee Smolin’s 5 Great Problems

1. Combine general relativity and quantum theory into a single theory that can claim to be the complete theory of nature.

2. Resolve the problems in the foundations of quantum mechanics.

3. The unification of particles and forces problem: Determine whether or not the various particles and forces can be unified in a theory that explains them all as manifestations of a single, fundamental entity.

4. Explain how the values of the free constants in the standard model of physics are chosen in nature.

5. Explain dark matter and dark energy. Or, if they don’t exist, determine how and why gravity is modified on large scales.
A deconstructed Universe

Described in terms of reals ... With natural laws based on algorithmic relations between reals

Emergence described in terms of definability/invariance

... with failures of invariance of information content modelling quantum ambiguity

... which gives rise to new levels of algorithmic structure

... and a fragmented scientific enterprise
Thank you!