The Simplicity of Physical Laws

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- Relation between epistemology and metaphysics of laws
- Response to the epistemic argument for Humeanism (e.g. Earman and Roberts, 2005)

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Talk Outline

In this talk:

1. the commitments of nomic realism;
2. the issue of empirical equivalence;
3. the puzzle about simplicity;
4. a proposal for the role of simplicity;
5. relevance to Humeanism vs. non-Humeanism.

Nomic Realism

Let's start with nomic realism.

Nomic Realism

- Many physicists and philosophers are realists about physical laws.
- Call realism about physical laws *nomic realism*.
- It contains two parts.
- First, physical laws are objective and mind-independent.
- Second, we have epistemic access to physical laws.

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Metaphysical Realism: Physical laws are objective and mind-independent; more precisely, which propositions express physical laws are objective and mind-independent facts in the world.

Epistemic Realism: We have epistemic access to physical laws; more precisely, we can be epistemically justified in believing which propositions express the physical laws, given the evidence that we will in fact obtain.

Nomic Realism

- Nomic realism gives rise to an apparent epistemic gap:
- if physical laws are really objective and mind-independent, it may be puzzling how we can have epistemic access to them, since laws are not consequences of our observations.
- The epistemic gap can be seen as an instance of a more general one regarding theoretical statements on scientific realism.

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I think the general lesson carries over to other versions of Humeanism and non-Humeanism.

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For both, we must have that $\xi \in \Omega^L$, with Ω^L the set of mosaics compatible with L. This means that L is true in ξ.

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On BSA, we also have that $L = BS(\xi)$.

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That would be incorrect.

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Let us allow E to include not just our current evidence but also all past evidence and all future evidence about the universe that we will in fact gather.

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Hence, on BSA, just as on MinP, E does not pin down (L, ξ). There is a gap between what our evidence entails and what the laws are.

Empirical Equivalence

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Let us consider three reasonable algorithms for generating empirical equivalents.

Algorithm A: General Strategy

Move parts of ontology (what there is in the mosaic) into the nomology (the package of laws)

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Given a theory of physical reality $T_1 = (L, \xi)$, if ξ can be decomposed into two parts $\xi_1 \& \xi_2$, we can construct an empirically equivalent rival $T_2 = (L \& \xi_1, \xi_2)$, where ξ_1 is moved from ontology to nomology.

Algorithm A: Example

Consider the standard theory of Maxwellian electrodynamics, T_{M1}:

- Nomology: Maxwell's equations and Lorentz force law
- Ontology: a Minkowski spacetime occupied by charged particles with trajectories $Q(t)$ and an electromagnetic field $F(x,t)$.

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Here is an empirically equivalent rival, T_{M2}:

- Nomology: Maxwell's equations, Lorentz force law, and an enormously complicated law specifying the exact functional form of $F(x, t)$ that appears in the dynamical equations
- Ontology: a Minkowski spacetime occupied by charged particles with trajectories $Q(t)$

Algorithm A: Example

Our evidence E is compatible with both T_{M1} and T_{M2}.

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- The outcome of every experiment in the actual world will be consistent with T_{M2}, as long as the outcome is registered as certain macroscopic configuration of particles.

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Both $F(x, t)$ and the Hamiltonian are components of respective laws of nature that tell particles how to move.

This is not new. Cf: the nomological interpretation of the quantum state.

Algorithm B: General Strategy

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This strategy is designed for MinP.

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- There are infinitely many such candidates for Ω^{L_2}.

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Note: L_2 is a case of strong determinism. See Chen 2022 and Adlam 2022 for discussions.

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- Or: we can expand ξ to $\xi' \neq \xi$ such that ξ is a proper part of ξ'.
- For a continuous infinity of choices of ξ', $L_2 = BS(\xi')$ differs from L_1, even though E is compatible with all of them.

Algorithm C: Example

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Since ξ' violates the conservation of number of particles, L_2 should be more complicated than L_1.

A Puzzle about Simplicity

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Motivation: to justify preferences among empirical equivalents.

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Consider:

Guide-to-Truth: Simpler candidates are more likely to be true.

A Puzzle about Simplicity

Principle of Simplicity (PS) Other things being equal, simpler propositions are more likely to be true. More precisely, other things being equal, for two propositions L_1 and L_2, if $L_1 >_S L_2$, then $L_1 >_P L_2$, where $>_S$ represents the comparative simplicity relation, $>_P$ represents the comparative probability relation.

PS regards simplicity as a guide to *truth*. A proposition being simpler raises its probability of being true relative to a more complicated proposition.

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- Problem of precision: It is difficult to say exactly what simplicity is and how simplicity should be measured.
- Problem of justification: It is difficult to justify PoS in terms of epistemic principles.

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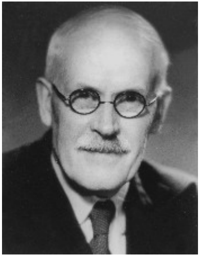
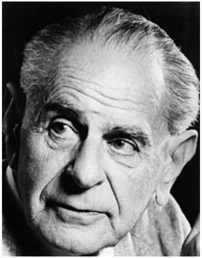
PS faces a more urgent problem; it is probabilistically incoherent and hence false.

First raised by Popper against Wrinch and Jeffreys's account of scientific inference. (Recent discussions: Sober 2015, Schupbach 2019, Henderson 2022.)

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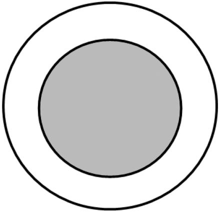

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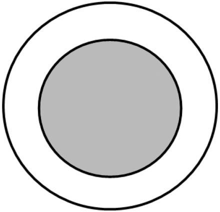

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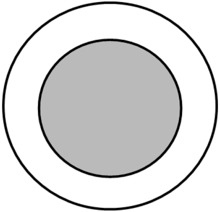

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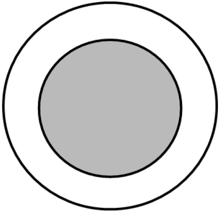

The problem of nested theories (sometimes called the problem of conjunctive explanations):

- Consider two theories with nested sets of models
- $\Omega^{L_1} \subset \Omega^{L_2}$
- The probability that L_1 is true cannot be higher than the probability that L_2 is true.

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- Let Ω^{GR} denote the set of models compatible with the fundamental law in general relativity—the Einstein equation
- Let Ω^{GR^+} denote the union of Ω^{GR} and a few random spacetime models that do not satisfy the Einstein equation.
- Suppose there is no simple law that generates Ω^{GR^+}.

A Puzzle about Simplicity

- Let Ω^{GR} denote the set of models compatible with the fundamental law in general relativity—the Einstein equation
- Let Ω^{GR^+} denote the union of Ω^{GR} and a few random spacetime models that do not satisfy the Einstein equation.
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- Suppose there is no simple law that generates Ω^{GR^+}.
- While the law of GR (the Einstein equation) is presumably simpler than that of GR^+, the former cannot be more likely to be true than the latter
- Every model of GR is a model of GR^+, and not every model of GR^+ is a model of GR.

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Puzzle about Simplicity: If simplicity is not a guide to truth **in general**, what is it a guide to?

Simplicity as a Fundamental Epistemic Guide to Lawhood

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- This principle solves the problem of nested theories in a straightforward way.
- It also vindicates a variety of realist convictions.

I suggest that we accept this principle:

Principle of Nomic Simplicity (PNS) Other things being equal, simpler propositions are more likely to be laws. More precisely, other things being equal, for two propositions L_1 and L_2, if $L_1 >_S L_2$, then $L[L_1] >_P L[L_2]$, where $>_S$ represents the comparative simplicity relation, $>_P$ represents the comparative probability relation, and $L[\cdot]$ denotes *is a law*, which is an operator that maps a proposition to one about lawhood.

For example, $L[F = ma]$ expresses the proposition that $F{=}ma$ *is a law*. The proposition $F{=}ma$ is what Lange calls a "sub-nomic proposition."

- From the perspective of nomic realism, one can consistently endorse PNS without endorsing PS.
- Some facts are laws, but not all facts are laws.
- Laws correspond to a special set of facts.
- On BSA, they are the best-system axioms.
- On MinP, they are the constraints on what is physically possible.

- We are ready to see how PNS solves the problem of nested theories.
- Recall the earlier example of GR and GR^{+}.
- Even though we think that the Einstein equation is more likely to be a law, it is less likely to be true than the law of GR^{+}.
- I suggest that what simplicity selects here is not truth in general, but truth about lawhood, i.e. whether a certain proposition has the property of being a fundamental law.

- Let us assume that fundamental lawhood is factive, which is granted on both BSA and MinP.
- Hence, lawhood implies truth: $L[p] \Rightarrow p$.
- However, truth does not imply lawhood: $p \nRightarrow L[p]$.
- This shows that $L[p]$ is logically inequivalent to p.
- This is the key to solve the problem of coherence.

- On PS, in the case of nested theories, we have probabilistic incoherence.
- If L_1 is simpler than L_2, applying the principle that simpler laws are more likely to be true, we have $L_1 >_P L_2$.
- However, if L_1 and L_2 are nested with $\Omega^{L_1} \subset \Omega^{L_2}$, the axioms of probability entail that $L_1 \leq_P L_2$. Contradiction!

- On PNS, the contradiction is removed, because *more likely to be a law* does not entail *more likely to be true*.
- If L_1 and L_2 are nested, where L_1 is simpler than L_2 but $\Omega^{L_1} \subset \Omega^{L_2}$, then $L_1 \leq_P L_2$.
- It is compatible with the fact that $L[L_1] >_P L[L_2]$.

What we have is an inequality chain:

$$L[L_2] <_P L[L_1] \leq_P L_1 \leq_P L_2 \tag{2}$$

This is also a new and simple solution to the problem of nested theories / problem of coherence. It is compatible with but less demanding and perhaps more general than the recent proposal of Henderson (2022).

By the way, the solution can be generalized for other explanatory relations.

Principle of Nomic Virtues (PNV) For two propositions L_1 and L_2, if $L_1 >_O L_2$, then $L[L_1] >_P L[L_2]$, where $>_O$ represents the relation of overall comparison that takes into account all the theoretical virtues and their tradeoffs, of which of which $>_S$ is a contributing factor.

Principle of Explanatory Virtues (PEV) For two propositions L_1 and L_2, if $L_1 >_O L_2$, then $Exp[L_1] >_P Exp[L_2]$, where $>_O$ represents the relation of overall comparison that takes into account all the theoretical virtues and their tradeoffs, of which of which $>_S$ is a contributing factor, and $Exp[\cdot]$ denotes *is an explanation*, which is an operator that maps a proposition to one about explanations.

PNS is useful for resolving cases of empirical equivalence constructed along Algorithms A-C.

- Algorithm A. T_2 will in general employ much more complicated laws than T_1.
- Algorithm B. $L2$ will in general be more complicated than $L1$, if Ω^{L_2} is obtained from Ω^{L_1} by adding or subtracting a few models.
- Algorithm C. Even though the mosaics of $L1$ and $L2$ are not that different, if $L1$ is a simple system, then in general $L2$ will not be.

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- They are different kinds of principles
- One is a metaphysical definition of what laws are
- The other is an epistemic principle concerning ampliative inferences based on our total evidence.
- Even if a Humean expects that the best system is no more complex than the mosaic, it does not follow that she should expect that the best system is relatively simple
- There is no metaphysical guarantee that the mosaic is "cooperative."

- Both Humeans and non-Humeans can be uncertain about the laws.

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- Both Humeans and non-Humeans can be uncertain about the laws.
- Both need a new principle to justify epistemic realism.
- If Humeans are epistemically warranted in making such a posit, non-Humeans are too.

Simplicity as a Fundamental Epistemic Guide to Lawhood

Further clarifications:

- *Simplicity*
- *Guide*
- *Lawhood*
- *Epistemic*
- *Fundamental*

Simplicity

- It is unrealistic to insist that there is a single measure of simplicity regarding physical laws.
- There are many aspects of simplicity, as shown by recent works in computational complexity, statistical testing, and philosophy of science.
- Among them are: number of adjustable parameters, lengths of axioms, algorithmic simplicity, and conceptual simplicity.
- Certain laws may employ more unified concepts, better achieving one dimension of simplicity, but require longer statements and hence do less well in other dimensions of simplicity.
- There need not be any precise way of trading off one over the other.
- I suggest that we take simplicity to be measured in a holistic (albeit vague) way, taking into account these different aspects of simplicity.

- The vagueness of simplicity might seem like as a problem for nomic realists.
- However, what matters to a realist who believes in simplicity is that there is enough consensus around the paradigm cases.
- There are hard cases of simplicity comparisons, but there are also clearcut cases, such as T_{M1} and its empirical equivalents generated by Algorithm A, or general relativity and its empirical equivalents generated by Algorithms B and C.

- The vagueness of simplicity does not imply that there are no facts about simplicity comparisons.
- Let us think about an analogy with moral philosophy.
- Judgments about moral values are also holistic and vague.
- While there are moral disagreements about hard cases, there can still be facts about whether helping a neighbor in need is morally better than poisoning their cat.
- Moral realists can maintain that we have robust moral intuition in paradigm cases, which are not threatened by the existence of borderline cases.
- Sometimes different moral considerations conflict. In such cases, we may need to trade-off one factor against another. There is no precise metric.

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- It is what we presuppose when we set aside (or give less credence to) those empirical equivalents as epistemically irrelevant.
- For our preferences to be epistemically justified, the principle of simplicity should be an epistemic guide.

Epistemic

Other epistemic issues grounded in PNS:

- Induction
- Symmetries
- Determinism
- Dynamics
- Explanation

Epistemic

- Hume's problem of induction is closely related to the problem of underdetermination.
- We want to know the physical reality (L, ξ).
- Given our limited evidence about some part of ξ and some aspect of L, what justifies our inference to other parts of ξ or other aspect of L that will be revealed in upcoming observations or in observations that could have been performed? It does not follow logically.
- Without some *a priori* rational guide to what (L, ξ) is like or probably like, we have no rational justification for favoring (L, ξ) over any alternative compatible with our limited evidence.
- On a given L we know what kind of ξ to expect. But we are given neither L or ξ. Without further inferential principles, it is hard to make sense of the viability of induction.

Epistemic

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It is not clear what the principle says and how it relates to induction.

We should just replace PU with PNS (or PNV more generally) as the ultimate justification of induction.

Epistemic

- As such, PNS is not merely a pragmatic principle, although it may have pragmatic benefits.
- Simpler laws may be easier to conceive, manipulate, falsify, and the like.
- But if it is an epistemic guide, it is ultimately aiming at certain truths about lawhood and providing epistemic justifications for our believing in such truths.
- There is, to be sure, the option of retreating from epistemic realism. But it is not open to nomic realists.

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- There is no inconsistency, because *which laws actually obtain* can differ from *which laws we should believe in*.
- Hence, defenders of BSA are in a similar epistemic situation as defenders of MinP.

Humeanism vs. non-Humeanism

- To see this, let us recall the comparison between T_{M1} and T_{M2}.
- Following Guide-to-Lawhood, a Humean scientist living in a world with Maxwellian data would (and should) prefer T_{M1} to T_{M2} because the laws of T_{M1} are simpler.
- However, on BSA, it is metaphysically possible that the actual ontology does not include fields.
- If that is the actual mosaic, the best system may in fact correspond to the enormously complicated laws of T_{M2}.
- It follows that what counts as the actual best system on the BSA may differ from what we should accept as the best system according to Guide-to-Lawhood.

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- Influential argument (Earman and Roberts 2005; Roberts 2008): Humeanism has an epistemic advantage over non-Humeanism, because the former offers better epistemic access to the laws.
- Basic idea: the Humean mosaic is all that we can empirically access, on which laws are supervenient, but non-Humeans postulate facts about laws that are empirically undecidable.

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- Our total evidence E (macroscopic and finite) will never exhaust the entire mosaic ξ.

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- Our epistemic access to laws depends on this new principle of simplicity.
- It does not follow from the metaphysical posits of either Humeanism or non-Humeanism.
- They are epistemically on a par, with respect to the discovery and the evaluation of laws.

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- But the risk is no smaller on Humeanism than on non-Humeanism.
- We need to decide what the physical laws are, in the vast space of possible candidates, based on our finite and limited evidence about the universe.
- The principle of simplicity encourages us to look in the direction of simpler laws.

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- It vindicates epistemic realism when there is empirical equivalence (at least in those cases discussed here),
- avoids probabilistic incoherence when there are nested theories,
- and supports realist commitments regarding induction, symmetries, dynamics, determinism, and explanation.

With many theoretical benefits for only a small price, it is a great bargain.

Thank you for your attention!