

The Macro-Micro Gap

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Failures of supervenience reveal gaps. There is a mental-physical gap if the mental facts fail to supervene on the physical facts. There is a nomic-categorical gap if the nomic facts fail to supervene on the categorical facts. In the same way, there may be macro-micro gaps. Some terminology: let an *atom* be any object in spacetime without proper parts; let a *composite* be any object in spacetime with proper parts; let the *micro facts* be the facts about the atoms, their identities, their intrinsic properties, and their relations to one another; and let the *macro facts* be the facts about the composites, their identities, their properties, their relations to one another, and their relations to the atoms. There is a *macro-micro gap* just if the macro facts fail to supervene on the micro facts.

We think that some sorts of macro-micro gaps are intolerable—that we should reject any metaphysics that leads to them—while other sorts are fine, and the first of our two main aims in this paper is to give a criterion that says which are which. The second aim is to make use of the criterion. We argue that, on pain of being forced to countenance intolerable macro-micro gaps, we must reject a three-dimensional conception of persisting objects (3d'ism) in favor of a four-dimensional conception (4d'ism), and we must accept a weak but universal form of mereological essentialism.

I. Can Atoms Persist?

We begin with the dispute between 3d'ists and 4d'ists. The dispute is about temporal parts. According to 4d'ists, persisting objects have temporal parts. Persisting objects are

composed of *stages*, objects that exist for only an instant. Poodles, for example, are composed of poodle-stages—objects briefly indistinguishable from poodles, but maximally short-lived. According to 3d'ists, persisting objects do *not* have temporal parts. Persisting objects are three-dimensional entities; they sometimes have spatial parts, but never have temporal parts.¹

The dispute between 3d'ists and 4d'ists gives rise to a dispute about atoms. According to 3d'ists, atoms can persist—and indeed they often do. Consider some particle, some electron or boson, zipping around the universe. That persisting particle, according to 3d'ists, might well be an atom, in the technical sense: an object in spacetime without proper parts. 4d'ists, by contrast, think that atoms cannot persist. Of course, electrons and bosons can persist, and often do. But persisting particles are not atoms; rather, they are composites, composed of temporal parts. The atoms, according to 4d'ists, are the particle-stages, the instantaneous temporal parts of persisting particles.

At first glance, this difference about whether atoms can persist seems to tell in favor of 3d'ism. After all, electrons do not seem to have proper parts. But we are convinced that this difference, at the end of the day, actually tells in favor of 4d'ism, because we are convinced that the persistence of atoms leads to intolerable macro-micro gaps.

II. The Problem of Recycling

The path from the persistence of atoms to intolerable macro-micro gaps begins with *the problem of recycling*.

¹ For more on the dispute between 3d'ism and 4d'ism, see the papers in Haslanger and Kurtz (2006).

Given some atoms, let an *arrangement* of those atoms be a maximal, intrinsic, fully specific way for them to be.² If the *xx* are some atoms that are arranged F-wise, then “F*xx*” refers to the F-wise arrangement of the *xx*.³ We are particularly interested in arrangements of atoms that give rise to composites.⁴ Let A be some composite, and suppose that at the first instant at which A exists, the *xx* are arranged F-wise, and the *xx* are exactly the atomic parts of A. We then will say three things: that F*xx* *generates* A, that F*xx* is *fruitful*, and that A is one of the *possible fruits* of F*xx*. This terminology is meant to be suggestive. We say that F*xx* generates A because A is brought into existence by the *xx* being arranged F-wise. We say that F*xx* is fruitful because it is possible to bring a composite into existence by arranging the *xx* F-wise. We say that A is one of the possible fruits of F*xx* because A is one of the composites that can be brought into existence by arranging the *xx* F-wise.

We will assume that it is metaphysically impossible for material objects to be exactly co-located. This assumption is only for the sake of simplicity; it does not affect our argument.⁵ But with the assumption in place, let us introduce one last bit of terminology. Say that an

² Arrangements of atoms are sensitive to individualistic differences. Let *a*, *b*, and *c* be duplicate atoms, and suppose that they are arranged left-to-right as follows, *a-b-c*. At a world at which they are qualitatively unchanged and arranged left-to-right as follows, *b-c-a*, they are *arranged* differently.

³ The most natural way to think of arrangements is as repeatable states of affairs, but the ontology is not important.

⁴ We assume that compositional nihilism is false, that some arrangements of atoms do give rise to composites. For the purposes of this paper, we need not take any stand on whether compositional universalism is true.

⁵ We could allow for co-location by generalizing some of our technical terms. Instead of saying that F*xx* generates a composite, we would say that F*xx* generates a maximal set of co-located composites, the set that includes every composite generated by F*xx*. We also would tweak our understanding of what it is for an arrangement of atoms to be multiply fruitful. Instead of saying that F*xx* is multiply fruitful just if it can generate distinct composites, we would say that F*xx* is multiply fruitful just if it can generate distinct maximal sets of co-located composites. The argument then would proceed in the same way. The problem of recycling would show that 3d’ism, unlike 4d’ism, is committed to multiply fruitful arrangements of atoms, and hence that 3d’ism, unlike 4d’ism, is committed to intolerable macro-micro gaps.

arrangement of atoms is *multiply fruitful* just if it is possible for the arrangement of atoms to generate one composite, and it is also possible for the arrangement of atoms to generate a distinct composite.

The problem of recycling will show that 3d'ism is committed to multiply fruitful arrangements of atoms.⁶ This, in turn, will lead to intolerable macro-micro gaps.

Suppose that 3d'ism is true and that atoms persist. Then a fruitful arrangement of atoms can be recycled: it can recur multiple times over the course of history. If each recurrence generates a distinct composite, then the arrangement of atoms is thereby shown to be multiply fruitful. Consider the tale of Aseus and Bseus:

In 1500 CE, some atoms, the *xx*, are arranged ship-wise, generating Aseus, a particular ship (much like the better-known ship of Theseus). Over time, Aseus changes. It loses some atoms and gains others. By 1600 CE, none of the *xx* are parts of Aseus. Aseus is composed of the *yy*, a disjoint plurality of atoms. In 1650 CE, Aseus catches fire and is destroyed. Over the next 50 years, the *xx* find their way back together, and in 1700 CE, the *xx* are, miraculously, arranged ship-wise again, in exactly the same way, thereby generating a distinct ship, Bseus, a perfect duplicate of Aseus.

If atoms can persist, then the tale of Aseus and Bseus is metaphysically possible, and a ship-wise arrangement of the *xx* is multiply fruitful: Aseus is one of its possible fruits, and Bseus is

⁶ The recycling argument is familiar from disputes about origin essentialism. For discussion, see e.g. Barnett (2005), Carter (1983), Damnjanovic (2010), Forbes (1985; 1986; 1994; 2002), Hawthorne (2006b), Hawthorne and Gendler (2000), Kripke (1980), Mackie (1987; 2002), McKay (1986), Noonan (1983), Price (1982), Robertson (1998; 2000), Rohrbaugh and deRosset (2004; 2006), and Salmon (1979; 1981; 1984; 1989). Although the recycling argument is not a familiar part of the dispute between 3d'ists and 4d'ists, the argument that we develop in this essay draws on aforementioned discussions, especially Forbes (2002) and Hawthorne (2006b).

another. And the tale could continue: the xx might be arranged ship-wise a third time, thereby generating a third ship, Cseus. Indeed, if the xx persist over time, then a ship-wise arrangement of the xx has infinitely many possible fruits; infinitely many different ships can be generated by arranging the xx ship-wise.

Of course, neither ships nor ship-wise arrangements are special in this regard. The same goes for automobiles: the arrangement of atoms that generated your neighbor's car has infinitely many possible fruits. So too for writing utensils: the arrangement of atoms that generated this pencil has infinitely many possible fruits. If 3d'ism is true and atoms persist, then (nearly) every fruitful arrangement of atoms is multiply fruitful and has infinitely many possible fruits.

III. Fruitful Recombination

The macro-micro gaps that result from multiply fruitful arrangements of atoms are most obvious, and most prevalent, if we assume *fruitful recombination*. According to fruitful recombination, possible fruits are freely recombining: subject to the constraint that distinct recyclings generate distinct composites,⁷ any recombination of possible fruits across fruitful arrangements is possible. As an illustration, consider the following two worlds:

w_A , at which: The xx are arranged ship-wise only once and generate Aseus.

w_B , at which: The xx are arranged ship-wise only once and generate Bseus.

Fruitful recombination entails that both of these worlds are possible, and this immediately leads to a macro-micro gap. Worlds w_A and w_B are micro-indiscernible; the same micro facts

⁷ See note 16 for a distinction between distinct composites being generated and a composite being generated and then regenerated.

hold at both. But they are macro-discernible: Aseus exists at w_A , but not at w_B . Hence, if they are both possible, they are both worlds at which there is a macro-micro gap.

As another illustration, consider:

w_{AB} , at which: The xx are arranged ship-wise twice, generating Aseus and then Bseus.

w_{BA} , at which: The xx are arranged ship-wise twice, generating Bseus and then Aseus.

Fruitful recombination again entails that these two worlds are possible, and again this leads to a macro-micro gap; for worlds w_{AB} and w_{BA} are micro-indiscernible, yet macro-discernible.⁸

At this point we can see that if 3d'ism is true and possible fruits are freely recombinable, then macro-micro gaps are *everywhere*. A macro-micro gap arises (almost) *whenever* an arrangement of atoms generates a composite. If there is a fruitful arrangement of atoms, and if, as we will assume, it is not a contingent matter whether an arrangement of atoms generates a composite, then the micro facts will entail that the fruitful arrangement generates one of its possible fruits. But the micro facts will be consistent with the generation of any of the possible fruits; they will not determine *which* of the possible fruits is generated. The fact

⁸Here and throughout, we move freely between the claim that there are distinct possibilities and the claim that there are distinct possible worlds. It is sometimes thought that a single possible world could witness multiple possibilities which differ only individualistically; cf. Lewis (1986). As it happens, we are convinced by Kment (2012) that that's not so. But even if we allowed that a single possible world could witness multiple possibilities, that would not alter our discussion. For we, like Skow (2008), think that the philosophically interesting questions are about possibilities, not possible worlds. When it comes to qualitative-individualistic gaps, for example, the important question is whether the qualitative facts necessarily entail the individualistic facts; whether there are possible worlds that are qualitatively indiscernible but individualistically discernible is not particularly important. Similarly, when it comes to macro-micro gaps, the interesting question is whether the micro facts necessarily entail the macro facts; whether there are possible worlds that are micro-indiscernible yet macro-discernible is not particularly important.

about which particular composite is generated therefore will fail to supervene on the micro facts.

Now, of course, 3d'ists are not obligated to accept fruitful recombination. In an effort to avoid macro-micro gaps, they can impose various sorts of modal constraints. We will argue, in section V, that no plausible constraints will help 3d'ists avoid gaps: short of something drastic and exceedingly implausible—for example, denying that it is possible for there to be composite objects,⁹ denying that it is possible for objects to have properties contingently,¹⁰ or denying that it is possible for a composite object to survive a complete replacement of its atomic parts¹¹—there is no way to rid 3d'ism of macro-micro gaps.

But before considering how 3d'ists might try to rid their view of macro-micro gaps, it is worth asking why they should even bother trying. *Question:* Are macro-micro gaps *always* intolerable?¹²

IV. Intolerable Macro-Micro Gaps

Answer: No; not necessarily. Some macro-micro gaps might be fine. But others are bad, and 3d'ism and fruitful recombination together lead to bad gaps.

If we thought that all macro-micro gaps were intolerable, we would endorse:

⁹ As do compositional nihilists, e.g. Dorr and Rosen (2002) and Sider (2010).

¹⁰ As do necessitarians. For a contemporary defense of the sort of rationalistic necessitarianism defended by Leibniz and Spinoza, see e.g. Dasgupta (2016) and Della Rocca (2010; 2011).

¹¹ Cf. Chisholm (1973). However, denying that it is possible for composites to undergo a complete replacement of their atomic parts *still* does not solve the problem, since that claim is compatible with the claim that some arrangements of atoms are multiply fruitful.

¹² Hawthorne (2006b) seems to endorse both 3d'ism and fruitful recombination.

Microism. At any possible world w , the micro facts at w together entail the macro facts at w .

We then would use Microism to argue against 3d'ism.

But Microism faces two serious threats—serious enough that we are doubtful about whether it is true. The first is the possibility of gunk.¹³ A composite is *gunky* if all of its proper part have proper parts, *ad infinitum*. If gunk is possible, then the following two worlds are possible:

w_{pink} , which contains nothing besides a pink cube of gunk.

w_{green} , which contains nothing besides a green sphere of gunk.

The possibility of these two worlds is incompatible with Microism. No micro facts hold at either w_{pink} or w_{green} , so the worlds are trivially micro-indiscernible. But the worlds are macro-discernible: w_{pink} contains a composite that is pink and cube-shaped, while w_{green} does not.

The second threat is the possibility of irreducible quantum entanglement. There is an important and ongoing debate in the philosophy of physics about whether facts about the quantum states of entangled composites—for example, the fact that a system of particles is in the singlet state—supervene on the micro facts. It is too early to say whether they do; more science and philosophy is needed. But it is at least an epistemic possibility that the quantum states of entangled composites fail to supervene on the micro facts, and it is therefore an epistemic possibility that quantum physics provides a counterexample to Microism.¹⁴

¹³ See e.g. Schaffer (2003; 2010).

¹⁴ For discussion of whether entangled composites are fundamental objects, see e.g. Bhogal and Perry (2017), Maudlin (2007), Miller (2014), and Schaffer (2010).

If our argument against the combination of 3d'ism and fruitful recombination essentially relied on Microism, then it would not be a very good argument; one of its premises would be highly questionable. But the argument does not essentially rely on Microism. We can replace Microism with a weaker principle, one that does not force us to take a stand on whether gunk or irreducible quantum entanglement are possible.

To state our principle, we need to draw the distinction between *qualitative* and *individualistic* facts. Roughly, the qualitative facts are those that can be stated in a language without names, demonstratives, or other referential devices.¹⁵ The individualistic facts are the facts that cannot be. The fact that Bob is wearing a hat is individualistic. The fact that someone is wearing a hat is qualitative. The fact that someone is wearing Bob's hat is individualistic. The fact that someone is wearing someone else's hat is qualitative.

Both gunk and irreducible quantum entanglement threaten Microism by putting a gap between the qualitative facts and the micro facts. If there are gunky worlds, then at those worlds the micro facts fail to entail the qualitative facts. In the same way, if there are worlds in which there is irreducible quantum entanglement, then they, too, are worlds at which the micro facts fail to entail the qualitative facts.

Call a world "Democritean" just if the micro facts at the world entail the qualitative facts. We take no stand on whether there are non-Democritean possible worlds. If there are, then there are macro-micro gaps at them. But at Democritean worlds—nongunky, Newtonian worlds,¹⁶ for example—there cannot be macro-micro gaps. Macro-micro gaps at Democritean

¹⁵ Cf. Adams (1979).

¹⁶There is an argument that threatens our claim that there are Democritean worlds at which fruitful arrangements of atoms are recycled. Consider two worlds (cf. Hawthorne 2006b, note 11):

worlds would be “merely individualistic” macro-micro gaps, and we say that there can be no such thing. We endorse:

Minimal Microism. If w is Democritean, then the micro facts at w together entail the macro facts at w .

One might wonder why merely individualistic macro-micro gaps are bad. Our answer is that they lead to an implausible picture of fundamental reality, on which, even at Democritean worlds, the fundamental objects include composites.

The notion of a fundamental object derives from the notion of a fundamental *fact*. The fundamental facts at a world are an (interestingly proper) supervenience base for the rest of the facts. A fundamental *object* is one “mentioned” by some fundamental facts. (If we are operating in an Russellian framework, in which facts are true propositions composed of objects, properties, and relations, we can make this characterization more precise: an object is fundamental, then, just if it is a constituent of one of the fundamental facts.)

w_{AB} , at which: The xx are arranged ship-wise twice, generating Aseus and then Bseus.

w_{AA} , at which: The xx are arranged ship-wise twice, generating and then “regenerating” Aseus.

Worlds w_{AB} and w_{AA} are micro-indiscernible, but qualitatively discernible, so if they are both possible, then neither is Democritean.

We claim that w_{AB} and w_{AA} are not both possible. Say that an arrangement of atoms *regenerates* a composite just if it brings the composite back into existence. Regeneration can happen; for instance, a watch can be assembled, disassembled, and then reassembled. But we claim that the micro facts at worlds like w_{AB} and w_{AA} always fully determine which arrangements of atoms are which are regenerative. No two such worlds differ only in whether an arrangement of atoms is generative or regenerative. Hence, we stand by our claim that there are Democritean worlds at which fruitful arrangements of atoms are recycled.

If there is a macro-micro gap at a world, then it must contain fundamental composites. For example, if the micro facts do not entail that Aseus exists, then Aseus must be fundamental. As a general rule, it is bad to include composites among the fundamental objects; the fundamental facts should not mention any individuals forks, spoons, or ships. But there might be cases where composites *should* be fundamental. If there are gunky worlds, for example, then they *should* include fundamental composites. (After all, *everything* at w_{pink} is a composite.) Similarly, if there are worlds with irreducible quantum entanglement, then entangled composites are fundamental at those worlds; the fact that an entangled composite has a particular quantum state *is* one of the fundamental facts at such a world. The pattern illustrated by these two cases generalizes: non-Democritean worlds, if there are any, contain fundamental composites.¹⁷

We think, however, that non-Democritean worlds are the *only* worlds with fundamental composites. On our view, there can be no fundamental composites at Democritean worlds, and hence there can be no merely individualistic macro-micro gaps. That's the idea Minimal Microism captures: it rules out merely individualistic macro-micro gaps.

There is a thesis that places even stronger modal constraints on individualistic facts than Minimal Microism does: namely, *anti-haecceitism*, the thesis that the individualistic facts necessarily entail the qualitative facts. Minimal Microism is weaker than anti-haecceitism and, in our estimation, is much more plausible.

¹⁷ Even in gunky or quantum worlds, only some composites can be fundamental: entangled composites, maybe, but not ships or forks. If the actual world turns out to be non-Democritean, as it might, none of the actual forks of ships should be included among the fundamental objects.

Take the standard argument against anti-haecceitism.¹⁸ Imagine a world, w_{Black} , at which there are two qualitatively indiscernible nongunky iron spheres, Castor and Pollux, separated by a spatial distance in an otherwise empty universe. Castor and Pollux are distinct existents; they are on opposite sides of the world; they bear no special relations to one another, besides being qualitatively similar and spatially separated; neither seems to metaphysically depend on the other. Therefore, it should be possible for each to exist without the other, without any intrinsic change. There should be two possible worlds: w_{Castor} , at which Castor exists and Pollux does not, and w_{Pollux} , at which Pollux exists and Castor does not.¹⁹ But if w_{Castor} and w_{Pollux} are both possible, then anti-haecceitism fails; it is not true, then, that the individualistic facts are necessarily entailed by the qualitative facts.

This argument, together with some further bolstering,²⁰ convinces us that anti-haecceitism fails. But notice that this argument cuts no ice against Minimal Microism. We may suppose that all three worlds— w_{Black} , w_{Castor} , and w_{Pollux} —are Democritean. Minimal Microism then predicts that all three should be worlds at which the micro facts entail the macro facts. But there is no reason to doubt this prediction. Consider w_{Black} , again. At w_{Black} , Castor and Pollux are qualitatively indiscernible, but they are composed of different atoms, so they are micro-discernible. Castor, we may suppose, is composed of the *aa*, whereas Pollux is composed of the *bb*. If we arrive at worlds w_{Castor} and w_{Pollux} by a process of modal subtraction, then w_{Castor} and w_{Pollux} are also micro-discernible. At world w_{Castor} , the *aa* are arranged sphere-wise, whereas, at w_{Pollux} , it is instead the *bb* that are arranged sphere-wise.

¹⁸ Cf. Black (1952) and Adams (1979).

¹⁹ Here we move between the claim that there are distinct possibilities and the claim that there are distinct possible worlds. See note 8 for why this is legitimate, and why, even if it were illegitimate, the interesting philosophical claims would be unchanged.

²⁰ There are two ways of resisting the argument: (1) saying that w_{Black} is impossible, that the possible world imagined really contains a single bilocated sphere, cf. Hawthorne (1995); or (2) saying that although w_{Black} is possible, w_{Castor} and w_{Pollux} are the same world, cf. Dasgupta (2009) and Lewis (1986). For a rejoinder to both, see Russell (2016). Also see Kment (2012).

We think that Castor cannot be a fundamental object at w_{Castor} because Castor is a composite and w_{Castor} is Democritean. The fundamental facts at w_{Castor} , whatever they are, must entail that Castor exists, without ever mentioning Castor. Anti-haecceitists say that the fundamental facts are qualitative. But, since Pollux could be a synchronic, unaccompanied iron sphere, the qualitative facts at w_{Castor} do not entail that Castor exists. Minimal Microism suggests an alternative, which we endorse: the fundamental facts are the micro facts. On our view, Castor *is* the only thing that could be a synchronic, unaccompanied iron sphere composed of the *aa*, and hence the micro facts at w_{Castor} , despite nowhere mentioning Castor, *do* entail that Castor exists.

We want some sort of modal constraint on individualistic facts, and we think that Minimal Microism imposes a constraint of the right stringency.

V. Is There Any Plausible Way to Reconcile 3d'ism and Minimal Microism?

Let's now turn back to 3d'ism.

Our argument against the conjunction of 3d'ism and fruitful recombination is simple: the conjunction is incompatible with Minimal Microism. In fact, the incompatibility is spectacular. Together, 3d'ism and fruitful recombination entail that there is a macro-micro gap whenever an arrangement of atoms generate a composite, and hence entail that every possible composite—every possible, ship, fork, spoon, and plank—is a fundamental object.²¹ We accept Minimal Microism, and therefore reject the conjunction of 3d'ism and fruitful recombination.

²¹ Or anyway, *almost* every possible composite. 3d'ism and fruitful recombination clearly entail that every possible ordinary object is fundamental. It's less clear that they entail the same for very small composites, composed of only a few atoms.

As we said above, 3d'ists are not obligated to accept fruitful recombination. Many philosophers give plausible reasons for denying the possibility of various recombinations.²² But denying fruitful recombination is not enough. Even highly restricted recombination principles make 3d'ism incompatible with Minimal Microism. To eliminate the threat, 3d'ists must offer some account of composites that blocks all potential counterexamples to Minimal Microism.

Our question in this section is whether there is any plausible way to reconcile 3d'ism and Minimal Microism. And our answer is that there isn't.

The best bet for 3d'ists, we think, is to appeal to *predecessor sufficientism*.²³ According to predecessor sufficientism, although a fruitful arrangement of atoms does not always determine which composite it generates, a fruitful arrangement of atoms, taken together with the facts about the composites it *previously* generated, does. To illustrate, consider world w_{ABC} , at which a ship-wise arrangement of the xx is recycled three times, generating Aseus, Bseus, and then Cseus. If 3d'ists want to accept Minimal Microism, then they need to explain, among other things, (1) why Bseus could not have been the first ship, and (2) why Cseus could not have been the second ship (thus taking Bseus' position as the immediate successor of Aseus). According to predecessor sufficientism, (1) and (2) are explained in the same way. Bseus could not have been the first ship because it is essential to Aseus to be the composite generated by the first ship-wise arrangement of the xx . Cseus could not have been the third ship because it is essential to Bseus to be the immediate successor of Aseus, and it is essential to Cseus to be the immediate successor of Bseus. In general, according to predecessor sufficientism, if it is possible for Y to be the immediate successor of X, then it is Y is essentially X's immediate

²² See e.g. Wang (2016) and Wilson (2010).

²³ The problem of recycling is best known as an argument against origin essentialism. Philosophers who have tried to defend origin essentialism in the face of the problem of recycling often appeal to some sort of predecessor sufficientism; see e.g. Forbes (1997) and Salmon (1981, ch. 7).

successor; necessarily, Y is the immediate successor of X, if there is one. Thus, a fruitful arrangement of atoms, together with a possibly empty list of the composites it previously generated, always determine which composite is generated.²⁴

We should note that predecessor sufficientism has some vices. First, it is incompatible with plausible-seeming recombination principles. In the case of ships, for example, it seems (to

²⁴ Predecessor sufficientism is neutral with respect to the issue of generative toleration. Suppose that a ship-wise arrangement of the *xx* can generate Aseus. A question of toleration arises. Could a slightly different arrangement of the *xx* generate Aseus? If the *xy* are a plurality of atoms that include most but not all of the *xx*, could a ship-wise arrangement of the *xy* generate Aseus? If the answer to either of these questions is yes, then there is *generative toleration*. In the main body of the essay we set the issue of generative toleration aside, since its additional complexities do not alter the main dialectic. But let us address it here.

Generative toleration is puzzling because modal centering is puzzling. If there is generative toleration, then it seems that every object is at the center of its tolerant range. For example, if there is generative toleration, and Aseus is generated from the *xx*, then it seems that the range of pluralities of atoms that can generate Aseus center on the *xx*—that Aseus could have been generated from any plurality of atoms that overlap the *xx* to a high enough degree.

Suppose that the *xy* and the *xx* overlap to a high enough degree, and that the *xy* and the *yz* overlap to a high enough degree, but that the *xx* and the *yz* do not. Then it is possible for Aseus to be generated from a ship-wise arrangement of the *xy*, but not possible for Aseus to be generated by a ship-wise arrangement of the *yz*.

Then the puzzle of modal centering arises. Had Aseus been generated from the *xy*, would it then have been possible for Aseus to be generated from the *yz*? Would the *xy* then have been the center of the tolerant range? Both answers are puzzling. If yes, then we are denying the S4 axiom as applied to metaphysical modality. If no, then either the actual world is oddly special, since it is the only possible world at which every object is at the center of its tolerant range, or there is co-location.

Fortunately, it does not matter for our purposes which of the four theoretical possibilities—denying that there is generative toleration, denying S4, claiming that the actual world is special, or allowing co-location—we accept. No matter which of the four we go for in, still we say that Minimal Microism is true, still we say that 3d'ism conflicts with Minimal Microism, still we say that 4d'ism does not conflict with Minimal Microism, and still we say that Minimal Microism entails a weak but universal form of mereological essentialism.

For more discussion of generative toleration and modal centering, see e.g. Chandler (1976), Hawthorne (2006b), Kment (2014; Forthcoming), and Salmon (1984; 1989).

us and to many philosophers, anyway) that it should be possible for Bseus to exist without Aseus existing, and that it should be possible for Bseus to come into existence before Aseus does. Predecessor sufficientism denies these. Second, predecessor sufficientism makes generation extrinsic. Which composite is generated by an arrangement of atoms is not intrinsic to the arrangement of atoms. To know which composite is generated, we have to look into the past and see what other composites, if any, were previously generated by the arrangement of atoms. This is somewhat counterintuitive; it would be better if we could say that generation is intrinsic.

These vices would be acceptable if predecessor sufficientism really did reconcile 3d'ism and Minimal Microism. But there's no reconciliation. There's improvement: predecessor sufficientism allows 3d'ists to avoid the intolerable macro-micro gaps from section III. But even granting predecessor sufficientism, 3d'ism and Minimal Microism cannot both be true. The problem can be cast as a four-premise argument.

P1: Recycling is possible.

As we have seen, 3d'ism is committed to P1. If atoms persist, then fruitful arrangements of atoms can be recycled.

P2: If recycling is possible, then backward-infinite series of recycling are possible.

By P2, there is a possible world w_z , at which every ship-wise arrangement of atoms is preceded by infinitely many others. The final ship-wise arrangement of the atoms generates Zseus, at

time t ; the penultimate ship-wise arrangement of the atoms generates Yseus, one epoch prior to t ; and this pattern continues infinitely into the past.²⁵

P3: Composites do not have their successor essentially.

By P3, there is a possible world w_Y , which is exactly like w_Z except that the universe ends after Yseus comes into existence.

P4: Composites do not have their time of generation essentially.

By P4, there is a possible world w_{Yt} , which is exactly like w_Y except that every ship is moved forward one epoch. (Note that on a relationalist conception of time, temporal shifts of the whole universe do not result in any change. In that case, $w_Y = w_{Yt}$, making our conditional claim—that w_Y is possible, if w_{Yt} is possible—a trivial truth, since identical worlds do not differ in their possibility.)

But, now, of course, we have a macro-micro gap. Worlds w_Z and w_{Yt} are micro-indiscernible: each is a world at which a backward-infinite series of the same arrangement of the same atoms ends at time t . But they are macro-discernible. There is, so to put it, one yacht too many: Zseus exists at w_Z , but not at w_{Yt} .²⁶

²⁵ In his argument against *de re* determinism, Hawthorne (2006b, note 10) discusses backward-infinite series of recycling and says that such cases are counterexamples to a global supervenience thesis, one akin to Microism, which states that “the *de re* facts about macrophysical objects at a world supervene on the qualitative description of the world plus the *de re* facts about the microphysical particles at that world” (p. 242). Hawthorne, who appears to implicitly assume 3d’ism and is concerned primarily to argue against *de re* determinism, takes the argument to refute the global supervenience thesis and thus to cast doubt on *de re* determinism. We reject 3d’ism, and we think that *de re* determinism is true of at least some worlds.

²⁶ Thanks to [omitted for blind review] for pointing out to us that, although we appeal to S4 here, we needn’t.

The four premises together entail that Minimal Microism is false.²⁷ It is easy to see how 4d'ists can block the argument. Whereas 3d'ism entails P1, the premise that says that recycling is possible, 4d'ism, if necessarily true, entails that recycling is *impossible*. If atoms cannot persist, then arrangements of cannot be recycled. 4d'ists thus block the argument by denying P1. But it is not easy to see how 3d'ists can block the argument. The case for P2 is strong. If recycling is possible, then infinite series of recycling are possible, and if infinite series of recycling are possible, then backward-infinite series of recycling are possible. The case for P3 is strong. It is very hard to believe that Yseus depends for its existence on Zseus, in the same way that it is very hard to believe that Aseus depends for its existence on Bseus. The case for P4 is also strong. It is very hard to believe that ships have their time of generation essentially.

We think that there is no plausible way to deny P2, P3, or P4, so we think that there is no plausible way to reconcile 3d'ism and Minimal Microism. But Minimal Microism is true, so 3d'ism is false.

VI. Atomic Sufficientism

While there is no plausible way to reconcile 3d'ism and Minimal Microism, there is a plausible way to reconcile 4d'ism and Minimal Microism.

Operating now in a 4d'ist framework, let us introduce some terminology. Previously we talked of arrangements, which are always three-dimensional; we now will talk of *profiles*, which are often four-dimensional. The *profile* of some atoms, at various spatiotemporal distances from one another, is a maximal, fully specific characterization of how those atoms are

²⁷ Of course, since anti-haecceitism entails Minimal Microism, the four premises also entail that anti-haecceitism is false. Not only are w_z and w_{y_t} macro-discernible while being micro-indiscernible, they are also individualistically discernible while being qualitatively indiscernible.

intrinsically and how they are internally related to one another.²⁸ For clarity's sake, we use boldface capital letters for profiles. If the xx are the atomic parts of Aseus, now construed as a four-dimensional object, and \mathbf{G} is their profile, then we will say that $\mathbf{G}xx$ is the *atomic profile* of Aseus.

Just as we distinguished fruitful and non-fruitful arrangements of atoms, we distinguish fruitful and non-fruitful atomic profiles. An atomic profile is *fruitful* just if it is possible for it to be the atomic profile of some composite.

With this terminology in place, we can state the following thesis:

Atomic Sufficientism. For any atoms xx , any profile relation \mathbf{G} , and any possible composite A, if $\mathbf{G}xx$ can be the atomic profile of A, then necessarily, if $\mathbf{G}xx$ obtains, $\mathbf{G}xx$ is the atomic profile of A.

According to atomic sufficientism, an atomic profile always determines which composite it gives rise to. If $\mathbf{G}xx$ is the atomic profile of A, then no other possible composite could have $\mathbf{G}xx$ as its atomic profile. No atomic profile is multiply fruitful.

We saw in the previous section that predecessor sufficientism does not rid 3d'ism of intolerable macro-micro gaps. But atomic sufficientism *does* rid 4d'ism of intolerable macro-micro gaps, because atomic sufficientism entails Minimal Microism. If the micro facts at world w together entail the qualitative facts at w , then every composite at w is composed wholly of atoms. If every composite at w is composed wholly of atoms, then, by atomic sufficientism, the identity of each composite at w is determined by its atomic profile, and

²⁸ Like arrangements (see note 2), profiles are sensitive to individualistic differences.

therefore entailed by the micro facts at w . Hence, the micro facts at w entail both the individualistic macro facts at w and the qualitative macro facts at w .

Moreover, atomic sufficientism is plausible and appealing in its own right, much more so than predecessor sufficientism is. Recall predecessor sufficientism's two vices. First, various plausible recombination claims—for example, the claim that Bseus could exist without Aseus existing, or the claim that Bseus could come into existence before Aseus does—are incompatible with predecessor sufficientism. Second, predecessor sufficientism makes generation implausibly extrinsic; to know which composite is generated by an arrangement of atoms, we have to look far into the past to see which composites, if any, the arrangement of atoms generated previously. Atomic sufficientism avoids both vices. It satisfies the plausible recombination principles, allowing Bseus to exist without, or before, Aseus. And it makes generation intrinsic. If atomic sufficientism is true, we do not need to look into the past or future to determine which composite an atomic profile gives rise to. The identity of a composite of atoms is always fixed by its atomic profile.

There is, then, a plausible way to reconcile 4d'ism with Minimal Microism—namely by embracing atomic sufficientism. We thus have a new argument for 4d'ism over 3d'ism.

VII. Atomic Essentialism

Atomic sufficientism leaves a number of questions undecided, most of which we will leave unexplored. But it is worth addressing the question of modal flexibility. Atomic sufficientism concerns micro-to-macro necessitation; it says that if $\mathbf{G}xx$ can be the atomic profile of Aseus, then it *must* be, if it obtains. But what about the converse direction? The question of modal flexibility is a question about *macro-to-micro* necessitation. For example, which atomic profiles could be the atomic profile of Aseus?

Someone who accepts atomic sufficientism could defend the maximally inflexible view, on which composites have at most one possible atomic profile. On the inflexible view, there is two-way necessitation: $\mathbf{G}xx$ entails that $\mathbf{G}xx$ is the atomic profile of Aseus, and the existence of Aseus entails that $\mathbf{G}xx$ is the atomic profile of Aseus. But the maximally inflexible view is, of course, extremely implausible. It entails that Aseus could not have been bigger or redder or longer, that Aseus could not have persisted for a longer or shorter duration, and that Aseus could not have had different atomic parts. Each of these claims is absurd (and their conjunction even more so).

Fortunately, atomic sufficientism is consistent with a great deal of modal flexibility. We can allow that Aseus could have been bigger or redder or longer; we can allow that Aseus could have persisted for longer or shorter durations; and we can allow that Aseus could have been composed of very different atoms.²⁹ But there is less modal flexibility than one might have thought. One might have thought that there is no necessary connection between a composite and its atoms, that a composite could be composed of wholly different atoms. But atomic sufficientism, together with some almost uncontroversial modal principles, entails that every possible composite of atoms has the disjunction of its atomic parts essentially.³⁰

Let us introduce the notion of a *disjointed* composite. A composite A is disjointed just if A could have been composed of some atoms, the xx , and could have been composed of some

²⁹ Once we allow modal flexibility, the issues discussed in note 24 arise. Again, we have to reckon with the puzzle of modal centering. But again, how we address the puzzle has no bearing on the dialectic. We could maintain that the actual world is special because it is the only world at which objects are at the center of their tolerant range; we could deny S4; or we could allow co-location. No matter which of these three options we take, our main claims remain unchanged. Still we defend Minimal Microism; still we reject 3d'ism, on account of being incompatible with Minimal Microism; still we favor 4d'ism over 3d'ism because, unlike 3d'ism, 4d'ism is compatible with Minimal Microism; and still we defend atomic sufficientism.

³⁰ Here we assume that a composite of atoms could not have been wholly composed of gunk.

atoms that are disjoint from the xx . It is natural to think that composites *can* be disjointed. Any given ship could have been different in a great many ways; one of these, plausibly, is that it could have been composed of completely different atoms. But the possibility of disjointed composites, like the possibility of atoms persisting, is incompatible with Minimal Microism.

To show this, we argue by *reductio*. Let A be some composite, and suppose for *reductio* that A is disjointed, that $\mathbf{F}xx$ and $\mathbf{G}yy$ each could be the atomic profile of A . (\mathbf{F} and \mathbf{G} could be the same profile relation, but by hypothesis the xx do not overlap the yy .) Then we have two possible worlds:

w_1 , at which: $\mathbf{F}xx$ is the atomic profile of A .

w_2 , at which: $\mathbf{G}yy$ is the atomic profile of A .

(Although it is not necessary for the argument to go through, it is helpful to think of the worlds as small and synchronic. At world w_1 , then, all of the atoms are among the xx , and at world w_2 , all of the atoms are among the yy .)

If worlds w_1 and w_2 are possible, then another world is also possible, namely:

w_3 , at which: $\mathbf{F}xx$ is the atomic profile of A , and $\mathbf{G}yy$ is the atomic profile of some composite $B \neq A$.³¹

The fact that $\mathbf{G}yy$ obtains should be compossible with $\mathbf{F}xx$ being the profile of A . But, if $\mathbf{F}xx$ is the atomic profile of A , then $\mathbf{G}yy$ is the atomic profile of *some* composite, B , distinct from A . The possibility of w_1 and w_2 thus entails the possibility of w_3 .

³¹ And an additional world, too, at which: $\mathbf{F}xx$ is the atomic profile of $C \neq A$, and $\mathbf{G}yy$ is the atomic profile of A . Together, the possibility of this world and world w_3 would provide another counterexample to Minimal Microism.

But now consider the world that results from subtracting the xx from world w_3 , namely:

w_4 , at which: $G\gamma\gamma$ is the atomic profile of B.

If worlds w_1 , w_2 , and w_3 are possible, then world w_4 is possible, too. But the possibility of worlds w_2 and w_4 contradicts Minimal Microism; they are Democritean worlds at which there are macro-micro gaps.

Minimal Microism is thus shown to be incompatible with the possibility of disjointed composites. Since we accept Minimal Microism, we accept:

Atomic Essentialism. Disjointed composites are impossible.

Atomic essentialism is the weak but universal form of mereological essentialism promised in the introduction. It says, in effect, that every possible composite necessarily has one or another of its atomic parts. We can and should allow that composites could have had different atomic parts, but on pain of being forced to countenance intolerable macro-micro gaps, we must deny that composites could have had entirely different atomic parts.

VIII. Conclusion

A true Democritean would be bolder than we have been. They would defend Microism unreservedly, insisting that any metaphysics that leads to any macro-micro gap should therefore be rejected. Microism is an attractive thesis; it would be nice if it proved true. But if either gunk or irreducible quantum entanglement are possible, then Microism is sunk, and at

the current state of inquiry we are not in a position to determine whether gunk or irreducible entanglement is possible.

Fortunately, we can wield macro-micro gaps in metaphysics without first determining whether Microism is true. By embracing Minimal Microism, we can rule out bad macro-micro gaps, without taking any premature stances on what is metaphysically possible. The bottom line is this: there are no merely individualistic macro-micro gaps; if the micro facts at a world entail the qualitative facts, then they also entail the macro facts.

Minimal Microism has many consequences, and we have explored only some of them.³² However, the consequences that we have explored are surprising. Minimal Microism gives us a new reason to favor 4d'ism over 3d'ism and a reason to believe that no possible composite is disjointed.³³

³² For example, Minimal Microism can be used to argue against the view that composition is contingent; cf. Cameron (2007) and Rosen (2006). Thanks to [omitted for blind review] for discussion here.

³³ For helpful comments and discussion, thanks to [omitted for blind review].

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