# Fundamental Nomic Vagueness

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# A Snapshot of the Universe

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- Despite its complexity, it seems to follow simple laws.
- To discover what they are: one of the coolest projects we have attempted.

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  - and how they fit in our system of the world.

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- Contrast: the vagueness of ordinary language.

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- Predicates such as "bald" are indeterminate: there are individuals such that it is indeterminate whether they are bald.

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E.g. the Sorites paradox.

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- The fundamental laws of physics, the predicates they invoke, and the properties they refer to should be exact.
- The expectation is perhaps supported by the history of physics and the ideal that physics should deliver an objective and precise description of nature.

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- If some fundamental laws are vague, it will be difficult to describe them mathematically in a way that genuinely respects their vagueness and does not impose sharp boundaries anywhere.
- The kind of mathematics we are used to, built from a set-theoretic foundation, does not lend itself naturally to model the genuine fuzziness of vagueness.

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- The successful application of mathematical equations in formulating physical laws *seems* to leave no room for vagueness to enter into a fundamental physical theory.
- If there is fundamental nomic vagueness, and if vagueness is not completely mathematically expressible, then the fundamental physical theory is not completely mathematically expressible.

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- How does it relate to ontic vagueness?


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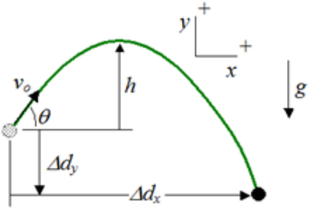


Figure: Newtonian mechanics for a projectile. Picture source: Wikipedia

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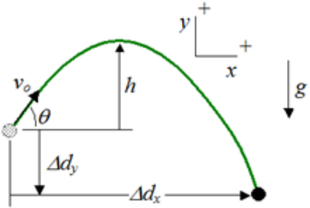


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Note: unless noted otherwise, I shall use "laws" and "fundamental laws" interchangeably. Likewise for "nomic" and "fundamental nomic."

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- In the space of possible worlds, there is an exact and determinate set of worlds compatible with Newtonian mechanics.
- A law $L$ is exact only if, for any world $w$, there is a determinate fact about whether $w$ is compatible with $L$.

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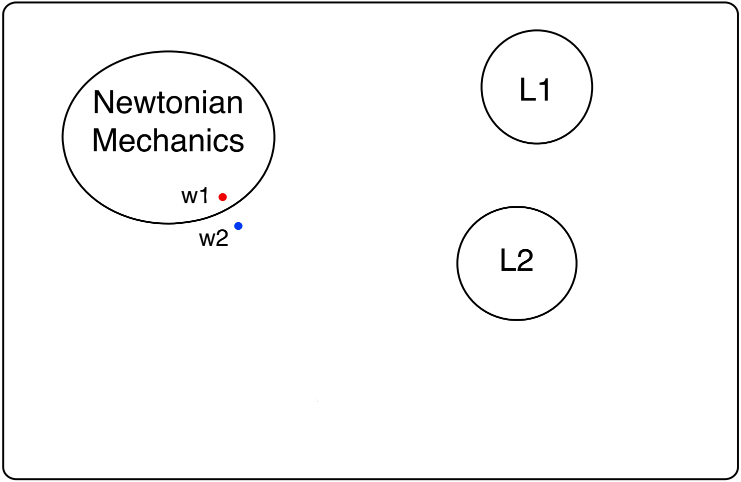
- $\Omega_\alpha$: the set of possible worlds that satisfy the actual fundamental laws obtaining in $\alpha$, i.e. the set of all physically / nomologically possible worlds.

# Exact Laws

W, the space of all possible worlds



What about a vague law?

# Vague Laws

Figure: Visual imagery of a vague law. Picture source: Flickr, seiichi o

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- $L$ is a vague law only if there exists some world $w$ such that there fails to be a determinate fact about whether $w$ is compatible with $L$.
- Some worlds are close to the (fuzzy) boundary of $L$.

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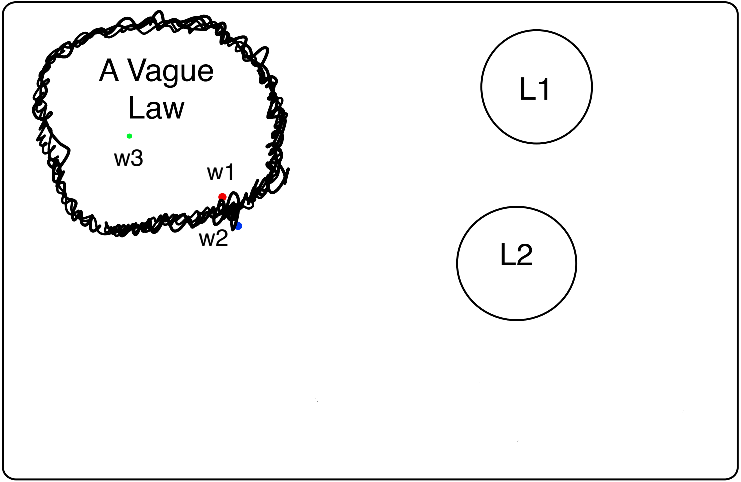

Let's compare this with familiar cases of vagueness in ordinary language.

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A case of Sorites paradox.

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Similarly for other vague predicates: tall, low, red, ....

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- The same point applies to imprecise probabilities that are treated in terms of set-valued measures. Set membership is exact.

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I shall assume that it cannot be. If my assumption is incorrect, then my paper can be seen as another reason to look for a perfect mathematical representation.

# Higher-Order Nomic Vagueness

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Impossibility Conjecture It is impossible to adequately express a vague fundamental law using the language of mathematics.

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- Laws are not material objects and do not have boundaries or parts in spacetime

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On V1, if Tom the cat is an actual vague material object, then there is ontic vagueness.

# Nomic Vagueness and Ontic Vagueness

In contrast, Keefe and Smith (1996) suggest that vagueness of Tom is “merely superficial.” Facts about Tom supervene on the material objects and their properties at the “base level.” Only vagueness at the base level qualifies for “non-superficial” ontic vagueness.

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Neither V1 nor V2 recognizes nomic vagueness as a version of ontic vagueness.

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V3 There is ontic vagueness if and only if every possible world is exact but it is vague which world is the actualized world.

Fundamental nomic vagueness does not imply ontic vagueness in the sense of V3. A fundamental law may be vague without it being vague which possible world is actualized.

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Even so, it does not entail this:

> V5 It is vague which worlds are metaphysically possible.

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- If the criterion of ontic vagueness is the violation of Fundamental Exactness, then fundamental nomic vagueness can count as ontic vagueness.
- However, if the criterion is more restrictive (along the lines of V1–V3), then fundamental nomic vagueness does not count as ontic vagueness.

Is there a realistic example of fundamental nomic vagueness?

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- Newtonian mechanics is exact.
- Schrödinger equation is exact.
- Einstein field equations are exact.

A possible case: textbook versions of quantum mechanics

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> *What exactly qualifies some physical systems to play the role of 'measurer'? Was the wavefunction of the world waiting to jump for thousands of millions of years until a single-celled living creature appeared? Or did it have to wait a little longer, for some better qualified system...with a Ph.D.?....The first charge against 'measurement', in the fundamental axioms of quantum mechanics, is that it anchors there the shifty split of the world into 'system' and 'apparatus'. (Bell, "Against Measurement," 1990, p.34)*

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- Even supposing terms such as 'measurement' have determinate cases, it is hard to imagine there be a sharp split between systems that are measurers and systems that are measured.
- Hence, there will be histories of the wave function that count as borderline possible.

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- The "shifty split" shows that the division is not a principled one.
- On my view, fundamental nomic vagueness in this case is a *symptom* that points us to the deeper problem that the theory is disunified.

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- Observers are just part of nature and nothing special.
- Even setting aside the issue of vagueness, there are reasons not to take textbook quantum axioms as candidate fundamental laws.
- In order to find a more realistic case of fundamental nomic vagueness, we must look elsewhere.

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- Context: arrows of time; philosophy of statistical mechanics
- PH is a good candidate of a fundamental law
- PH is best construed as a vague law

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These may seem like **metaphysical** questions going beyond the scope of physics.

Following Boltzmann, Feynman, Reichenbach, and Penrose, we suggest that questions like these require a **scientific** explanation.

A proposed explanation in the literature:

Past Hypothesis (PH) The universe 'initially' was in a low-entropy macrostate.

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- PH is part of the scientific explanation for nomic regularities, such as the Second Law of Thermodynamics.
- PH is not derived from other laws.
- PH plays a crucial role in our reasoning about counterfactuals, records, and influence.

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- We can return to it in the Q&A.

# Vagueness of the Past Hypothesis

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- PH is stated in the language of macrostates and macro-variables.

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# Vagueness of the Past Hypothesis

**Super Weak Past Hypothesis (SWPH)** The universe initially was in a low-entropy state.

- How low is low?
- The harder case is the slightly stronger version that I think Albert (2012) and Loewer (2016) have in mind.

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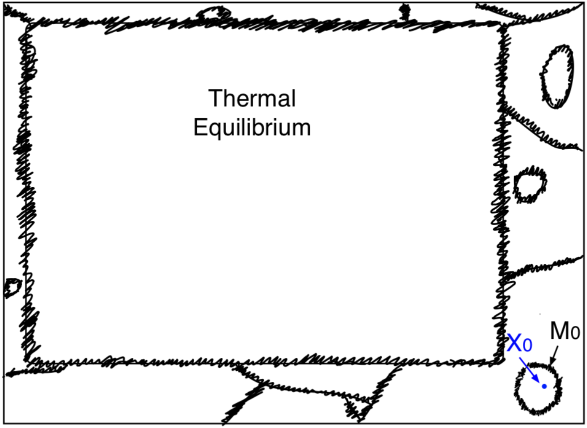
- There are many admissible precisifications of $M_0$ in terms of different sets of microstates that are more or less similar.
- Perhaps one can imagine taking a union of all the admissible ones.
- But admissibility itself is also vague. [Higher-order vagueness]

# The Phase Space



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Let's call them C-parameters. In practice they don't make too much of a difference as long as we are sensible in our choices.

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Cf: the Sorites paradox.

# C-Parameters

The correspondence between macrostates and sets of microstates:

- Not exact.
- Not even "imprecise."
- It is vague.

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- Mathematical expressibility!

# Getting Rid of Nomic Vagueness

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- Carroll-Chen (2004) model
- Open question

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- If we stay within the standard Boltzmannian framework, an exact version of PH will commit us to an unusual kind of arbitrariness that is objectionable.
- But there is reason to be hopeful if we are open to a new way of thinking about quantum mechanics in a time-asymmetric universe. (see paper version; omitted in this talk)

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SPH supports an epistemic interpretation of the vagueness of PH.

# Strong Past Hypothesis

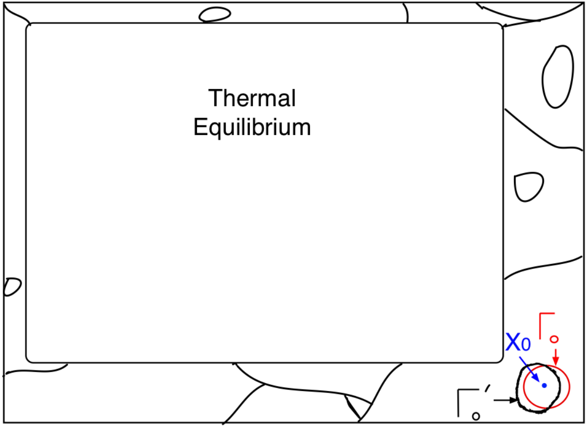


Figure: The Strong Past Hypothesis with a precise set of microstates $\Gamma_0$. The fuzziness is removed.

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- The exact choice of $\Gamma_0$ is arbitrary in an objectionable sense.
- It amounts to an exact size of cells for coarse-graining, an exact correspondence of coarse-grained distributions with thermodynamic quantities, and an exact cut-off of macrostate membership when we have quantum superposition.

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- Same for the exact forms of other fundamental laws.
- We call this property 'traceability.'

# Traceability

**Traceability-at-a-World** A certain adjustable parameter $O$ in the physical law $L$ is traceable at world $w$ if any change in $O$ (while holding other parameters fixed) will result in some change in the nomological status of $w$ with respect to $L$, i.e. from possible to impossible or from likely to unlikely (or some other change in the probabilistic measures).

**Traceability** A certain adjustable parameter $O$ in the physical law $L$ is traceable if $O$ is traceable at most worlds allowed by $L$.

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- Change the constant G= 6.67430 to G'=6.68 (in the appropriate unit);
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- Change the multiplication by $m_1$ to multiplication by $m_1^{1.00001}$.

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- Change the multiplication by $m_1$ to multiplication by $m_1^{1.00001}$.

These changes are traceable at typical worlds that satisfy Newton's law of motion and law of universal gravitation.

# Traceability

Example: Newtonian mechanics $F = ma$ plus Newtonian theory of universal gravitation $F_G = Gm_1 m_2/r^2$

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For a typical Newtonian world whose microscopic history $h$ is a solution to the Newtonian laws, $h$ will not be possible given any of those changes.

# Traceability

Other examples: the laws and dynamical constants of Maxwellian electrodynamics, of Bohmian mechanics, of Everettian quantum theory, of special and general relativity.

Stochastic theories: GRW.

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- Most "admissible" changes of the boundary of $\Gamma_0$ will not have any effects in typical worlds compatible with $\Gamma_0$.
- In general, you can replace an infinity of borderline worlds inside $\Gamma_0$ with another infinity of borderline worlds just outside the boundary such that there will be no differences to whether the actual world is possible or whether the actual macro-history is likely.

# Vagueness of PH is Robust

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- $M_0$ only vaguely corresponds to sets of wave functions. It vaguely corresponds to subspaces in Hilbert space.

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The importance of traceability as a theoretical virtue: it explains why we are more ok with a vague PH than a vague theory of QM.

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All else being equal, if we can avoid nomic vagueness without committing untraceable arbitrariness, we should prefer an exact alternative.

But if we can do it only if we commit untraceable arbitrariness, then a fundamental yet vague law is perfectly acceptable.

# Past Hypothesis as a Case Study

We have a realistic candidate for a fundamental yet vague law.

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- In the paper version: dilemma dissolved in the Wentaculus package.
- Surprise: quantum theory actually removes vagueness.

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- Perhaps not all laws are exact. (e.g. probabilistic laws)
- Not all laws are mathematically expressible.
- Or: new mathematical foundation for physics that refutes the impossibility conjecture.

**Impossibility Conjecture** It is impossible to adequately express a vague fundamental law using the language of mathematics.

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- Vagueness not only permeates ordinary language but can also arise in the objective nomological order;
- We need to rethink the foundations of mathematics if mathematics is the ideal language for physics.

# Paper Versions

"Fundamental Nomic Vagueness," *The Philosophical Review*, 131(1), 2022

"Welcome to the Fuzzy-Verse," *New Scientist*, Issue 3298, Sep 5th, 2020

Both can be accessed on: www.eddykemingchen.net

Thank you for your attention!

# Bonus: The Classical Case

The quantum maneuver in my approach is compatible with solutions to the measurement problem.

The classical maneuver would not be strictly parallel. It could introduce a version of the measurement problem, which requires complicating the dynamics or the ontology.

Obstacles:

- Determinism $\rightarrow$ indeterminism.
- Single world $\rightarrow$ many worlds.

# Bonus: PH and SP are laws?

Four arguments for the nomological status of PH and SP.

1. Scientific explanation: laws ground laws.
2. Counterfactual asymmetry: holding certain facts fixed.
3. Reliability of records: a modal notion.
4. Humean argument: the best summary includes PH and SP.

# Bonus: Empirical Equivalence

**Criterion for Empirical Equivalence**

Two theories $A$ and $B$ are empirically equivalent if at any time $t$, they assign the same probability distribution over all possible experimental outcomes.

- We can show this rigorously for $W$ versions of Bohm, Everett, and GRW.
- Is it enough? Bell's jumpy Everettian world.
- Subsystem analysis.

arXiv: 1901.08053

# $W_{IPH}$-Bohmian mechanics: $(Q, W_{IPH})$

The Initial Projection Hypothesis:

$$\hat{W}_{IPH}(t_0) = \frac{I_{PH}}{dim\mathscr{H}_{PH}} \tag{1}$$

The Initial Particle Distribution:

$$P(Q(t_0) \in dq) = W_{IPH}(q, q, t_0)dq \tag{2}$$

The Von Neumann Equation:

$$i\hbar\frac{\partial \hat{W}}{\partial t} = [\hat{H}, \hat{W}] \tag{3}$$

The $W_{IPH}$-Guidance Equation (Dürr et al. 2005):

$$\frac{dQ_i}{dt} = \frac{\hbar}{m_i}\text{Im}\frac{\nabla_{q_i} W_{IPH}(q, q', t)}{W_{IPH}(q, q', t)}(q = q' = Q) \tag{4}$$

# $W_{IPH}$-Everettian mechanics

The Von Neumann Equation:

$$i\hbar \frac{\partial \hat{W}}{\partial t} = [\hat{H}, \hat{W}] \tag{5}$$

The Mass Density Equation:

$$m(x,t) = \mathrm{tr}(M(x)W(t)), \tag{6}$$

$W_{IPH}$-S0: only $W_{IPH}$.
$W_{IPH}$-Sm: $m(x,t)$ and $W_{IPH}$.

# $W_{IPH}$-GRW spontaneous collapse theories

The linear evolution of the density matrix is interrupted randomly (with rate $N\lambda$) by collapses:

$$W_{T^+} = \frac{\Lambda_{I_k}(X)^{1/2} W_{T^-} \Lambda_{I_k}(X)^{1/2}}{\mathrm{tr}(W_{T^-} \Lambda_{I_k}(X))} \tag{7}$$

with $X$ distributed by the following probability density:

$$\rho(x) = \mathrm{tr}(W_{T^-} \Lambda_{I_k}(x)) \tag{8}$$

where the collapse rate operator is defined as:

$$\Lambda_{I_k}(x) = \frac{1}{(2\pi\sigma^2)^{3/2}} e^{-\frac{(Q_k - x)^2}{2\sigma^2}} \tag{9}$$

$W_{IPH}$-GRWm and $W_{IPH}$-GRWf: defined with local beables $m(x,t)$ and $F$.