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THE NATURE OF NATURAL LAWS

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That laws of nature play a vital role in explanation, prediction, and inductive inference is far clearer than the nature of the laws themselves. My hope here is to shed some light on the nature of natural laws by developing and defending the view that they involve genuine relations between properties. Such a position is suggested by Plato, and more recent versions have been sketched by several writers.[1] But I am not happy with any of these accounts, not so much because they lack detail or engender minor difficulties, though they do, but because they share a quite fundamental defect. My goal here is to make this defect clear and, more importantly, to present a rather different version of this general conception of laws that avoids it.

I begin by considering several features of natural laws and argue that these are best explained by the view that laws involve properties, that this involvement takes the form of a genuine relation between properties, and, finally, that the relation is a metaphysically necessary one. In the second section I start at the other end, and by reflecting on the nature of properties arrive at a similar account of natural laws. In the final section I develop this account in more detail, with emphasis on the nature of the relation between properties it invokes. Along the way several natural objections to the account are answered.

I. Nowadays there is widespread agreement that natural laws are true statements of the form '$\forall x(Gx \supset Fx)$', where 'G' and 'F' are predicates that make no reference to any particular spatio-temporal locations. This general view is often known as the *regularity theory,* for although variants are possible, all share the Humean conviction that there is no necessity in nature and, hence, that laws record only actual or *de facto* regularities. Laws require something more than mere regularities, however, for not every true universal generalisation with purely qualitative predicates expresses law. For Hume this something more was psychological, a certain sort of expectation fostered by habit. Recent regularity theorists have favoured logical, pragmatic, or epistemological additions, however, urging that a generalisation qualifies as a law only if it is integrated into a comprehensive deductive system, if we have acquired the habit of projecting predicates coextensive with those it contains, if

[1] For Plato's remarks see *Phaedo,* pp. 103ff; more recent versions of this position are defended by Armstrong [1], Dretske [4], and Tooley [17]. Sometimes laws are said to involve observable things while theories involve unobservables, but to avoid multiplying distinctions I shall construe laws more broadly so that they can involve properties like charge and angular momentum that, by any standard, are unobservable.

it plays a certain cognitive role (say by figuring in explanations), or the like (cf., Brathwaite [3], p. 317; Goodman [7], p. 98; Nagel [13], p. 64).

But although these accounts manage to draw *a* distinction between laws and merely accidental generalisations, the way in which they do so leaves them powerless to account for a number of basic features that laws are widely acknowledged to have. For example laws — unlike accidental generalisations — can be confirmed by their instances and sustain counterfactuals. But it has never been made clear how such things as being integrated into a comprehensive theory or being employed in explanations could enable a generalisation to support counterfactuals, lend it predictive power, or allow it to be confirmed by its instances. Some regularity theorists have taken the heroic line that it is a mistake even to try to explain such matters, insisting, for example, that a sentence is viewed as a law *because* we use it in making predictions, rather than conversely (Goodman [7], ch. 1). But this makes the existence of a law thoroughly dependent upon our conventions or habits, and so ill accords with our intuitive picture of laws as objective — as discovered rather than created. Indeed, milder forms of this difficulty beset most versions of the regularity theory, for whether a generalisation is integrated into a deductive system or plays a certain cognitive role depends upon us and the systems that we happen to have devised. And although objectivity might be restored by holding that laws are generalisations that *could* be part of a theory or put to a certain use, this would require the employment of precisely the sort of modal idiom regularity theorists have been so anxious to avoid.

These difficulties lie at the very core of the regularity theory, but they do not exhaust its shortcomings. In addition, its basic notion of a purely qualitative predicate has proven extremely elusive. Moreover, many versions of the regularity theory are not even extensionally adequate, for it is not difficult to find sentences that were once justifiably regarded as expressing laws even though they were not embedded in any deductive network, had no obviously unique cognitive role, or possessed little explanatory power. Then too, the regularity theory leads to well-known paradoxes of confirmation, to implausible accounts of counterfactuals, and to difficulties in accounting for statistical laws and vacuous laws.[2] Yet for lack of competitors the regularity theory is with us still. What seems needed to dislodge it is a better account of laws, and the remainder of this section is devoted to outlining one.

If properties are viewed in certain common ways, say, as meanings of predicates or as transcendent universals, the claim that they figure in laws will seem implausible, so I shall first say a word about the conception of properties at work in what follows. There are, to begin with, a number of reasons for rejecting the fashionable view that properties are meanings (Swoyer [15]), the simplest of which is that non-synonymous terms like 'temperature' and 'mean-molecular kinetic energy' can refer to the same property. Indeed, the only reason I can see for supposing that there are such things as properties at all is that a philosophical theory of them has *explanatory value,* helping us to account

[2] For detailed criticisms see Harré and Madden [8] or Dretske [4].

for such things as qualitative resemblance, possibility, various semantic notions, and our ability to correctly apply predicates to novel instances.[3] Hence the best way to learn what properties are like is to ask what something would *have* to be like in order to account for the things that properties are invoked to explain. And once we adopt this strategy, we find strong reasons for supposing that properties exist only if they are exemplified in space and time, and that they confer some sort of causal powers upon the things instantiating them. In a nutshell, the reason for concluding this is that unlocalised or causally inert properties would lack explanatory value. Moreover, the difficulties concerning the way in which language could be linked to such properties and, indeed, the way in which we could ever come to know anything about them at all are at least as great as the similar epistemological difficulties surrounding abstract objects like numbers and sets (cf. Benacerraf [2]).

On the view I am proposing, the claim that there are such things as properties is a philosophical one, but determining just what properties there are is — like questions about existence generally — an empirical matter. At least in the case of properties of interest in science, discovery of which properties there are goes hand in hand with discovery of the laws of nature. We come to believe that candidate properties like entropy and charge are genuine because we have reason to accept statements of laws that postulate them, while we may doubt the existence of impetus or electrodynamic potential because of doubts about accounts that postulate either. Scientists themselves, of course, need not use the word 'property' or embrace a realist metaphysics, for the claims that if there is such a thing as entropy then it is a property, or that two terms designate the same property rather than ones that are merely correlated, are philosophical interpretations. But the material for these interpretations is empirical.

Science is more plausibly thought to involve properties than might be supposed. It is true that many philosophers think of laws as involving physical magnitudes rather than properties, often explicating such magnitudes as functions from sets of physical objects into the real numbers, and for such purposes as axiomatisation this can be useful. Nevertheless a function like 'rest mass in kilograms' will map an object to 5.3 *because* of something about the object, viz. the mass that it has, rather than conversely. And so I propose to view *each* specific physical magnitude of this sort as a genuine property. (Following W. E. Johnson, we may call such specific properties *determinates* and the general classes into which they fall, e.g. mass simpliciter, *determinables*.) Again, some laws involve natural kinds, and these too can be viewed as properties, typically complex ones (cf. Armstrong, [1], pp. 65ff). On this account, for example, the property of being an electron may be viewed as conjunctive, including such determinate properties as a charge of -1.602×10^{-19} coulomb (*e*, hereafter), a rest mass of 9.10908×10^{-31} kg, and a spin of 1/2.

[3] These remarks are intended only to make this view of properties reasonably clear; the view itself, and particularly the remarks in this paragraph, are defended in Swoyer [15] and [16]. A more detailed defence of a position that is in some though not all aspects similar to mine may be found in Armstrong [1].

Talk of such properties as rest mass of 3.0 kg is not meant to suggest that there is anything particularly quantitative about either properties or laws. Assignments of numerical values depend upon the system of units we have chosen to represent our measurements, and this choice is at least partly conventional. Still our talk of values and our use of mathematics in drawing inferences about determinate magnitudes is justified because there are usually basic structural features that a family of determinates has in common with numbers. More precisely, there are typically relations between the determinate properties falling under a given determinable, and it is often possible to devise axioms characterising these relationships and to prove a *representation theorem* showing that there is an isomorphism between any model of the axioms and some appropriate numerical model which justifies our application of numbers to things in the world.[4]

Finally it is worth noting that many properties are likely to be rather different from such stock examples as colours or shapes. They may be unfamiliar features of unfamiliar things, e.g., the mass-energy or gravitational-field intensity instantiated by space-time points. Moreover, it is arguable that the uncertainty principle reflects more than a limitation of our ability to determine the simultaneous values of conjugate parameters and that a particle simply does not have, say, a definite position and momentum at the same time. Hence, some properties may be a sort of smear along a given region of values. Again, in a special-relativistic world an object's energy will differ when measured from different inertial frames of reference. Yet if properties are objective entities, their existence and nature should be independent of such contingent matters as the frame of reference that we happen to occupy (compare the way in which the dependence of secondary qualities upon aspects of our sensory apparatus has led many to deny that they are objective features of physical objects). Indeed, this dependence of such things as momentum, energy, and (purely) spatial or temporal relations upon our point of view suggests that many of the things commonly regarded as properties and relations are really just components — differing from frame to frame — of more complicated, invariant things like the energy-momentum 4-vector and the interval. And this suggests that it is these more complicated, invariant things — vectors and tensors — that are genuine properties.

Special relativity, of course, is not the last word on these matters, though as

[4] We would also want to prove what measurement theorists call a *uniqueness theorem,* showing how any two such isomorphisms are related and thereby justifying the use of a particular kind of scale of measurement. For us, the relevant empirical model would have the form $\langle D, R_1 \ldots R_n \rangle$, where D is a set of determinate properties (rather than a set of things exemplifying them) and $R_1, \ldots R_n$ relations on D. If D is the set of determinate masses, for example, R_1 might be the relation that holds between two properties just in case the first is an equal or smaller amount of mass than the second (R_1 will not also hold between objects that have mass, though below we will see how to define it in terms of relations that do). And our numerical model might be $\langle N, \leq, + \rangle$, where N is the set of positive real numbers and $\leq$ and + the obvious relations on it. We could then adopt well-known axioms to get the theorems we want. This may seem to commit us to the existence of abstract objects like numbers, but an important step toward dispensing with them is taken in by Field [5] (who notes, but doesn't develop, the view of representation and uniqueness theorems proposed here).

we move beyond it properties become even more exotic, until in a programme like geometrodynamics all of them might be thought of roughly as complicated structural properties of space-time. But while such possibilities should not be forgotten, they raise complications that are not directly relevant to our present concerns, and to keep our discussion manageable, I shall often use more familiar examples of (putative) properties and laws, some of which are no doubt fictitious.

It will be easiest to develop our positive account of laws in several stages, beginning with reasons for supposing that laws somehow involve properties. In the first place, there is the Quinean consideration that scientists may quantify over properties, as in 'There is some property of salt that makes it soluble in water', in ways that are not easily analysed away. Far more significant, I think, is the difficulty of explaining how science can be as objective as it is if we are unwilling to speak of properties. For example, writers like Feyerabend and Kuhn have urged that theoretical terms draw their meanings from the theories in which they occur, so that different theories, or different stages of an evolving theory, cannot easily be compared. A standard realist response to such claims is to grant that the meanings of theoretical terms may in *some* sense alter as their containing theory undergoes change, but to argue that in at least some cases their reference remains fixed. And since it is reference (or, more generally, extensional notions) that determines truth-conditions, this is enough to let rational theory comparison get under way. Yet such an answer makes little sense unless there *is* something to which theoretical terms can refer, and with such terms as 'mass' or 'kinetic energy' the only plausible candidate for a referent seems to be a property.

It has also been argued, plausibly I think, that inter-theoretic reduction often proceeds by showing that some terms of the reducing theory refer to the same things as do certain terms of the theory being reduced (though the latter theory may make less accurate claims about them). But with such terms as 'mean molecular kinetic energy' and 'temperature' the thing referred to must be something very like a property. Again, it is natural to think of measurement as an attempt to obtain knowledge about the objective features of things, so that talk of a correct scale of measurement, use of different operations to measure the same quantity, and measurement error make sense. Yet such talk is difficult to interpret unless objects are taken to have certain determinate properties or magnitudes. In short, a nominalist cannot avail himself of the sorts of accounts of theory comparison, reduction, and measurement alluded to here. And though it is possible to adopt an anti-realism with respect to these matters, such representative versions of this doctrine as verificationism and operationalism suggest that this is an unappealing alternative. One could enjoy these advantages of properties, however, while yet maintaining that laws merely express *regularities* in the ways in which properties are exemplified, rather than a genuine relation between properties. But as we will now see, the latter view has much to recommend it.

The leading idea of property theories of laws is that 'all Gs are Fs' expresses a law (when it does), not because of a mere regularity, but because there is something about a thing's being G that is responsible for its being F. Minimally, a property theory holds that there is some relation, let us call it *nomic implication* ('*I*' for short), that holds between properties just in case anything exemplifying the first exemplifies the second as well. On this account, laws are not sentences or statements, but objective facts, and the logical form of a *statement* of a law is simply '*I*gf'.[5] Different versions of the theory will construe the *I*-relation in different ways, but it is useful to begin with this minimal characterisation so that we may discuss property theories generally, without having to worry about such differences.

A chief virtue of the property theory is that it takes widely acknowledged features of laws at face value and provides a *better explanation* of them than do its competitors. Unlike regularity theories, for example, it can account for the objectivity of laws, for the *I*-relation holds between whatever properties it does quite independently of our conventions and practices. Moreover, it locates the difference between a law and a mere regularity in the nature of things, with the former holding because of a genuine relation between properties and the latter because of facts about individual objects. Talk of nomic implication may seem merely to label the difference between laws and regularities, however, and the real test comes in seeing whether it enables us to explain why statements expressing laws are confirmed by their instances, have predictive power, support counterfactual conditionals, and the like.

The property theory's account of these matters, foreshadowed by such writers as Keynes ([9], ch. 22), is basically this. It is unclear what could justify accepting a mere generalisation (even one with pragmatic or epistemological trappings) short of checking all of its instances, for if laws *merely* record regularities, why should the fact that two properties have been found to be coinstantiated or to be instantiated in succession be thought to tell us anything about unobserved cases? Yet if a sentence telling us that all Gs are Fs is regarded as 'lawlike', we often feel justified in accepting it after observing just a few positive instances. This practice would seem to be warranted only if there is something *about* a thing's being G that at least makes it probable that it is also F. And the property theory nicely accounts for this, for if g bears the *I*-relation to f, the second property will accompany the first in all cases, allowing us to make predictions about unexamined instances as well as to confirm a

[5] I shall use 'F', 'G', 'H', ... as predicate variables and 'f', 'g', 'g', ... as variables for abstract *singular* terms that are formed from each of the respective predicates by a nominalisation transformation (cf. 'is red' and 'redness' in English). On this view properties are denoted only by singular terms, and so we may confine ourselves to first-order logic. The question is a delicate one, but for purposes of illustration we may imagine abstract singular terms and predicates to be related by a principle along the lines of '$\mathrm{f} = (\iota y) \Box \forall x (x \alpha y \equiv \mathrm{F}x)$', where x and y are distinct variables, y is not free in F, and '$x \alpha y$' tells us that x exemplifies or instantiates y. The schema of course needs refinement, for the view that every open sentence determines a property leads to paradox and, moreover, on our view it is an empirical question just what properties exist. Nevertheless, I think that an acceptable version of the principle and of one giving the identity conditions for properties can be framed in a (modal) first-order theory of the exemplification relation that is in some ways analogous to first-order theories of the set membership relation (for further discussion, see [16]).

generalisation about all of them.

This is not to deny that the presence of a property in some circumstances may be evidence for that of another even when the two are not in general nomically related. When this occurs, however, we typically have reason to believe that the two are coinstantiated because of some further laws and properties, known or unknown. Thus we may view the presence of g in things of a given kind as evidence for the presence of f because we suppose there are properties of things of that kind that lead them to have f when they have g. In other cases g and f may be linked by properties of highly theoretical objects or by a number of properties of events in some causal chain connecting instantiations of g and of f. But the general point remains that *unless* we have reason to suppose that there is something about these further properties that is responsible for their being coinstantiated or successively instantiated in the way that they are, we would have no reason for predicting that f will accompany g in the circumstances in question. Of course in any given case we may be mistaken in supposing properties to be lawfully connected — that is one reason why a variety of evidence is important — but it is not the task of a theory of laws to abolish the inductive uncertainty of science.

We frequently accept counterfactual conditionals telling us that if something *had* been G, then it *would* have been F, and our reasons for doing so are often similar to our reasons for accepting the claim that unobserved Gs are actually Fs. Recent property theorists would like to explain this by saying that if g nomically implies f, then if anything had exemplified g, it would have exemplified f as well. But here we encounter a snag, for according to current versions of the property theory, laws of nature are contingent (Armstrong [1], Dretske [4], Tooley [17]). But if so, what assurance do we have that g and f will be nomically related in counterfactual situations? There is no guarantee that they will be. Indeed, if the laws of our world are deterministic, the truth of the antecedent of *any* of our common counterfactuals about situations like the actual one up to a given time, but different thereafter, will require the violation of at least one natural law (cf. Lewis [11], ch. 3). It may be that in most of our counterfactual reasoning the law in question should for some reason be assumed to hold, but this response is equally available to the regularity theorist. Furthermore, these ruminations suggest that *if* it is merely a *contingent* fact that a given property bears the *I*-relation to another, the property theorist's accounts of prediction and confirmation are not so straightforward as they might seem. For even if one property bears this relation to a second in all observed cases, what justifies the claim that it does so in unobserved ones, especially those in the remote future or past?

In light of these difficulties, why have recent property theorists held that the *I*-relation can only provide a contingent link between properties? The reasons seem to be those that have led so many others to view laws as contingent. *First,* natural laws can only be known *a posteriori,* and this alone has often been taken to guarantee their contingency. *Second,* it often seems that we can imagine what it would be like for at least some laws to have been different, and the Humean tendency to collapse conceivability and possibility has led many empiricists to conclude that these laws could fail to obtain. *Third*, any suggestion that laws enjoy some sort of necessity is usually met with the claim that their mode of necessity is unfathomable. And until recently these considerations were powerful ones. With the exception of William Kneale's writings, for example, many expressions of the view that laws are necessary suffer guilt by association with an idealist metaphysics. More important, in much twentieth-century philosophy the only necessities countenanced were logical necessities and other analytic truths, and these — unlike laws — can be known *a priori*.[6]

The first consideration noted above reflects a tendency to view modal notions in epistemological terms. The resulting conception of necessity is unduly narrow, however, for as recent work by various philosophers has shown, there certainly appear to be necessary truths — christened *metaphysical necessities* by Kripke — that can only be known *a posteriori*. As for the second consideration, we often suppose we can imagine some situation that there is, upon reflection, good reason to suppose impossible (cf, Kripke [10]), and in any case there is surely little to recommend the view that what is possible is determined by our imaginative capacities. Thus the first two reasons for supposing natural laws to be contingent have lost much of their force. As for the third, although metaphysical necessity is not as clear as we might wish, the work of a number of recent philosophers has cast enough light on it to suggest that it is real enough. This of course at most clears the way for the claim that laws are necessary. I shall try to give reasons for supposing that they are.

Recent property theorists tell us that (1) '*I*gf' is a logically sufficient but not necessary condition for (2), '$\forall x((x\alpha g \supset x\alpha f)$ & Exists g & Exists f)' — though little is said about the logical principle underlying this entailment. This means that there could be two impoverished worlds, w_1 and w_2, in which g and f are the only properties and such that exactly the same sentences not involving '*I*' — including (2) — are true at each, while (1) is true at w_1 but false at w_2.[7] Such a possibility is not fatal to recent property theories, but it does show that their distinction between laws and *de facto* regularities is not so sharp as it originally seemed. For under such circumstances, what difference could the *I*-relation make? Indeed, what could warrant the belief that the actual world contains laws rather than mere regularities, that it is a complicated analogue of w_1 rather than of w_2?

It might be replied that there is still an important though undetectable difference between w_1 and w_2, for in the latter everything would happen by coincidence — which is unlikely. But even if this is so, recent property theories

[6] The only clear notion of a logical necessity is surely that of a logical truth. Roughly speaking, a sentence is logically true (relative to a given list of logical constants) just in case it remains true under every grammatically acceptable reinterpretation of its non-logical vocabulary. A sentence is said to be analytic just in case it is true solely in virtue of the meanings of its terms — whatever that may mean.

[7] This point could be made more cumbrously by talking about counterfactual situations without mentioning possible worlds. The existence claims in (2) are needed because there is reason to suppose that a property exists only if it is exemplified; those who disagree may view these clauses as redundant.

face a similar problem one level up (this is the difficulty alluded to in the introduction). In effect, they offer us a second-order Humean picture, according to which it is simply a brute fact that given properties happen to stand in the *I*-relation to each other; different laws could hold in different possible worlds, and it is just a cosmic coincidence that a given law holds in certain worlds but not in others. On this account, hydrogen might have had an atomic number of 124, neutrons a positive charge, and an increase in the pressure of a gas at constant volume always been accompanied by a decrease in its temperature — it is simply fortuitous that the *I*-relation didn't hold between properties in such a way that these things happen as a matter of law. But to regard the relation of nomic implication in this way is to relinquish the view that there is something *about* the very natures of pressure and temperature themselves that accounts for their lawful connection. I think this view both intuitive and the best reason for accepting a property theory in the first place, and in the next section I shall argue that it is right. First, however, it will be useful to examine briefly several intermediate positions between the view that all laws are merely contingent and the view that all are metaphysically necessary.

One such view tells us that a few, very basic laws are necessary while insisting that the rest are merely contingent. Apart from the problem of finding a principled way of separating these two classes of laws (cf. Shoemaker [14]), this position faces several difficulties. One, discussed in the next section, is that less basic laws often follow necessarily from the laws most plausibly viewed as necessary, and in such cases the former cannot be contingent. Moreover, as w_1 and w_2 show, any putative evidence that properties are contingently but nomically related would also be evidence for the view that they are not nomically related at all, but are merely involved in a *de facto* regularity. Finally, this intermediate position leaves us with the difficulty of accounting for the nature of an *I*-relation that sometimes holds of necessity and sometimes does not, of explaining how those laws that are merely contingent can support counterfactuals, and so on.

A second intermediate position holds that laws enjoy some sort of physical or nomological necessity. Unfortunately, the notion of physical necessity has never been made very clear. It cannot be explained in terms of situations or worlds that are similar to the actual one in any obvious respects, for example, for as the thought experiments of Einstein and others show, laws are often — and profitably — thought to hold in quite outré situations. Indeed, the only characterisation of physically possible worlds seems to be that they are those that have the same laws as the actual world. Hence, accounts of laws in terms of physical necessity fail to explain the notion of a law. Moreover, they suffer a more general version of the same problem that besets the view that laws are merely contingent. Hydrogen might still have had an atomic number of 124; the account in terms of physical necessity merely singles out those situations in which it *happens* not to, broadening its scope to consider all possible worlds sharing the same brute facts about regularities among properties. We will return to this point in the next section, but first we need to tie up a couple of loose ends.

Property theories, including the one I will defend below, must eventually be extended to account for statistical laws, but doing so would require us to answer questions about interpretations of probability that are largely independent of our present concerns. What I would urge here is simply that the property theory can accommodate most of the current interpretations. For example, one might view probabilities as limits of relative frequencies of the exemplification of a given property in certain infinite sequences of events. Or, if one prefers the logical interpretation of probability, one might hold that there is a range of relations of nomic probabilification that can hold between properties, so that if the first is exemplified there is such and such a probability that the second will be as well (Armstrong [1], p. 158). Again, if propensities are among the genuine properties of things and systems, we might have instances of '*I*gf' where g is, say, the complex property of being a polonium atom and f the dispositional property, probably also complex, of having a fifty-fifty chance of decaying within 138 days.

The ontological claim that laws are relations between properties should not lead us to ignore the pragmatic and epistemological issues surrounding laws. In practice we are fortunate to discover statements with terms that refer to genuine properties and which make approximately true claims about the laws in which the properties figure, and it is important to discover just what goes on in such cases. Moreoever, the claim that a property is identical with itself is ontologically trivial, but claims that mass and energy or gravitation and space-time curvature or some mental property and a given functional state are identical may represent important discoveries. Again, although explanation often involves redescribing something in terms of its theoretically relevant properties, one designator of a given property may be capable of figuring in a good explanation while another is not — it depends on what it is we want to understand and on what we already know. Confirmation and reduction also have an epistemological side, and so an account of the ontology of laws cannot fully explain them either. On the current view this is precisely what one would expect, however, for if properties are objective things, they should be capable of what Frege called different modes of presentation, and these are a fertile source of epistemological conundrums.

II. Our task in this section is to examine the nature of properties to see whether they are compatible with the view that laws involve necessary relations among properties. Let us begin by noting that we reason about many counterfactual situations easily enough and that such reasoning is sufficiently determinate to permit widespread agreement about the truth values of many counterfactual conditionals. When we ponder counterfactual situations — (aspects of) possible worlds, as some say — we have little difficulty making sense of the 'transworld identity' of a variety of properties.[8] Indeed, this seems to be a requirement for

[8] Hence abstract singular terms denoting such properties are what Kripke calls 'rigid designators'. I have, with some hesitation, adopted talk of possible worlds because of its familiarity and convenience, but nothing in what follows requires any thorough-going realism with respect to them; if they can be completely analysed away, so much the better (a strategy for doing so is

our using common modal idioms with the success that we do, for without the transworld stability of certain properties we would lose all grip on the identity of individuals and of natural kinds. Imagine trying to decide whether an object in some possible world is identical with some actual table if we were uncertain as to which properties in that world were (determinates of) mass, shape, and colour. Envision trying to discover whether certain sorts of particles were electrons if we had lost our grip on such properties as charge and spin. This is not to say that we typically identify individuals in counterfactual situations by appealing to their properties; usually we do so by stipulation. Nor is it to suggest that any set of properties is sufficient to ensure the transworld identity of an individual. But without some properties to provide limits on admissable stipulations and to provide some foothold for transworld identification, our counterfactual reasoning would be far more indefinite than it is.

What lets us get a handle on talk of the transworld identity of properties? Someone might suggest that their transworld identity is simply primitive, citing standard challenges to the principle of the identity of indiscernibles involving symmetrical universes of cyclical times which seem to provide cases in which we have distinct individuals (in different possible worlds) with exactly the same properties. However, such examples ground the primitive difference of individuals in their distinct spatio-temporal locations, and since a single property can be instantiated at different locations, no similar arguments can be given for the primitiveness of its transworld identity. Moreover, these very examples require a clear picture of what counts as the same property in different worlds, and so they provide little reason to suppose that the transworld identity of properties is primitive. Indeed, I know of no reasons for supposing that they are, and this suggests that properties have essential features. But what might these be?

Perhaps the essential features of properties are somehow phenomenal — their characteristic look or feel, for example. But how an object looks to us depends upon such contingent facts as that the human race has not been struck colour-blind by some exotic disease and, in any case, such properties as valence have no distinctive phenomenal aspects.[9] Perhaps, then, the essential features of a property are higher-order properties. But if so, these higher-order properties will need yet higher-order properties as their essential features, and so on up through an infinitely ascending series of orders. Such a regress need not be vitiating, but there is no evidence for the existence of infinitely many orders or

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noted below). For definiteness, one may interpret my account in terms of S5 with the standard Kripke semantics, though much of it could be reformulated in terms of other systems and approaches.

9 Certain properties of sentient beings may provide an exception. Being in pain, for example, involves a very real content or feel; as Thomas Nagel has aptly put it, there is something that it is *like* to be in pain. If this something is essential to a mental property (rather than just its functional role or physical aspects being essential to it), my claim below that all essential features of properties involve their nomological relations to other properties will need to be qualified in an important, but straightforward, way. However, this would not affect the basic account of laws; indeed, it would help explain why it is so very difficult to find a place for phenomenal features in any nomological account of the world.

properties; indeed, there is little evidence for more than a few. So unless new evidence turns up, we have little reason to accept this solution. But perhaps we can salvage something from this proposal by viewing the essential features of a property as its relationships to other properties of some finite number of orders.

What seems fundamental about the property (of being) one unit of elementary negative charge is that things exemplifying it have certain dispositions or powers, for example, the active power to exert force upon other particles and the passive power or capacity to be acted upon by particles that have various other properties. Indeed, if we subtract the active and passive dispositional powers that a property bestows upon its instances, whatever is left would not enable it to affect our sensory apparatus, measuring instruments, or anything else. Hence, we could never find out about the property, much less regard these inert features as securing its transworld identity when we reason counterfactually. In many cases, of course, an object must instantiate a number of different properties if it is to have a given power and, especially in combination with other properties, a given property may confer a variety of powers. But this does not affect the basic point that the key features of properties are dispositional. Moreover, the causal powers that a property confers upon its instances are not powers to affect or be affected by just anything whatsoever; whether a particle with a negative charge will attract or repel a second particle depends upon what properties the second one has, whether litmus turns red depends upon the properties of the liquid in which it is immersed, and so on. And so it is very plausible to conclude that the essential features of a property lie in its relationships to other properties.[10]

But such relationships between properties look uncommonly like laws. Indeed, I suggest, the essential features of properties simply are (or at least include) their relations of nomic implication to each other. This means that a given property is what it is in virtue of its lawful relations to other properties, while these are what they are in virtue of their further nomic relations, including the ones to the original property. But these interdependencies are not viciously circular, for — unlike numbers, which (if there are any) seem to have as essential features only structural relations to other numbers — we can break into the circle of properties at points where a property confers upon its instances the ability to affect us, either directly through our sensory apparatus or indirectly through measuring instruments or its influence upon other properties. And once we learn something about a property in this way, science may (empirically, of course) discover more and more of its essential features.

This means, for example, that if the determinate property of negative charge *e* as a matter of law always accompanies the complex property of being an electron, then the two properties are necessarily related. This view is reinforced

[10] A nominalistic counterpart of this view is defended by Goodman ([7], pp. 40-42). More realistic versions of a similar position may be found in Harré and Madden [8], Armstrong [1], and especially Shoemaker [14] — though not all would be pleased to see their position allied with essentialism. Anticipations occur in a variety of historical figures. Locke, for example, held that the only real properties ('qualities', as he called them) of physical objects were their primary ones, and often spoke of these mainly as powers (or sources thereof) for affecting other things in certain ways [*Essay*, Bk. II, ch. 8].

by the fact that many would balk at counting something an electron if it lacked *e*. Here, though, it may be objected that the necessity in question does not involve any essential connection between the properties themselves, but rather derives from the meaning of 'electron', 'charge', or the like. However this would be to ignore the detailed experimentation of Millikan and others needed to determine the value of *e*. Moreover, even if someone like J. J. Thomson had first spoken of electrons as 'those particles with *e*', such practices rarely determine the meaning of a term but at most fix its reference. So our tendency to think that there is a very intimate relationship between being an electron and having *e* cannot easily be explained in terms of *de dicto* necessity.

I do not know of any conclusive argument for the claim that the property of being an electron and *e* are essentially related, but perhaps the following example will make this claim seem more intuitive. Imagine a possible world w_1 in which there are putative electrons with some determinate amount of charge e' ($\neq e$) and a world w_2 which includes these particles of w_2 as well as electrons from the actual world. Now in w_2 are the first sort of particles (with e') electrons as well? Most people find it counterintuitive to suppose that they are and, moreover, our best theories of microphenomena seem to require that all electrons have the same charge if claims about the behaviour of atoms and the like are to be correct. And for lack of any good reasons for concluding that both sorts of particles are electrons, these reasons create a presumption that only the first sort are. But if the complex property, call it *p*, possessed by the first sort of particles in w_2 (with e') is not identical with the property of being an electron, then *p* in w_1 is surely not the property of being an electron either. For the presence of some *other* sort of particle in w_2 should have no influence on the identity of the property of being an electron.[11]

Necessary connections among properties are most plausibly thought to exist, I think, at very fundamental levels involving properties of elementary particles or the like. But since such particles constitute all physical things, then unless there are genuinely emergent properties, the properties and relations of fundamental particles are responsible for all other physical properties and relations as well. For example, the particles of an atom are held together partly by electrostatic forces, and these are grounded in properties of charge like *e*. Indeed, the atomic structure of an atom is determined by the arrangement of these particles, mainly the electrons, and this forms a sort of real essence which determines many of the atom's chemical and spectroscopic properties. But if the very basic properties of elementary particles that give rise to (or in some cases are identical with) properties of atoms, molecules, and so on up are themselves

[11] This argument is inspired by a well-known example of Kripke's ([10], fn. 56), though when applied to properties it is less decisive than it is with individuals since we also have to consider whether both properties in w_2 are the same as some actual property. The two sorts of particles in w_2 must be compossible, but since our opponent holds laws to be contingent, we can assume this when arguing against him. If one views the property *e* as *part* of the complex property of being an electron, one may wish to deny that there is a law linking the two properties. Since a variant of this argument can be given to support the claim that *e* is necessarily a component of the property of being an electron and other examples which avoid this difficulty can be found, I have used this example because of its simplicity.

necessarily related, necessity will surely exist at the higher levels as well. And this suggests that if even a few laws are necessary then most laws will be. Such considerations are not conclusive, but together with earlier arguments they provide strong support for the view that laws involve a genuine and necessary relation between properties. In the next section we will examine this relation in more detail.

III. If *I*gf obtains because g and f are essentially connected, it is tempting to conclude that the intrinsic natures of the two properties give rise to the law without the need for any additional relation. Indeed, we might even be able to define '*I*' away, perhaps by viewing '*I*gf' as shorthand for '$\Box \forall x (x\alpha g \supset x\alpha f)$'. However this would make '*I*gf' true whenever g necessarily fails to exist, and this seems undesirable, since it is unclear how a law could be grounded in the nature of an impossible property. Furthermore, this definition would count many things as laws that clearly are not. To require that g actually exist would rule out vacuous laws, however, so let us replace *I*gf by:

N: $\Diamond$ (Exists g & Exists f) & $\Box \forall x (x\alpha g \supset x\alpha f)$.

This makes explicit why a statement of law will entail an accidental generalisation (but not conversely) without the need for any novel principles of inference. Moreover, on any plausible account of counterfactuals, the former will also entail the relevant counterfactual conditional.

The model suggested by *N* is also sensitive to the fact that statements of laws may have quite complicated logical forms, involving relational predicates, layers of quantifiers, and other complexities. For example, if *r* is a genuine relational property and '$xy\alpha r$' tells us that *x* bears *r* to *y*, then '$\Box \forall x \forall y ((xy\alpha r \ \& \ x\alpha g) \supset y\alpha f)$' may be a conjunct of a statement of a law in which the antecedent is about a complex property of *x* and *y*. Indeed, we can now simply appropriate many of the universal generalisations regularity theorists have devised to express laws, adding modal operators, property designators, and existence assumptions in the obvious ways. The property theory differs from the regularity theory in viewing such matters as peripheral, however, for the central contention of our account is that laws involve relations among properties, and there are doubtless many ways of expressing claims about these.

In analysing the *I*-relation away it may seem as though we have abandoned the view that laws involve a genuine relation between properties. This would indeed be the case had we treated laws as brute necessities or construed properties as by-products of our modal apparatus (say as functions from possible worlds to objects therein). But our account does neither. For although it tells us that *I*gf obtains only if f accompanies g in every possible world in which g exists, there will be dramatic differences among many of these worlds — every possible difference from a given world will turn up in some other one.[12] Hence the only things constant in *all* these worlds that could explain why g cannot occur without f are just the properties themselves. In short, *I*gf does not hold *because* '$\forall x (x\alpha g \supset x\alpha f)$' is true in every world; the latter is true in every world because the very natures of g and f make it impossible for there to be a world in which it is false. So Igf obtains, when it does, not because some contingent, primitive relation happens to hold between g and f, but because of a far more intimate, internal relationship grounded in the properties themselves. This relationship is not some third entity over and above the two properties themselves, and this may incline some to deny that it is a genuine relation at all. A dispute over such matters would be mainly verbal, however, for the fact remains that the two properties are internally, and hence genuinely, related.

On the current view laws are necessary while the existence of properties is not, but how could Igf obtain in a world without g and f? If the remarks of the preceding paragraph are correct, there is a straightforward answer in cases where g and f exist in the actual world, for if Igf is necessary, '$-\exists x(x\alpha g\ \&\ -x\alpha f)$' must be true in every possible world. And since what *can* happen *does* happen in some possible world, the truth of this sentence in each can only be explained by the fact that g and f are such that it could not possibly be true. Thus Igf holds in worlds without g and f because of the *nature* of properties in the actual world. There is nothing untoward about this, however, for as I shall argue below, our only grip on the notion of truth in a merely possible world is based upon what is true in the actual one.

This account clearly will not work when g and f fail to exist in the actual world. Nor can we simply ignore this case, for many — perhaps most — of our best guesses about the laws of nature are stated in terms of such idealisations as perfectly black bodies, completely isolated systems, and bodies free of impressed forces. Moreover, statements of general laws of functional dependence have as instances statements about the relationship between specific determinate magnitudes, and these are plausibly thought to express laws even if the specific magnitudes are never instantiated.

Formally matters may seem much the same whether it is the actual world or some merely possible world in which the properties in question fail to exist, but in fact there are important differences between the two cases. We can often be confident about what would be true in certain counterfactual situations on the basis of evidence gathered here in the actual world, but few would claim the power to make predictions about the actual world on the basis of evidence gathered in merely possible situations. Moreover, it would be an utter mystery as to how evidence gathered in the actual world could bear on the truth of counterfactuals unless the truth about might-have-beens is somehow grounded in facts in the actual world. By contrast, it is less clear how facts about merely possible objects or situations could ground the truth of claims about how things actually are. And such considerations recommend the view, sometimes labeled *actualism*, that truths about merely possible worlds, including their properties and laws, must be rooted in facts about the actual world.

Ideally, we would like to show how talk about, and quantification over, *possibilia* can be reduced to talk about, and quantification over, actual particulars, actual properties, and (primitive) modal expressions. But even if we

[12] For brevity, when multiple quantifiers are not involved I shall use the *I*-notation as shorthand for that given by *N*.

can only approximate such reductions, and then case by case, that would support the view that facts about *possibilia* are somehow determined by facts about the actual world. Moreover, sketches of such approximations can sometimes be given. If Kripke is right that a person's origin is essential to him, for example, a geneticist of the future might be able to specify a merely possible individual as the one who would have resulted from the union, never actualised, of a pair of actual gametes and to make true claims about some of her properties and relations to actual things (she *would* have had curly hair and have been shorter than her mother).[13]

Let us call this sort of specification of a merely possible thing in terms of its essential properties and necessary relations to actual things a *rigid description*. Rigid descriptions of merely possible individuals are quite difficult to come by, but they can often be devised for merely possible properties. Thus if $g_1, g_2, \ldots, g_n$ are actual properties that could be exemplified together (but in fact are not), we can sometimes specify the conjunctive property that would result were they to be coinstantiated; something of this sort might occur, for example, if a never-to-be-created variety of elementary particle were to be described in terms of such basic properties as quantum numbers. Again, we often specify determinate properties that may well be uninstantiated in terms of their relationships to actual determinates of the same determinable; in effect this is what happens when we describe a given mass or length in terms of some commonly used system of units. But while such strategies enable us to talk about merely possible properties and to say how they would have been related to actual ones, they do not show how such properties should figure in the laws that they do.

Many vacuous laws involve a dependence between two or more uninstantiated determinate magnitudes, say specific amounts of force, mass, and acceleration, and it is quite natural to suppose that statements of such laws are true simply because they are entailed by a more general principle like Newton's second law of motion. The idea is that such a general principle tells us that any possible determinate masses or forces are related in accordance with the rule laid down by the principle, and the general principle itself is true because it expresses a relationship between determinable properties. Unfortunately, however, there is reason to doubt that determinables are genuine properties. The determinable mass, for example, would not confer any causal powers on an object instantiating it over and above those already conferred by whatever determinate mass the object happens to have. Nor is there much reason to view determinables as properties of determinates themselves, for if my earlier argument is correct, the latter are what they are in virtue of their intrinsic natures and so need no higher-order properties to account for their characteristics. But if determinables are not genuine properties, the truth of a general principle must be explained by facts about

[13] The description must also be non-circular, must not essentially contain terms referring to non-actual objects unless these are in turn backed by rigid descriptions, and so forth. The description of our merely possible individual in fact is too simple because of the possibility of identical twins; more elaborate examples avoid this problem, but the complications aren't worth bothering with here. (For *one* sort of actualist treatment of necessity see Fine [6].)

determinates, rather than conversely. Moreover, we need to explain what it means to say that certain determinates fall under the same determinable.

Any satisfactory account of these matters will likely be intricate, but I think that something like the following is on the right track. One way to rigidly describe a property is to give its dimensions and units. In general, the former can be expressed as monomial combinations of a few basic dimensions — in classical mechanics, for instance, mass (M), length (L), and time (T) allow us to express the dimensions of force (MLT^{-2}), density (ML^{-3}), and so on. And for most genuine properties the specification of units in terms of a particular scale involves citing its ratio to some selected property of the same dimensions, e.g. mass of one kilogram. Now in addition to the *I*-relations between determinates of *different* dimensions, there are relations between those of a *single* dimension (cf. fn. 4), and there is a highly systematic interplay between the two. To contrive a simple example, if P and Q are families of determinates, and R and R′ ordering relations on P and Q respectively, then we may find that whenever Rq_iq_j, Iq_ip_k, and Iq_jp_l, then $R'p_kp_l$.

Often determinates of the same family are so related that they can be combined additively (in the sense that 3 kg is a sum of 1 kg and 2 kg), whereas genuine combinations of members of different families are multiplicative (force times acceleration has monomial dimensions, while force plus acceleration does not). And it is the very tight constraints placed on a determinate by these sorts of relations, I suggest, that make it a member of the family of determinates it is; indeed, standing in certain sorts of relations to other determinates is constitutive of falling under the same determinable that they do. Moreover, it is just such facts about actual determinates of a given family that determine facts about its merely possible members, for each possible determinate will receive a unique place in the family and will therefore be involved in whatever laws that it is.[14]

Missing values are not the only source of vacuity in laws; many statements of laws invoke idealisations and so have *no* actual instances at all. Idealisations themselves, however, often involve properties that occur as a limit of an ordering of determinate properties, say that of being a completely frictionless surface or being acted upon by no impressed forces. And in such cases, the statement of a vacuous law becomes more and more nearly correct as we approach such a limit; as certain parameters are held constant, for example, the ideal-gas equations follow from van der Waals' as the volume of a gas approaches infinity. In a few cases an idealisation literally requires impossible properties, and on our account there can be no laws involving these. But in at least many cases there is little reason to view statements purportedly about such

[14] Talk of *combinations* of properties may be explicated in terms of operations on the members of the domain of an isomorphic numerical model. Although 'general laws' do not directly involve a relation between properties, statements of them are true, when they are, in virtue of *I*-relations among their instances. Since it seems pedantic to insist that these are not real laws, we could broaden our characterisation of laws to include necessary universal generalisations asserting that the determinates of one family are necessarily related to those of other families in the appropriate ways.

properties as expressions of genuine laws, for we can explain their usefulness simply by noting that they are more and more accurate as we approach an unreachable limit.

This is not the end of the matter, however, for D. H. Mellor has recently discussed general laws like $P = \exp(A - B/\theta)$, where P is the vapor pressure of a substance, θ its temperature, and A and B constants for the particular substance in question ([10]). He notes that there are some temperatures which water cannot attain since, as a matter of law, it would decompose before it ever reached them. If θ' is such a temperature, then according to our theory it is necessarily the case that samples of water never reach it, and the (conjunctive) property of being water at temperature θ' is an impossible one. Consequently, according to our theory, $P' = \exp(A - B/\theta')$ is necessarily vacuous and so not a law at all. But, Mellor urges, it is a perfectly good law.

Quite apart from any philosophical account of laws, however, it is surely natural to respond that if water will decompose before it could reach θ', then *it* will not be around at this temperature to have any vapor pressure at all. It is indeed plausible to regard a general law as claiming that to every *possible* value of the independent variable there corresponds a value for the dependent variable, but this licenses no extrapolation to impossible values. This is not to deny that we are sometimes inclined to accept counterfactuals with impossible antecedents as non-trivially true. But even if there are circumstances in which we would agree that if a sample of water had been heated to θ', it would have had vapor pressure P', that is not enough to qualify the conditional as a law. For acceptance of counterfactuals, especially unusual ones, depends upon judgments about relevant similarity and decisions as to what to hold constant from one situation to another, and these may vary depending on context and purposes at hand, so that the acceptance of such a counterfactual depends upon pragmatic considerations — but the existence of a law does not. It *may* be that this counterfactual is somehow supported by a genuine law. But this is not enough to make *it* a law, for laws support — even entail — all manner of counterfactuals that are not laws. And there are no obvious features of scientific practice, nor any conspicuous intuitive considerations, that recommend classifying Mellor's conditional as a law. Still, there may be sentences that do seem to be statements of laws which on our account have necessarily false antecedents. I think many of these can be explained away as useful approximations of genuine laws, but if this cannot be done in all cases, then our account of vacuous laws will have to be elaborated or amended. In this respect it is in no worse shape than its competitors, however, for I know of no completely satisfactory account of vacuous laws.[15]

Counterfactuals with impossible antecedents also pose a difficulty for our theory, for if the laws of our world are deterministic, there are *no* possible worlds that share its exact history up to a given time and diverge from it thereafter. Yet we often seem able to imagine such worlds, and we regard some counterfactuals about them as (non-trivially) true, others as false. I do not believe that our theory has any quick and easy answer to this difficulty. It will not do to say that when we imagine a world differing from ours after a given moment we are in fact imagining a world whose laws are slightly different from those of the actual world, for this would require that the imagined world contain different properties from the actual world, contrary to the assumption that the two were the same before the divergence. In some cases, perhaps, it may be that the two worlds had different initial conditions and that the difference between them only became noticeable at the moment we regard as their divergence. But there is in general no guarantee that our laws allow a world to differ just a little from the actual one until a given moment and to differ thereafter in all of the ways we may imagine it to when reasoning counterfactually.

I am hopeful of explaining much of our counterfactual reasoning in epistemological terms, for we are often willing to reason about impossible situations simply because we do not know that, or whether, they are impossible; we can reason equally well, for example, from the hypothesis that Goldbach's Conjecture is true or from the hypothesis that it is false. More important, a variety of counterfactuals that are *known* to have necessarily false antecedents strike many people as non-trivially true. In some contexts, for example, many regard 'If Babe Ruth had published a sound proof that recursive arithmetic is complete, he'd have been celebrated as a logician', as true, while rejecting the counterfactual with the same antecedent but opposite consequent. It seems a plausible conjecture that in thinking about such matters we employ fairly systematic principles for selecting certain aspects of the situation, as that people are esteemed for proving major theorems, while simply disregarding others. But explaining such mysteries is a task for a theory of counterfactuals rather than for a theory of laws. What is important here is that *even* if it turns out to be a consequence of our account that we do reason selectively about counterfactuals with necessarily false antecedents, this requires nothing of us that we can't do already.

According to our theory of natural laws, if ϕ is a true statement of law, then it is necessarily true, and evidence that ϕ states a genuine law is thereby evidence for its necessity. The conditional that licenses such inferences is vouchsafed by philosophical reasoning, but whether ϕ states a law at all remains an empirical question to be answered by scientists using whatever methods they do to resolve such matters. Nor need these methods be seen as involving anything like a mysterious faculty for intuiting properties, for if properties exist where they are exemplified and confer causal powers upon their instances — including powers to affect our sensory apparatus and measuring instruments — then knowledge about them is to be gained simply by studying their instances. And so our account is quite compatible with a naturalistic epistemology.

Our theory of natural laws is ontological, and it counts some things as laws that are not customarily so regarded. This discrepancy likely results from the fact that laws are important to us mainly because of the *use* we can make of them in explanation, prediction, inference. And since these enterprises are

[15] For example, many regularity theorists hold that a vacuous universal generalisation counts as a law only if it's derivable from a non-vacuous law. But especially when idealisations are involved, we do not always have a non-vavuous law from which the vacuous one can be derived.

fraught with pragmatic and epistemological considerations, it is hardly to be expected that our ordinary concept of a law will entirely escape their influence. Indeed, this is surely why the regularity theory's emphasis upon such matters often seems so plausible. By adding various pragmatic and epistemic requirements to our ontological account we can narrow the class of essential connections among properties to bring it more nearly into line with our vague, everyday conception of a natural law, and I have no objection to doing so. I shall not pursue the matter here, however, for the more promising restrictions seem reasonably straightforward — obvious candiates include variants of the more plausible conditions noted by regularity theorists — and in any case they mark no significant ontological distinctions.

I have tried to show that several lines of argument converge on the conclusion that laws of nature are metaphysically necessary relations between properties, though of course many details must be worked out and, no doubt, certain problems must be solved, if our account is to furnish an adequate theory of laws. I have not attempted a defence of properties or metaphysical necessity themselves; arguments on behalf of each can be found elsewhere, and here I will but add the customary observation that their usefulness in explaining laws gives us yet another reason for thinking that properties exist and that metaphysical necessity makes sense. It is worth emphasising, however, that our theory is nearly as austere as any account accepting these notions could be: it forswears transcendent properties in favour of those that are actually exemplified, it avoids generic or determinable properties, and it seeks to explain facts about the possible in terms of the actual. It does not avoid properties and modalities altogether, but then a robust sense of reality requires the acknowledgment of what there is no less than the repudiation of what there isn't.[16]

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