symmetric will depend on what language we use to describe the possibilities. If we use the 'grue' language, an otherwise reasonable principle of indifference might recommend Pr' over Pr. Now, even with a suitable language picked out, there are serious obstacles. To take a familiar example, suppose a factory is making cubes of varying sizes. If I have no information specific to a given cube produced by the factory, how should I assign prior probabilities to propositions of the form the side length of the cube is between 1, and 2? In direct proportion to the difference \( l_1 - l_2 \), one wants to say. And how should I assign prior probabilities to propositions of the form the face area of the cube is between \( a_1 \) and \( a_2 \)? In direct proportion to the difference \( a_1 - a_2 \), one wants to say. But these two answers are incompatible (van Fraassen, 1989, 303–4). So selecting the right language doesn’t, on its own, solve the problem of formulating principles of indifference. But without an appropriate language, we cannot even get started on a solution.

To constrain prior probability distributions, then, we need some way to pick out appropriate languages for evaluating simplicity, symmetry, and related notions. And—to finally get to the point—it seems reasonable to pick them out by using the notion of structure. Now, even given the notion of structure, there are nontrivial questions about how exactly to pick out the appropriate languages. For example, how do we pick the appropriate languages need to carve at the joints? Again, the appeal to structure is the beginning of a solution, not the end of one.

The argument of this section has been that epistemology fills a need in epistemology. A reply would be that epistemology does not demand structure objectively construed; a conception of “structure” tied to human history, biology, psychology, or interests would do. My reply to such challenges elsewhere is that subjectivity in structure would infect all notions to which structure is connected (similarity, intransigence, duplication, laws of nature, and so on). But in this case, the infected notion would be epistemic value. And perhaps we should embrace the idea that values in general are not objective.

But even if epistemic value is subjective along some dimensions, we shouldn’t embrace the idea that it’s subjective along all dimensions. Let Pr be a rational credence function we ought to adopt and Pr' be one that we ought not to adopt. Intuitively speaking, we might embrace subjectivity in the “oughtness” of the obligation while rejecting subjectivity in the distinction between Pr and Pr'. The objective facts might not mandate that we have our notion, or any notion, of epistemic obligation, but might nevertheless mandate that we choose Pr over Pr' if we do have our notion (or anything like our notion). We will return to this issue in section 4.2.

3.4 Intrinsic structure in physical spaces

We need structure to understand talk in physics of the “intrinsic” structure of space, time, spacetime, and other spaces.\(^{35}\)

\(^{35}\)See also Bricker (1993); Sider (1993a, chapter 6).

Non-Euclidean geometries were discovered in the early nineteenth century, proved consistent relative to Euclidean geometry later that century, and applied in physics by Einstein in the early twentieth century, in his general theory of relativity. Taken at face value, Einstein’s claim that physical spacetime is curved is a substantive claim in direct conflict with the assumption of flat spacetime implicit in classical Newtonian physics (and in the special theory of relativity as well). But taken at face value, this claim raises various philosophical questions: epistemic, semantic, and metaphysical.

Let us approach the questions through the simpler case of spatial, rather than spacetime, curvature. Imagine a series of experiments, carried out with rigid measuring rods and the like, that apparently show that space in a certain region is curved. The epistemic questions arise because we do not observe space directly; what we observe is things in space, such as measuring rods. Effects attributable to curved space could instead result from systematic distortions to the rods. While this may at first appear to be mere Cartesian demonry, compare two alternative hypotheses. According to the first hypothesis, the measurements result from curvature. According to the second, space is flat but there are “universal forces” that affect all matter, cannot be blocked, and systematically shrink and expand the measuring rods so that their lengths are exactly as the first hypothesis predicts. Unlike Cartesian skeptical hypotheses, the second hypothesis is not scientifically absurd. The epistemological question, then, is: What reason could we have for attributing distortions in our measuring rods to spatial curvature rather than to universal forces?

The semantic questions concern how the meaning of spatial language could be fixed in such a way that it would remain an open question whether space is curved. To simplify, pretend that all spatial facts may be expressed using Tarski’s predicates.\(^{35}\)

\[\text{point } x \text{ is between points } y \text{ and } z\]

\[\text{points } x \text{ and } y \text{ are congruent to points } z \text{ and } w\]

One sort of semantic question arises only given an extreme empiricist philosophy of language. If every meaningful predicate must be associated with verification

\(^{34}\)See Reichenbach (1958, chapter 1).

\(^{35}\)These are the predicates from Tarski’s axiomatization of Euclidean geometry; see Tarski (1959); Tarski and Givant (1999). Really, though, the fundamental metafactual facts should probably not be taken to be direct point-to-point distance comparisons as in Tarski’s system, but should rather be local metrical facts, from which distances along paths may be recovered. On the other hand, the standard development of a local metric should probably not be taken at face value, since it grounds metric structure in the metric tensor, a mathematical object involving real numbers. Surely the fundamental distance facts are purely about points (as they are in Tarski’s account). That what we really want is a synthetic geometry from which one can prove representation theorems about the metric tensor (see Field (1980); Mundy (1987) for two approaches to representation theorems). I do not know whether such an account exists.
conditions for its application, then given the previous paragraph, the predicates ‘between’ and ‘congruent’ would seem not to be meaningful.

Other semantic worries will have force even for nonverificationists. If Einstein is right and Newton is wrong about curvature, then the referents of ‘between’ and ‘congruent’ must satisfy non-Euclidean rather than Euclidean axioms. But in addition to having an interpretation under which they satisfy non-Euclidean axioms, ‘between’ and ‘congruent’ also have an interpretation in which they satisfy Euclidean axioms. (The Euclidean axioms are true in the abstract model whose domain is \( \mathbb{R}^3 \) and in which the predicates are interpreted in the obvious way. Since the set of physical points of space has the same cardinality as \( \mathbb{R}^3 \), the model in \( \mathbb{R}^3 \) induces a model in physical space.) So if Einstein is to be right and Newton wrong, it must be that one of these assignments is the correct assignment, the intended interpretation of ‘between’ and ‘congruent’. But what determines that one of these assignments is the correct interpretation? We cannot specify the intended interpretation of ‘congruent’ by saying that “it is to apply to \( x, y, z \), and \( w \) when the distance between \( x \) and \( y \) is the same as the distance between \( z \) and \( w \),” for ‘distance’ is in the same boat as ‘congruent’; how is its intended interpretation determined?

The metaphysical questions concern the same issue as the semantic ones, only more directly. In what would the fact that spacetime is curved consist? In the fact that the congruence and betweenness relations satisfy non-Euclidean axioms, is the obvious reply. But since there are continuum-many spacetime points, there exist “Euclidean-congruence” and “Euclidean-betweenness” relations that satisfy Euclidean axioms. So in what sense is spacetime really Euclidean? What makes the “real” betweenness and congruence relations, as opposed to their Euclidean counterparts, “physically significant”?

We face the same questions when reading physics textbooks on special or general relativity that speak of the “intrinsic structure” of physical space, time, and spacetime. In classical physics, we are told, spacetime is flat, and there is a “well-defined” relation of simultaneity, whereas in Minkowski spacetime there is no such relation of simultaneity—there is no “distinguished” notion of simultaneity. But of course, there are relations—sets of ordered pairs, anyway—between space-like separated points of Minkowski spacetime that foliate the spacetime, many such relations. What does it mean to say that none of these relations is “distinguished”?  

Geometrical conventionalists like Henri Poincaré (1952, Part II) and Hans Reichenbach (1958, Chapter 1) give a deflationary answer to the semantic question that answers the epistemological questions, and which implicitly assumes a deflationary answer to the metaphysical questions. Return to the question of how to specify the intended interpretation of ‘congruent’. According to Reichenbach, a theoretical predicate like ‘congruent’ requires a “coordinative” definition, a definition that correlates the predicate with something that is (relatively) observable. An example of a coordinative definition would be the definition of straight lines through spacetime as the paths of light rays in vacuum. We might think to give a coordinative definition of congruence in terms of measuring rods: points of space are congruent when they can be the endpoints of a single measuring rod. But measuring rods can be distorted by forces. Might we then define congruence in terms of measuring rods unaffected by forces? The problem is that ‘force’ is itself a term in need of a coordinative definition, since one can no more directly measure forces than congruence. What Reichenbach says, in essence, is that one must simultaneously give coordinative definitions of ‘force’ and ‘congruent’ in terms of measuring rods: congruent points are those picked out by the endpoints of a measuring rod that is not subject to forces. Since this coordinative definition constrains two terms, there is a certain amount of freedom in assigning meanings to those terms. One can understand ‘force’ and ‘congruent’ so that space is Euclidean but there are universal forces acting on all objects that produce the measurements that we make, or one can understand ‘force’ and ‘congruent’ so that space is non-Euclidean and there are no universal forces. In fact, physicists have preferred the latter course, and so we speak of space as being curved. But this is in part a matter of arbitrary definition; physicists could have chosen the former course. They chose the latter only because the resulting physics was simpler. So according to conventionalists like Reichenbach, it is at best misleading to say that space itself is curved, that space is intrinsically curved. ‘Space is curved’ is true to say given the linguistic choices that physicists have in fact made. But those choices were arbitrary, and moreover are inextricably tied to the conventional choice of whether to speak of universal forces.

Given this view about the semantics of spatial language, the epistemological questions are immediately answered. How do we know that space is curved, rather than being flat but accompanied by compensating universal forces? We know this simply by knowing which conventions our linguistic community has adopted. (Better: knowledge of linguistic conventions plus empirical observation tells us that ‘space is curved’ is the right description. If different linguistic conventions had been adopted, the same observations would have called for the description ‘space is flat’.)

Reichenbach (unsurprisingly) does not address the metaphysical question. But it seems clear that he would regard talk of space as being “intrinsically” flat or curved as misguided, given the need for coordinative definitions. Insofar as conventionalists have a metaphysics of spatial structure at all, it is that space is not intrinsically structured (or perhaps that talk of intrinsic structure makes no sense).

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What might an anti-conventionalist—realist—account of physical geometry look like?\textsuperscript{38} Here is what the realist \textit{wants} to say. About semantics, spatial predicates like ‘between’ and ‘congruent’ can be understood \textit{purely spatially}; they need no coordinative definitions. And they are attached to particular relations over physical points, which satisfy non-Euclidean axioms (assuming that Einstein is right). As for metaphysics, space is intrinsically structured; the genuine betweenness and congruence relations are privileged in a way that Euclidean-betweenness and Euclidean-congruence are not. The naïve and natural picture of physical geometry one gets from physics is thereby vindicated. The epistemological problems then confront us head-on. But these problems should be solved the way we realists solve all such problems of theory being underdetermined by observation: by appealing to criteria—“simplicity” is a common placeholder—that choose between observationally indistinguishable theories. (If such criteria do not deliver a verdict, we remain agnostic until some new test or consideration breaks the stalemate.)

A realist about structure has a clear path to this realism about physical geometry. Metaphysically, the distinction enjoyed by the genuine betweenness and congruence relations is that they are part of reality’s distinguished structure: they carve perfectly at the joints, unlike any relations of Euclidean-betweenness and Euclidean-congruence. Semantically, given any reasonable metasemantics for theoretical terms, ‘between’ and ‘congruent’ attach to betweenness and congruence rather than to any Euclidean-betweenness and Euclidean-congruence relations precisely because only the former are part of the world’s genuine structure. Reichenbach was led to his position by his insistence on the need for coordinative definitions, deriving ultimately from an internalist and highly empiricist approach to meaning. But a more reasonable metasemantics will allow a role for a nonobservational and externalist determinant of meaning: the world’s structure.\textsuperscript{39}

More generally, questions about metric, affine, topological, and other structure of space, spacetime, and other physical spaces are questions about the distinguished structure of those spaces. There is a substantive purely spatiotemporal fact of the matter as to whether spacetime is Galileian, neo-Newtonian, Minkowskian, or a curved Lorentzian manifold.\textsuperscript{40} The fact is given by the joint-carving features of points of spacetime. If, for example, the joint-carving features of points of physical spacetime are as described by Minkowski’s theory, then physical spacetime is Minkowskian, and there is “no physically distinguished relation of simultaneity” in the sense that there is no joint-carving relation that foliates the spacetime (nor can any foliation be defined from the joint-carving relations over points).

Spacetime could have had a structure that would have vindicated a kind of geometrical conventionalism. Suppose spacetime had lacked distinguished metrical structure—suppose there had been joint-carving topological features but no joint-carving metrical features. Then no metric would have been distinguished from any other, and spacetime would have been a kind of amorphous “point soup”. Reality might at the same time have lacked sufficient structure to define forces. In such a Reichenbachian world, we would have been free to choose either of a pair of coordinative definitions, simultaneously defining force and metric predicates. Neither choice would have carved reality at its joints better than the other. Metric and force predicates would require coordinative definitions in such a world, not because of general semantic considerations, but rather because the world would lack the structure needed to supply semantic determinacy. What reason do we have to think that our world has any more structure? The fact that physical theories with primitive metrical predicates have been so successful (section 2.3).

\textsuperscript{38}\textsuperscript{38}Merleau (1976), especially chapter 9, defends realism about spatiotemporal structure, and distinguishes this realism from realism about the existence of entities (chapter 5, §6). See also Bricker (1993).

\textsuperscript{39}\textsuperscript{39}Grübaum (1973) also defended conventionalism about metric structure, but based it on metaphysical considerations rather than on an empiricist account of meaning. An intrinsic metric, Grübaum argued, would have to be definable from facts intrinsic to the points, but if space is continuous then there are no facts intrinsic to points that suffice for the definition. The realist about structure, however, regards the distinguished structure of space as constituting facts intrinsic to points from which a metric may be defined.

\textsuperscript{40}\textsuperscript{40}Or even whether there is a fundamental four-dimensional spacetime at all, as opposed to a massively dimensional configuration space; see Albert (1996), North (2009, 2010).