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HOLES IN SPACETIME: SOME NEGLECTED ESSENTIALS*

Call a proposition *qualitative* just in case it's not about any particular objects; call all other propositions *haecceitistic* (I'll also call these *non-qualitative* propositions). For example, the proposition that someone is sitting is qualitative, whereas the proposition that Larry is sitting is haecceitistic. Call a property F qualitative just in case the proposition that something has F is qualitative; call all other properties haecceitistic or non-qualitative. For example, the property of liking someone is qualitative, whereas the property of liking Larry is haecceitistic. With these distinctions in hand, we can state two senses in which some laws of nature L may be deterministic:

> *Full Determinism*: For all metaphysical possibilities w and w' where L is true, if there is a time t at both w and w' such that t has the same intrinsic properties at both w and w', then w and w' agree on the truth value of every proposition.

> *Qualitative Determinism*: For all metaphysical possibilities w and w' where L is true, if there is a time t at w and a time t' at w' such that t has the same *qualitative* intrinsic properties at w that t' has at w', then w and w' agree on the truth value of every *qualitative* proposition.[1]

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[1] A few comments about these definitions. First, arguably the definitions should be phrased in terms of arbitrarily small temporal intervals rather than particular times (so as to allow rates of change into the initial data when evaluating whether some laws are deterministic), but I'll ignore this subtlety throughout. Second, the intrinsic qualifiers are intended to exclude properties that directly encode information about different

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Ever since Earman and Norton resurrected Einstein's hole argument, and set it loose in the foundational discussion of spacetime theories, an industry has grown up around searching for doctrines which ensure that the qualitative determinism of the laws of Einstein's General Theory of Relativity (hereafter 'GR') implies that those laws are also fully deterministic.[2] I'm ultimately going to use this challenge to argue for certain doctrines in the metaphysics of spacetime and the metaphysics of modality, but before getting there let's first see what all the fuss is about.

I. THE HOLE STORY

Some quick preliminaries before stating Earman and Norton's argument. First, I'll take it for granted that metaphysical modality obeys the modal logic S5. Second, I'll assume throughout that the nomic possibilities at any metaphysical possibility *w* just are the metaphysical possibilities where the laws of nature at *w* are true. This assumption is neutral between the standard view that the space of nomic possibilities is properly included in the space of metaphysical possibilities, and its

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times as being among those we must consider when checking whether two metaphysical possibilities agree at a time. For instance, consider the property of being a time fifty years before a time at which there is a nuclear war. Supposing some time *t* has this property, it's not one of *t*'s intrinsic properties. Without some ideology to rule out such properties, any laws whatsoever will trivially turn out deterministic on either definition. Note the qualifiers are intended to allow properties concerning the material objects (if any) located at some time to nonetheless count as intrinsic properties of that time. For discussion of distinctions between different varieties of determinism akin to my qualitative versus full determinism, see Gordon Belot, "New Work for Counterpart Theorists: Determinism," *The British Journal for the Philosophy of Science,* XLVI, 2 (June 1995): 185–95; Carolyn Brighouse, "Determinism and Modality," *The British Journal for the Philosophy of Science,* XLVIII, 4 (December 1997): 465–81; Joseph Melia, "Holes, Haecceitism and Two Conceptions of Determinism," *The British Journal for the Philosophy of Science,* L, 4 (December 1999): 639–64; and John Hawthorne, "Determinism De Re," in his *Metaphysical Essays* (Oxford: Oxford University Press, 2006), pp. 239–43. Some of these works discuss notions of determinism that go beyond qualitative determinism but fall short of full determinism. These intermediate options don't affect the central dialectic in what follows, however, so I'll set them aside.

[2] For the classic reference, see John Earman and John Norton, "What Price Spacetime Substantivalism? The Hole Story," *The British Journal for the Philosophy of Science,* XXXVIII, 4 (December 1987): 515–25. For recent overviews of the hole argument and the menu of possible replies, see Oliver Pooley, "Substantivalist and Relationalist Approaches to Spacetime," in Robert Batterman, ed., *The Oxford Handbook of Philosophy of Physics* (Oxford: Oxford University Press, 2013), pp. 522–86, section 7; and John Norton, "The Hole Argument," in Edward N. Zalta, ed., *The Stanford Encyclopedia of Philosophy* (Fall 2015 Edition). As Earman and Norton point out ("What Price Spacetime Substantivalism?," *op. cit.*, pp. 517–18), their argument in fact applies to a general class of classical (non-quantum) field theories, sometimes called "local spacetime theories," not just to GR, but in the main text I'll focus on GR (our current best spacetime theory).

PRINCIPLES OF INDIFFERENCE*

Bayesian epistemology is often characterized by the core constraints that (1) the epistemic states of rational agents should be conceived of in terms of precisely quantified numerical "degrees of belief" or "credences," (2) a rational agent's credences should always be probabilistic, and (3) upon learning new evidence, rational agents should update their credences by means of Bayesian conditionalization.[1] But these norms alone are not sufficient to define a universally applicable epistemic strategy for rational agents. Most pertinently, (1), (2), and (3) tell us nothing about what initial credences agents should adopt at the very beginning of their credal lives, before they obtain any relevant evidence about the world.[2] The best-known solution to this problem is given by the *principle of indifference*, as follows:

> *Principle of Indifference* (PI): Let $X = \{x_1, x_2, ..., x_n\}$ be a partition of the set W of possible worlds into n mutually exclusive and jointly exhaustive possibilities. In the absence of any relevant evidence pertaining to which cell of the partition is the true one, a rational agent should assign an equal initial credence of $\frac{1}{n}$ to each cell.[3]

Armed with PI, the Bayesian now has access to a complete recipe for rationality that instructs agents not only on how to revise their credences in the face of new evidence, but also on what credences they should adopt in the absence of all evidence. And of course, PI is an extremely intuitive and plausible principle with a number of independent justifications.[4]

Sadly though, it turns out that PI leads immediately to paradox once one attempts to apply it across multiple partitions of possibility

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[1] That is, upon learning evidence E, an agent should assign any proposition X a posterior degree of belief $P(X|E) = \frac{P(X \wedge E)}{P(E)}$.

[2] Rather, they tell us nothing other than that those credences should be probabilistic.

[3] For simplicity, I restrict my analysis to the finite case throughout the article. Since the paradoxes in question already arise in the finite setting, I take this to be an admissible simplification for present purposes.

[4] PI has been justified, for example, by considerations concerning epistemic utility (Richard Pettigrew, "Accuracy, Risk, and the Principle of Indifference," *Philosophy and Phenomenological Research*, XCII, 1 (January 2016): 35–59), risk aversion (Jon Williamson,

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space at the same time. To illustrate, consider the following example (due to van Fraassen[5]). A hypothetical factory manufactures qualitatively identical cubes. The only information you are given is that the length of a side of any cube is at most two feet. This implies that the length of a side is either between 0 and 1 ($L_{0,1}$), or between 1 and 2 ($L_{1,2}$). These possibilities define a partition $X_1 = \{L_{0,1}, L_{1,2}\}$, and PI requires you to distribute your credence equally across its cells. Specifically, your prior probabilistic credal state *Pr* should satisfy the equality $Pr(L_{0,1}) = 1/2 = Pr(L_{1,2})$.

However, instead of asking about the length of a side, you could equally well ask about the area of a side. The fact that the length of any side is at most two feet entails that the area of any side is at most four square feet. So we can partition the possibility space into the four possibilities: $X_2 = \{A_{0,1}, A_{1,2}, A_{2,3}, A_{3,4}\}$. Again, the evidence gives you no reason to prefer any one of these possibilities to any other, so PI requires you to assign them all equal prior probability, $Pr(A_{0,1}) = Pr(A_{1,2}) = Pr(A_{2,3}) = Pr(A_{3,4}) = 1/4$.

Now note that the sentences $L_{0,1}$ and $A_{0,1}$ are *logically equivalent*. But PI has required you to assign them different probabilities (1/2 and 1/4, respectively). Following PI, you have assigned two contradictory credences to a single proposition.

This paradox, of which there are many versions, has puzzled philosophers for roughly a century. One popular prospective solution (advocated by Keynes[6] and Kass and Wasserman,[7] among others) has been to argue that there are certain "privileged" partitions over which rational agents should apply PI. For example, it might be argued that in the cube example, you should only apply PI to the finer partition X_2, and then derive your credences over X_1 from the distribution over X_2. However, the details of such a resolution have remained problematic, and the philosophical foundations of this approach have been extensively critiqued in the literature (see, for example, von Mises,[8]

"Motivating Objective Bayesianism: From Empirical Constraints to Objective Probabilities," in W. Harper and G. Wheeler, eds., *Probability and Inference: Essays in Honour of Henry E. Kyburg, Jr.* (London: College Publications, 2007), pp. 155–83), evidential support (Roger White, "Evidential Symmetry and Mushy Credence," *Oxford Studies in Epistemology*, III (2009): 161–86), informativity (E. T. Jaynes, "The Well-Posed Problem," *Foundations of Physics*, III, 4 (1973): 477–92), and the Principal Principle (John Hawthorne et al., "The Principal Principle Implies the Principle of Indifference," *The British Journal for the Philosophy of Science*, LXVIII, 1 (March 2017): 123–31).

[5] Bas C. van Fraassen, *Laws and Symmetry* (Oxford: Clarendon Press, 1989).

[6] John Maynard Keynes, *A Treatise on Probability* (New York: AMS Press, 1979).

[7] Robert E. Kass and Larry Wasserman, "The Selection of Prior Distributions by Formal Rules," *Journal of the American Statistical Association*, XCI, 435 (1996): 1343–70.

[8] Richard von Mises, *Probability, Statistics, and Truth*, 2nd rev. English ed. (New York: Dover, 1981).