Review of ***Space, Time and Stuff**,* Frank Arntzenius, Oxford University Press, 2012.

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A polygraph more than a monograph, *Space, Time and Stuff* is an "examination of some loosely related topics" (p. 2) at the place where physics meets metaphysics. Among the loosely related topics are questions regarding the proper mathematical representations of space, time and spacetime and a bit on other "stuff", mainly the interpretation of quantum mechanics and gauge field theories. What thematic unity it has comes from a few methodological assumptions, acknowledged in the introduction but neither explicated nor defended. Hence the book will be of interest largely to those sympathetic to these precepts.

Arntzenius is interested in extracting information about the nature of space, time and matter from physical theory. His fundamental assumption is that "the laws of the world are simple in terms of the fundamental objects and predicates." The truth about the world is to be found in discovering the simplest formulation of the theory. He thinks that the history of science shows us "that our best estimate as to the relative merits of theories should be based on judgments concerning the simplicity (or perhaps naturalness, or something like that) of theories (which are compatible with phenomena), not on judgments regarding the genuineness of the possibilities that are (arguably) associated with each theory." (p. 2)

Though many might well agree with the author that intuitive judgments regarding which possibilities are genuine are not reliable, it is not at all obvious to this reviewer that the history of science indicates that simplicity (or naturalness, or something like that) is a guide to truth, especially since, as Arntzenius himself acknowledges, the history of science is full of empirically successful theories that are now known to be *false*. Even if it were true that simplicity (or naturalness, or something like that) were a useful criterion for theory selection, we have no particular reason to think that *simple* theories are *true* theories.

Suppose we concede for the sake of argument that "simplicity" is indeed a guide to truth, history notwithstanding. We are unfortunately not offered any account of what simplicity (or naturalness, or something like that) actually amounts to. There is a reference to ongoing, as yet unpublished work by Cian Dorr (co-author of chapter 8) on this important topic, but nothing further. Yet in chapter after chapter, simplicity is appealed to as a criterion in order to find a winner amongst either conflicting theories or conflicting interpretations of a given theory or theoretical framework. Thus the plausibility of the author's conclusions will depend largely on whether one shares his intuitive conception of what counts as simple. Or natural. Or something like that.

Much of *Space, Time and Stuff* is given over to technical exposition, and this is done in the informal style beloved of metaphysicians who model themselves after David Lewis. But the informal tone veers too often into glibness, and the presentation is further marred by poor mathematical typesetting and sloppy mathematical notation (e.g., integrals without limits of integration), all of which combine to render the technical content nearly incomprehensible to anyone not already familiar with it.

All of the above is by way of critique of the general approach to the topics and the exposition thereof. Let us know take a brief look at the subjects covered, and Arntzenius's take on some of them.

Chapter 1 is an examination of the ontological status of time, of whether time can in some sense be dispensed with as a fundamental entity in classical physics. The author's answer is a qualified yes – Arntzenius is impressed with, but not entirely swayed by, Julian Barbour's Leibnizian arguments.

Chapter 2, "There Goes the Neighbourhood", is a critique of David Lewis's claim that "the world is a vast mosaic of local matters of fact" (quoted on p. 39) consisting of properties instantiated at points in spacetime. Arntzenius investigates and concludes that Lewis is wrong, that really the properties are intrinsic to *neighbourhoods* of those points, infinitesimal regions surrounding the points. Arntzenius's straightforward point is that many of the properties Lewis is concerned with, such as velocities of particles or rates of change of fields, are in fact not intrinsic, in the sense of "intrinsic" given by Lewis, to the points themselves. Rather, they are intrinsic to the infinitesimal neighborhoods around the points. This point could be made, it seems to me, quite clearly in five pages or so, but the author takes the reader on a nearly forty page excursion, including a rather unnecessary side-trip into the axioms of topology. Concision is not one of the book's strong suits.

Chapter 2 is atypical of the rest of the book in one respect: the discussion is not about choice between conflicting interpretations of physical theory, but is rather a critique and emendation of a view on offer. Elsewhere, Arntzenius attempts to adjudicate between competing interpretations. Chapter 3 has to do with selecting amongst conflicting interpretations of quantum mechanics, while chapter 4 inquires as to whether spacetime really consists of points. Chapter 5 takes on the centuries-old question about the implications of Newtonian and later Einsteinian physics for the existence of space (and time): does space exist, or is space merely a relation between objects? Chapter 6 deals with the interpretation of gauge theories, a type of field theory used to describe what are currently understood to be the fundamental particles and forces (except for gravity). Chapter 7 has to do with deciding whether space, time, or spacetime have a "handedness" structure, a distinction between right and left, and forward and backward in time. In most of these, considerations of simplicity play a central role in distinguishing the preferred interpretation or formulation.

Finally in chapter 8, "Calculus as Geometry", we find a project that seems fundamentally at odds with what has come before. Coauthored with Cian Dorr, this chapter explores what the authors call a "nominalization" of a chunk of physics. The project is driven by a worry that physics should fundamentally be about "concrete physical entities", and that these entities should have "intrinsic structure that has nothing to do with its relations to the mathematical realm." What is odd is that the fundamental objects and predicates of the various theories and interpretations have to this point all had a mathematical character. Clearly there are other motivations for re-expressing the content of physical theories in terms of various "concrete", non-mathematical entities. But there is no *a priori* reason to think that such re-expression would yield a theory that is *simple* in terms of its fundamental objects and properties. And if it is not simple, then under the methodological precepts adopted, it is not a legitimate guide to the truth about nature.

Be that as it may, Arntzenius and Dorr distinguish the "easy nominalistic project", in which the intrinsic properties of the entities are non-mathematical, from the "hard nominalistic project", in which the laws *governing* these properties are also stated in non-mathematical terms (p. 215). What they mean by `non-mathematical' is actually geometrical in the sense of Euclid's geometry (rather than Cartesian analytic geometry), since Euclid's axioms can be stated entirely in terms of "concrete" objects and their relations; these relations do not involve talk of real numbers, groups, or any of the other apparatus used in modern analysis. Since the usual formulation of calculus does rely heavily on this sort of apparatus, they take on the project of re-expressing calculus in purely geometrical terms. This takes up the bulk of chapter 8.

The conclusion of chapter 8 – and the book as a whole -- is so astonishingly modest as to make one wonder why the book was written in the first place. The authors acknowledge that it might be thought that "the theories we have been developing are much more complex than familiar platonistic ones" but suggest that the mathematical theories they are intended to displace actually have the "complexity of platonistic theories", albeit a complexity which is "hidden behind a hierarchy of definitions, which practitioners rarely have a need to consult" (pp. 269-270). And so it may be, but one might then think that some sort of sense needs to be made of measuring the complexity or simplicity (or naturalness) of the theories at issue. Indeed, this might be a case in which simplicity pulls in one direction (toward theories expressed in mathematical language) while naturalness pulls in another.

But rather than venture into these waters, Arntzenius & Dorr simply opine, "We think it is a mistake to think of mathematical ontology as an all-or-nothing deal," and that we should "feel free to avail ourselves" of mathematical structure "without fearing that once we start doing so, we will somehow end up having to believe that every one of those structures is instantiated somewhere in reality" (p. 270). And as the authors throw their hands up at adjudicating the ontological questions arising in the case of a successful nominalization/geometrization of physics, this reviewer shrugs his shoulders and wonders what the point of the project, and the book, might be in the first place.