The Bound-State Answer to the Special Composition Question

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1 The Special Composition Question and Some Physics-Based Answers

What are the *necessary* and *sufficient* conditions under which a set[1] of material objects S *composes* something? In other words: what is the *criterion*—i.e. a condition that is both sufficient and necessary—ψ such that:

$\psi(S)$ iff the objects in set S compose ($Comp$) an object x: $\exists x(Comp(S, x))$?

This is a version of the so called *Special Composition Question* (SCQ). SCQ was famously introduced in the metaphysics literature by Van Inwagen (1987),[2] and it has been driving the debate on composition ever since. Answers to SCQ can be broadly divided in two camps: *extreme* or *moderate* answers.[3] According to *extreme* answers ψ is *irrelevant* for composition: either composition *always* occurs, i.e. a set S of entities composes a further entity under any ψ whatsoever (*mereological universalism*), or composition *never* occurs, i.e. a set of entities S composes a further entity under no ψ whatsoever (*mereological nihilism*).[4] *Moderate* answers single out a non-empty and non-trivial criterion ψ—one that neither fails for every S, nor holds for every S—for composition to occur. Despite their initial attractiveness, satisfactory moderate answers are hard to come by.[5] Recently, different physics-based answers to the SCQ have been put forward

[1] I use set-theory, rather than, e.g. plural logic, because McKenzie and Muller (2017)—the main target of the paper—uses set-theory.

[2] See also Van Inwagen (1990).

[3] I leave aside *Brutalism*. According to Brutalism—to put it roughly—there is no non-trivial principled answer to the SCQ. Wheter some entities compose a further entity is a *brute fact*. For a defense, see Markosian (1998).

[4] This is rough. In effect, given the orthodox definition of composition, a singleton set does not compose a *further* object, even under mereological universalism. For a defense of mereological universalism see e.g. Lewis (1986). For a defense of mereological nihilism see, e.g. Sider (2013).

[5] See Van Inwagen (1990).

in the literature. This is a much welcome development. Metaphysical considerations should be sensitive to insights from empirical sciences. The main focus of this paper will be on the so-called *Bound State Answer* (BSA), suggested in McKenzie (2011), and recently advocated in McKenzie and Muller (2017), and Waechter and Ladyman (2019). However, before we enter into some of its details, it is worth introducing another physics-based answer, namely the *entanglement answer*. The reason for that will be clear in due course.[6] Roughly, according to the latter, a set S of material objects composes a further entity iff the members of S are entangled—thus, ψ is "being entangled".[7] The *entanglement answer*, which is considered in Calosi and Tarozzi (2014), is discussed and discarded in McKenzie and Muller (2017) on the grounds that it is extensionally equivalent to *mereological universalism*:

> In a strict sense every object is interacting with every other (...) As such the *Entanglement Proposal* amounts to *Universalism*. Since we hold that moderate answers to the question are to be preferred over the extreme counterparts, this counts against the tenability of the Entanglement Proposal (McKenzie and Muller, 2017: 240).

As I noted above, McKenzie and Muller go on to defend another physics-based answer. According to such an answer, ψ amounts to "being in a (common) bound state". While the formulations of the BSA due to McKenzie and Muller (2017), and Waechter and Ladyman (2019) differ in details the spirit is very much the same. I will mostly follow McKenzie and Muller (2017) for a simple reason. I find the reasons they give in favor of the BSA controversial. Waechter and Ladyman (2019) appeal to some of those same reasons and suggest others as well. I am prepared to concede that those other reasons do provide support for the BSA.[8] Given that I will be mostly—but not exclusively—concerned with the reasons in favor of the BSA, rather than with details of formulation, I will stick mostly to McKenzie and Muller (2017). That being said, the discussion will give me the chance to deal with Waecther and Ladyman (2019) as well.
The rest of the paper is structured as follows. I will first discuss the BSA and the reasons in its favor (§2). I will then contest those reasons (§3), and compare the BSA with a further restricted answer due to Van Inwagen, namely *Fastening* (§4). This is important insofar as Van Inwagen objects to *Fastening*. It is a substantive question whether the BSA is vulnerable to the same objection. Taken together, §3 and §4 provide a critical assessment of the BSA. In the light of the above, I go on to suggest a different general overlook on physics-based

[6] See especially §5.

[7] This is but a first stab towards a proper formulation. The entanglement answer is not the focus of this paper, so I will leave it at that.

[8] I should mention one caveat that Ladyman and Waecther mention themselves. They claim that one reason in favor of the BSA is that it is applicable, perhaps with some slight modifications, to virtually all physical theories. They explicitly recognize that General Relativity is a difficult case, insofar as the total energy of a system is "[o]nly known for an isolated system in certain conditions (Waechter and Ladyman (2019: 117)"—the total energy of the system being a key notion in the very formulation of the BSA, as will be clear shortly.

answers to SCQ which helps re-evaluate them (§5). A brief conclusion follows (§6).

2 The BSA and Its Virtues

The core of the BSA can be summed up as follows: a set S of material objects forms a composite object iff those material objects interact and are in a common bound state, i.e. they are in the potential well that results from their mutual interaction.[9] A *bound state* is a state where the constituent objects have a potential energy that is greater in absolute value than their kinetic energy.[10] Non-bound states are sometimes referred to as *scattering states*. Restricting our attention to potentials that go to zero at infinity, the criterion for distinguishing between bound and scattering states can be roughly phrased as follows:

$$\begin{gathered}\textbf{Bound State} \Rightarrow E_s < 0 \\ \textbf{Scattering State} \Rightarrow E_s \geq 0\end{gathered} \tag{1}$$

where E_s is the (expectation-value of the) energy of the physical system s—e.g., a particle (Griffiths, 1995: 51-52), or a composite system.
Without entering nitpicking technicalities, a little more precision will be useful. I follow McKenzie and Muller (2017) almost *verbatim*. Let S be a non-empty set of material objects, let $Comp(S, x)$ stand for: "The objects in S compose object x", and, finally, let $x \sqsubseteq y$ stand for: "Object x is part of y". Then:

BSA$_1$. If S contains a single object, then:

$$Comp(S, x) \ \text{ iff } \ S = \{x\} \tag{2}$$

BSA$_2$ If S contains at least two distinct objects, then:

$$Comp(S, x) \ \text{ iff } \ \forall y \in S \ (y \sqsubseteq x) \wedge E_x < 0 \tag{3}$$

Informally, condition (3) says that (i) every $y \in S$ is part of x, and (ii) the total energy of the system x is less than 0, that is, the members of S are in common bound state.

Direct Part x is a *direct part* of y—$x \sqsubseteq_d y$—iff there is a set S such that the objects in S compose y, and contain x:

$$x \sqsubseteq_d y \ \text{ iff } \ \exists S(Comp(S, y) \wedge x \in S) \tag{4}$$

[9] McKenzie and Muller (2017: 234).

[10] For a more accurate statement see Waechter and Ladyman (2019). (Some of) the details of the formulation do not matter for the following discussion, so I will stick to the simpler—if less rigorous—formulation here.

Part x is *part* of y iff there is a finite sequence of direct parts that begins with x and ends with y:

$$x \sqsubseteq y \ \text{ iff } \ \exists i_1, ..., i_n : x \sqsubseteq_d i_1 ... \sqsubseteq_d ... i_n \sqsubseteq_d y \tag{5}$$

The parts that arise for $i \geq 1$ are called **Indirect Parts**. I will use $x \sqsubseteq_i y$ for such a case. This exhausts the core of the BSA. BSA_1 and BSA_2 provide the answer to SCQ, McKenzie and Muller contend, whereas Direct Part and Part allow us to recover parthood and other mereological notions (e.g. *proper part*, *overlap* and so on)—*via* the usual mereological definitions.
Before going over the reasons in favor of the BSA, it is worth noting that McKenzie and Muller do not seem to take composition ($Comp$) as a primitive, as they *explicitly define* it in in terms of $\sqsubseteq$. They go on to define $\sqsubseteq$ in terms of $Comp$. This might be problematic. As of now, I just want to point out that they have three different notions of parthood, i.e., $\sqsubseteq$, $\sqsubseteq_d$ and $\sqsubseteq_i$, one of which figures twice: once in the definition of $Comp$, and once as defined in Part. I will return to all this in §3.

Let us then move on to discuss the reasons in favor of the BSA, or its "virtues" as I shall call them. McKenzie and Muller (2017) lists four of them, two of which are discussed by Waechter and Ladyman (2019) as well. I shall label them (i) *Moderation, Conservativeness, and Extensional Adequacy*, (ii) *Precision*, (iii) *Simplicity*, and (iv) *Parsimony*.[11]

Moderation, Conservativeness, and Extensional Adequacy. The first virtue of BSA is its moderation. BSA is a *moderate* answer to SCQ. *Some*, but *not all* material objects are in a bound state. Thus some sets of material objects, but not every non-empty set, compose something, *contra* nihilisim and universalism respectively. Given that

> [C]ommon sense will always prefer moderate answers to the Question (...), [i]nsofar as congruence to common sense judgments count as a reason in favor of an answer to the Question (McKenzie and Muller, 2017: 236)

this counts as a reason in favor of the BSA. In effect, the proposal is in line with (some) common sense judgments about composite objects. An hydrogen atom is sanctioned as a *bona-fide* composite object, whereas a trout-turkey—i.e. the "mereological fusion" of the undetached front half of a trout and the undetached back half of a turkey—is not.[12] Thus, the first reason seems to be one of *moderation and conservativeness*: the BSA is conservative insofar as it aligns with common-sense moderate judgments about composition, judgments that are "honed through immersion in physical science" (McKenzie and Muller, 2017: 235). Relatedly, Ladyman and Weachter (2019) claims that the BSA provides a moderate

[11] I follow the order in McKenzie and Muller (2017). Labels are mine.
[12] The trout-turkey example is from Lewis (1991).

answer to the SCQ that is *extensionally adequate*. In particular, Waechter and Ladyman (2019) claims that

> [O]ur account is extensionally adequate. All ordinary composite objects included in the Swadesh list comprise (chains of) bound states (Ladyman and Waecher, 2019: 120).

The Swadesh list is a list of words that have cognates in virtually all linguistic communities.[13]. Many such words refer to ordinary composite objects. I take it that this “Swadesh list” argument is relevantly similar to the conservativeness argument above, so that it is warranted to discuss them together.

Precision. Both McKenzie and Muller (2017) and Waechter and Ladyman (2019) note that there is an influential argument in the literature to the point that every moderate answer to SCQ entails *metaphysical indeterminacy* or vagueness, rather than less worrisome forms of indeterminacy, such as epistemic or semantical indeterminacy.[14] By contrast, the BSA offers a *sharp* criterion for composition. in effect, a set of objects compose iff those objects are in a common bound state. This ultimately boils down to (1), which offers, upon inspection, a precise, non-vague criterion.

Simplicity. The BSA is *simple* insofar as it offers the very same criterion of composition for different *kinds* of material objects. No matter whether fundamental particles, molecules, mid-size dry goods, or planets are at stake, the BSA will always tell the same story: they compose something iff they are in a common bound-state. Compare this with some other moderate answers, e.g. the answer Van Inwagen calls *Series*. Here is Van Inwagen:

> [W]e might (...) postulat[e] a sequence or hierarchy of multi-grade bonding relations $R_1, R_2, ..., R_n$, each of which can, for certain relata but not all relata, be the relation that binds those relata together to form a composite object. More formally we could try to this by constructing an answer to the SCQ that is for this form:
>
> *Series*: ($\exists y$ the xs compose y)[15] if and only if

[13]See e.g. Swadesh (1971: 283). The final list contains 100 words. Some examples that are relevant in the context at hand include: animal, bark, belly, berry, bird, bone, child, dog, ear, earth, egg, eye, father, feather, flower, grass, hand, head, heart, leaf, mother, mountain, mouth, neck, nose, road, rope, seed, stick, stone, tail, tooth, tree, woman, worm

[14]See e.g. Lewis (1986) and Sider (2001). This is supposed to be especially harmful for it will eventually lead to indeterminacy in numerical sentences, i.e. sentences that only contain logical vocabulary and identity.

[15]Van Inwagen uses plural-logic rather than set-theory.

the xs are F_1 and stand in R_1, or the xs are F_2 and stand in R_2, or..., or the xs are F_n and stand in R_n (Van Inwagen, 1990: 63).

According to *Series* different relations will account for composition of different *kinds* of objects. Fundamental particles, molecules, mid-size dry-goods, and planets will compose atoms, cells, cathedrals, and planetary systems by instantiating very different relations. The simplicity that is lost in a *disjunctive* answer like *Series* is retained in the BSA. *Other things being equal*, disjunctive moderate answers are less simple than non-disjunctive ones. *Other things being equal*, we should prefer the latter.

Parsimony. It is widely agreed that parthood has some formal features, e.g. it is widely agreed that it is a partial order. Usually these formal features are assumed axiomatically.[16] But, given the BSA, they need not be. In effect, Reflexivity and Transitivity (at least) can be *proven*. Reflexivity follows from Part and BSA_1.[17] Transitivity follows from Part.[18] Insofar as these features of the parthood relation need not be *further* axiomatic *assumptions*, the BSA is *parsimonious*.

3 Measure for Measure

There is no denying that the virtues of the BSA are attractive. But how virtuous is the BSA, really? In the following sections I will attempt to evaluate the"measure" of the aforementioned virtues. Unfortunately, at a closer scrutiny, the BSA will turn out to be less virtuous than it first appears. But then again, who isn't?[19]

[16] Along with *some* supplementation principles. For arguments in this direction see e.g. Simons (1987), Varzi (2016), and Cotnoir and Varzi (Forthcoming). Waechter and Ladyman (2019) suggests that one of the reasons in favor of the BSA is that it vindicates supplementation. However, it should be noted that their argument, if correct, shows that the BSA vindicates one of the weakest supplementation axioms, known in the literature as *Weak Company*—see Varzi (2016). However, this is usually viewed as too weak to pin down a parthood relation.

[17] Given BSA_1, for every x, $Comp(\{x\}, x)$. Thus, by Part, $x \sqsubseteq x$.

[18] Suppose $x \sqsubseteq y$ and $y \sqsubseteq z$. By Part $\exists i_1, ..., i_n : x \sqsubseteq_d i_1 ... \sqsubset_d ... i_n \sqsubset_d y$, and $\exists i^*_1, ..., i^*_n : y \sqsubseteq_d i^*_1 ... \sqsubseteq_d ... i^*_n \sqsubset_d z$. Hence, $x \sqsubseteq_d i_1 ... \sqsubseteq_d .... i^*_n \sqsubseteq_d z$. Thus, $x \sqsubseteq z$.

[19] The BSA has further limitations I am not going to discuss. First, it only applies to *material objects*. It simply does not apply to e.g., *abstract objects* or even to *spacetime regions*. Also, it applies—at least at first sight—only to *physically possible worlds*. I am not going to discuss such limitations because proponents of the BSA explicitly want to restrict their attention to composition of *physical objects* in *physically possible worlds*—see e.g., McKenzie and Muller (2017: 233) and Waecther and Ladyman (2019: 108). Whether such restriction is warranted is another matter. Thanks to an anonymous referee here.

3.1 Measuring Moderation, Conservativeness, and Extensional Adequacy

The BSA is a moderate answer to the SCQ. This much is indisputable. What I want to dispute is its conservativeness, i.e. its alignment with common-sense judgments about composition and, relatedly, its extensional adequacy. I will work under the assumption that conservativeness with respect to common-sense is a virtue of a prospect moderate answer to the SCQ. In effect, McKenzie and Muller explicitly consider such an assumption. And Waechter and Ladyman (2019) provides a defense of *ordinary* objects—though it should be admitted that their use of "ordinary" is philosophically sophisticated. Now, I suspect that when it comes to its alignment with common-sense judgments, the BSA is, on the one hand, too *restrictive*, and, on the other, too *permissive*.

The BSA is too restrictive insofar as it rules out several material objects that common-sense judgments sanction as *bona-fide* objects. McKenzie and Muller offer one example themselves: suits. The jacket and the trousers of a tailored suit fail to be in a common bound-state, hence they do not compose the suit, under the BSA. To see this note that, roughly speaking, a bound-state is a state in which parts remain relatively close, i.e. at relative spatial proximity, instead of being separated by an arbitrary large spatial distance. By contrast, the trousers and the jacket can be arbitrarily far apart—the same holds for the other alleged counterexamples mentioned below. McKenzie and Muller reply as follows:

> [O]ur judgment that trousers and jacket are part of a suit is conventional (...); and when the composition is conventional, mereological proposals need not cover it (McKenzie and Muller, 2017: 240).

But it's not just suits. Bikinis do not exist. Single volumes of the *Encyclopedia Britannica* exist, but the *Encyclopedia* does not. Cups, spoons, teapots exist, but the tea-service does not. You thought you wanted to buy a new deck of poker-cards, but you really can't. The cards exist but the deck does not. Other more controversial composite objects turn out not to exist: swarms and flocks, schools and herds, fleets and cavalries.
To be sure, those who endorse the BSA can maintain that in every such case there is a *plurality* of objects. But the question is whether there is a composite object that those pluralities compose. Are we to say that all judgments as to whether composition occurs in these cases are *conventional* as well? The point I want to make is modest. I am not saying that an argument for *conventionality of composition* cannot be given. I am just claiming that this is exactly where *an argument is needed*, rather than simple assertion. As far as I can see, proponents of the BSA have not provided such an argument. Surely it cannot be, on pain of begging the question, that the cards in the deck, the birds in the flock, the fishes in the school do not compose because they are not in a common bound-state. We can at this point put further pressure on the BSA. As I was saying, this is exactly where an argument is needed. Now, common-sense seems to provide an

argument that, at least in some cases, the pluralities just mentioned do compose. When you go buy a suit or a bikini, common-sensical judgments seem to underwrite the claim that you are buying *one object*, a composite one indeed, rather than a plurality of objects. The same is true for my copy of Goethe's *Faust* which came in two volumes. One can even look beyond common sense. Consider two entangled particles that are arbitrarily far apart. Entanglement can be thought of as *sufficient*—if not necessary—for composition. If so, the BSA will deliver the wrong result, insofar as the entangled particles are not in a bound-state—I will return to this in §5.[20]

On the other hand, the BSA seems too permissive, *vis-à-vis* common-sense judgments. Consider the *mereological monster* from the previous section, i.e. the trout-turkey. The trout-turkey does not exist, according to the BSA. Yet, the *trout-turkey-earth*, i.e. the mereological fusion of the front half of the trout, the back half of the turkey, and the entire earth does. This is because all *terrestrial objects* are in the gravitational well of the earth. In effect, think of any fusion of gerry-mandered, scattered parts of distinct terrestrial objects. Take any such fusion F whatsoever. F does not exist, yet any *Fearth*, i.e. the fusion of F and the earth, does.[21] Foes of mereological universalism often complain about fusions such as F on the grounds that they do not exhibit any kind of natural unity, organic cohesiveness, or the likes. The same complaint—it seems—applies to Fearths. I don't find these complaints particularly compelling. I love monsters. In fact, they do not look like monsters to me. Yet, these complaints are often voiced as coming from the common-sense perspective. If alignment with common-sense judgments is what we are after, I am afraid the BSA does not score that well.

It should be clear how the previous considerations bear on the fate of the *extensional adequacy* of the BSA, in the light of Waechter and Ladyman's "Swadish list" argument. The point is that the Swadish list does not contain the list of *all* ordinary composite objects. And even if it did, it would probably not contain each and every Fearth. But the BSA delivers that every Fearth exists. Its pronouncements are therefore arguably not extensionally equivalent to an "enriched" Swadish list. If this enriched Swadesh list is the paradigm against which extensional adequacy has to be measured, the BSA can be found wanting.

[20]Thanks to an anonymous referee for pushing me on this point.

[21]One might object as follows. Once there is a bound-state, it is the whole bound-state we should look at. We cannot pick arbitrarily any subset of objects in that state, and then claim they compose something. Now, the fusion of *all* terrestrial objects, call it F*, and the earth, are indeed in a common bound-state. So, it is that bound state we should look at, not just a fusion of *some* terrestrial objects and the earth. It is only Fearth* (the fusion of F* and the earth) we should be interested in. I can think of two replies. First, Fearth* is itself a *mereological monster* in the light of moderate answers of the SCQ. Second, any fusion F of subsets of parts of terrestrial objects and of the earth are in a common bound state as well, even if it is not the same bound state that F* and the earth are in. Thus, according to the BSA it would still be the case that any Fearth exist.

3.2 Measuring Precision

Once again, it is indisputable that the BSA gives a precise, non-vague moderate answer to the SCQ. The question is whether precision *per se* is really a virtue that is so hard to obtain. I contend that precision in itself is quite easy. And is something really a virtue, if it is so easy? What I am really challenging here is not the *measure* of precision, as much as its *worthiness*. Any moderate answer to the SCQ takes the following form:

$$\forall S(\exists x(x \in S) \wedge \psi(S) \leftrightarrow \exists z(Comp(S, z)) \tag{6}$$

where $\neg\forall S(\psi(S)) \wedge \neg\forall S(\neg\psi(S))$ holds.[22] (6) claims—roughly—that criterion ψ provides necessary and sufficient conditions for members of S to compose z. Pick any non-vague ψ whatsoever, plug it into (6), and the result will be a precise, non-vague moderate answer to the SCQ. Suppose ψ is "having negative charge". The corresponding moderate answer to the SCQ will be as precise as the BSA. Unfortunately it will entail that only things with negative charge undergo composition. Or suppose that ψ is the ancestral relation of *topological connection*. Insofar as topological connection is not vague, neither is the resulting moderate answer. Let us restrict our attention to binary fusions, i.e. fusions of two (atomic) parts. Then, the following is—according both to McKenzie and Muller's and to Waechter and Ladyman's own standards—a precise moderate answer to the SCQ:

$$x \circ y \leftrightarrow \exists w(Comp(\{x, y\}, w) \tag{7}$$

where $\circ$ is mereological overlap, defined as usual:

$$x \circ y \text{ iff } \exists z(z \sqsubseteq x \wedge z \sqsubseteq y) \tag{8}$$

Insofar as $\sqsubseteq$ is not vague, $\circ$ is not vague. Once again, (7) is precise, yet it is not plausible, for it states that two things compose another iff they overlap. All these examples teach the same lesson. Precision *per se* is not difficult to get. The real difficulty, and thus the real value, lies in specifying a *precise* ψ that *also meets further desiderata* for composition we might care about. In particular, if we want our restricted answer to the SCQ to align with common sense judgments, the task is to put forward a precise ψ that at the same time sanctions commonsensical judgments about composition. To put it differently: it is the combination of *conservativeness* and *precision* that should be considered a virtue (for moderate answers). And I already made my case about the "real conservativeness" of the BSA.

3.3 Measuring Simplicity

The BSA exhibits a certain simplicity (or unity), especially when compared with moderate disjunctive answers like *Series*. But there are other dimensions

[22] I am slightly abusing terminology here, as the criterion ψ applies to the members of S, perhaps collectively, rather than to the *set* S.

of Simplicity that should be considered, beside that of not being disjunctive. After all, when I discussed Simplicity I did claim that, "other things being equal", we should prefer non disjunctive answers. Are other things equal? One might argue they are not. For example, the BSA has *two distinct conditions for composition*—reflected in the distinction between BSA_1 and BSA_2. One condition is given for a singleton set, and a different condition is given for a set that contains at least two members. Surely, one might insist, a single condition would be simpler. In fact, we should strive for a single condition. If it is a necessary and sufficient criterion for composition we are after, and this is in fact the heart and soul of every moderate answer to the SCQ, shouldn't it apply to *all* cases of composition, including the limit case of a singleton set? Every thing—atoms included—counts as a mereological fusion of itself. Every thing—atoms included—self-composes, so to speak. And in fact, plenty of moderate answers to the SCQ do not need to distinguish cases of self-composition from other cases. Take the (admittedly unsatisfactory) answer in (7). Generalizing, we can say that members of S compose something iff they stand in the ancestral of the overlap relation—as defined in (8). Call this the *Overlap* answer to the SCQ. The *Overlap* answer does not need to distinguish between sets S_i with one or more members.

But does the BSA really need to distinguish the two cases? Could we just simply abandon BSA_1, and stick with BSA_2 only? *That* would be a welcome simplicity. In the end, if the hallmark of composition is being in a bound-state, shouldn't this apply, in all its simplicity, to cases when just one object is involved? Shouldn't we say that an object self-composes iff it is in a bound-state? Unfortunately we cannot. For there are simple physical systems that only admit of *scattering states*. A free particle, for instance, only admits of scattering states (Griffiths, 1995: 52). If we were to drop BSA_1 in the name of simplicity, we would have to admit that free-particles do not self-compose. As a consequence, Parthood—as defined in (4) and (5)—would not be Reflexive. For in general, it would not be true that for every x, $Comp(\{x\}, x)$.[23] Look at it this way. The argument above—if it is right—shows that according to the BSA "being in a (common) bound-state" is the hallmark for composition only for those *particular cases* where more than one object is involved. For cases where only one object is involved, "being in a (common) bound-state" does not play any role. One might at this point ask whether being in a "being in a (common) bound-state" is the hallmark of composition after all. I anticipate the following reply: the only interesting cases of composition are cases in which two or more objects are involved. We should not dwell too much on limit cases of self-composition. Now, there is some truth to the point that the focus of our epistemic interests is on the cases in which two or more objects compose. But is there a *metaphysically significant* difference there? Admittedly, there are some metaphysical differences. For example, if something self-composes, it does not compose a further entity. But limit cases of composition are still cases of composition, one might contend.

[23] See footnote 17.

In any event, it is enough for my present aims that I argued for the following point: (i) either we keep both BSA_1 and BSA_2, thus detracting significantly from the overall simplicity of the BSA, or (ii) we abandon BSA_1, we restore full-fledged simplicity but we lose self-composition, and along with that, Reflexivity.

There is a final dimension of simplicity one might worry about, although "simplicity" might not be the right label for it. As I noted already, McKenzie and Muller have three different notions of parthood: Parthood, Direct Parthood and Indirect Parthood. As a matter of fact, they really don't have three, but rather four. For they take Parthood as primitive in their definition of *Comp*, and then go on to define Parthood as a disjunction of two further defined notions, Indirect and Direct Parthood.[24] This is problematic: what guarantees do we have have that the primitive notion of Parthood and the defined notion of Parthood are at least extensionally equivalent—if they are meant to be the same relation at least? One can push the point that this proliferation of parthood relations detract from the simplicity of the proposal.[25] Now, I am not going to press this line of argument too much. This is because I think there is no need to take Parthood as primitive if one were to endorse the BSA. This also seems to be the line taken by Waechter and Ladyman (2019), insofar as their characterization of the BSA does not mention the parthood relation. But as I shall now contend, this is important. If we define the notion of *Mereological Parthood*[26] in terms of *Comp*, this turns out to be Direct Parthood. And this leads me to my final point: the measure of parsimony.

3.4 Measuring Parsimony

The BSA is allegedly parsimonious insofar as some formal features of the relation of parthood can be proved, rather than assumed axiomatically. McKenzie and Muller focus on Reflexivity and Transitivity. The argument in the previous section has some bearing on Reflexivity. It need not be assumed axiomatically only insofar as one assumes BSA_1, and distinguish two cases of composition, self-composition and composition of two (or more) objects. This detracts from

[24] The reader can verify that Parthood can be defined using that disjunction.

[25] This raises a further worry. Van Inwagen is explicit that any answer to SCQ should not use any mereological vocabulary. By contrast, $\sqsubseteq$ is mentioned explicitly here. I am not pushing this point mainly for two reasons. First, as I mention in the main text, I believe there is a way to phrase the BSA that does not use $\sqsubseteq$, nor any other mereological vocabulary for that matter. Second, it has been argued that van Inwagen's constraints are unnecessary stringent in this respect. For instance, Markosian writes:

> Van Inwagen lays down a similar, but more stringent, restriction on what can count as an interesting answer to SCQ. He in effect stipulates that answers to SCQ are to be instances of (S1) [the alleged answer to the SCQ] that contain no mereological terms after their occurrences of "iff". (See *Material Beings*, pp. 30-31.) Thus it is possible for a sentence to qualify as a non-trivial answer to SCQ on my account, but fail to qualify as an answer to SCQ at all on van Inwagen's account (Markosian, 1998: 244).

Thanks to an anonymous referee here.

[26] As will shortly be clear, the qualification "Mereological" is crucial in what follows.

Simplicity. Or so I argued. In effect, one can make a case that BSA_1 is *assumed only* to guarantee Reflexivity.[27] *Assuming* BSA_1 has the same costs that assuming Reflexivity directly has. There is actually no parsimony here. Let us move then to Transitivity.

In what follows it will be crucial to qualify parthood as *mereological* whenever needed—the reason will be obvious in a moment. Thus, at the risk of sounding repetitive, I will indeed explicitly add that qualification when necessary. The relation of mereological parthood axiomatized in (classical) mereology is usually taken as a primitive, and the notion of mereological fusion is defined in terms of mereological parthood as follows:

$$Fus(x, S) =_{df} \forall y(y \in S) \rightarrow (y \sqsubseteq x) \wedge \forall z(z \sqsubseteq x \rightarrow \exists w(w \in S \wedge z \circ w)) \quad (9)$$

Informally x is a fusion of (the members of a) set S iff every member of S is a mereological part of x, and every mereological part of x overlaps at least a member of S. But the two notions are inter-definable. Starting with a notion of Fusion, in mereology we define mereological parthood as follows:[28]

$$x \sqsubseteq y \text{ iff } \exists S(Fus(y, S \cup \{x\}) \quad (10)$$

That is to say that x is a mereological part of y iff there is a set S such that y is the fusion of the members of S and x. Taking Fus and $Comp$ as mutual converses, x is a mereologiocal part of y iff there is a set S such that the members of $S \cup \{x\}$ compose y. And naturally $x \in S \cup \{x\}$. Hence, what (10) claims is that x is a mereological part of y iff there is a set S^* such that the objects in S^* compose y and contains x. This is *verbatim* the notion of *Direct Parthood*. In other words, the argument above shows that the usual definition of mereological parthood given in terms of fusion in mereology is what McKenzie and Muller call Direct Parthood $\sqsubseteq_d$, not what they define in Part $\sqsubseteq$. So, the question of whether we can prove that mereological parthood is transitive, boils down to the question of whether $\sqsubseteq_d$ is transitive. This is problematic because, as McKenzie and Muller themselves point out, it turns out that $\sqsubseteq_d$ is not transitive after all. Ladyman and Weachter (2019) are explicit about this. Let me flesh out in some details an example McKenzie and Muller briefly mention. Three quarks q_1, q_2, q_3 compose a proton p, for they all lie in a *common* potential well—hence they are in a common bound-state:

$$Comp(\{q_1, q_2, q_3\}, p) \quad (11)$$

From (11) we get that, for every q_i, $q_i \sqsubseteq_d p$. The proton p and an electron e compose an Hydrogen atom H, insofar as they are both, once again, in a *common* potential well:

[27] Van Inwagen himself is explicit in this regard. See Van Inwagen (1990: 82; footnote 29).
[28] See e.g. Van Inwagen, (1987: 25).

$$Comp(\{p, e\}, H) \tag{12}$$

From (12) we derive that $p \sqsubseteq_d H$. Transitivity will dictate that, for each q_i, $q_i \sqsubseteq_d H$. That is, applying (4)—or (10)—there exists a set S such that $Comp(S, y)$, and $q_i \in S$, for each q_i. Clearly $S = \{q_1, q_2, q_3, e\}$. Unfortunately H does not compose S according to the BSA, for its members are not in *common potential well*, i.e. they are not in a common bound-state. Hence Transitivity of $\sqsubseteq_d$ fails.[29] In effect, the relation McKenzie and Muller define in Part is basically the *transitive closure* of $\sqsubseteq_d$. It is no wonder that it is transitive. The transitive closure of any relation is transitive.

This last argument can be generalized. The general point is that it is dubious that we should ascribe the merits of the alleged derivability of the formal profile of *some* parthood relation to the *physical details* behind the BSA. To argue for this claim, let me introduce a construction due to Fine (2010: 567-568). Suppose we start from a very general—and flexible—composition operation $\sum$. $\sum$ is flexible insofar as it can take any number of argument, $0, 1, ..., n$, for any n. Then we can define the notion of *component*, and *parthood**—the counterparts of McKenzie and Muller's Direct Part and Part—as follows:

Component. x is a *component* of y iff y is the result of applying $\sum$ to x and (possibly) some other object.

Parthood*. x is part of y iff there is a sequence of objects $x_1, ..., x_n$, $n > 0$, for which $x = x_1$, $y = x_n$, and x_i is a component of x_{i+1} for $i = 1, ..., n-1$.

Then, *independently of any physical details about* $\sum$, *parthood** is reflexive and transitive.[30] This shows that details about "being in a bound-state" are irrelevant when it comes to prove some formal features of *some particular part-like relation*—like *parthood**. They simply follow from taking an *operation* of general composition as primitive (and basic), rather than a *relation* such as parthood. This is important especially in the case of McKenzie and Muller for, as should by now be clear, they take Parthood as both a primitive and a defined notion. The point here is that if one takes it as it is defined in Part—and one should take it as a defined notion if one wants to *derive* some formal features, rather than assuming them axiomatically—one ends up with Component or Direct Parthood. In effect, as Fine himself remarks, the notion of mereological parthood is equivalent to that of *component*, rather than *parthood**.[31] This is in line with the argument I offered. And, as Fine points out,

[29] As I mentioned already, Waechter and Ladyman (2019) agrees on the failure of transitivity. Their argument is slightly different.

[30] The proofs are entirely similar to the ones in footnotes 17 and 18. Interestingly enough, Anti-symmetry depends on some details of $\sum$. Note that $\sum$ should be defined even when it takes only one object as an argument. This will ensure Reflexivity. That is why we do need BSA_1, as I argued in the previous section.

[31] The argument is relevantly similar to the one I gave for McKenzie and Muller's Direct Part.

> [I]f part is understood as component, it would be a substantive question whether the relation is transitive (Fine, 2010: 569).

Note that McKenzie and Muller are interested in offering an answer to the SCQ, *as it is understood in metaphysics.* They are explicit:

> [W]e are claiming (...) that the Bound State Proposal *identifies the sort of composition that is relevant to the Special Composition Question discussed in metaphysics* (McKenzie and Muller, 2017: 240, italics mine).

The SCQ, as it understood in metaphysics, is cashed out in terms of *component*, not of *parthood**, using Fine's terminology. Or, in McKenzie and Muller's terminology, it is phrased in terms of *Direct Parthood.* It is a substantive question whether *that* relation is transitive. And it turns out, that it is not. To conclude: the BSA can recover the Reflexivity and Transitivity of *some relation in the vicinity of mereological parthood.* And this is not because of some details about bound-states, or some other physical details about composition, but rather because of some general formal features.
But, in the end, what's in a name? That which we call a rose by any other name would smell as sweet.[32] And saying that a leg is a tail doesn't make it a tail.[33] Calling parthood a relation in the vicinity of mereological parthood, does not make that relation mereological parthood, as it is understood in the SCQ. And as far as *that* relation goes, we *cannot prove* that it is transitive. In fact, given the BSA, we can prove that it is not.

4 The BSA and *Fastening*

While going through some possible moderate answers to the SCQ, Van Inwagen discusses what he calls *Fastening*:

> [S]uppose that two objects (...) are so arranged that, among all the many sequences in which forces of arbitrary direction and magnitude might be applied to either or both of them, *at most only a few* would be able to separating them (...). Then let us say that these two objects are *fastened to each other*, or, simply, *fastened.* (...) Now the concept of "fastening" is pretty vague, and my attempts to explain it could probably be improved upon (Van Inwagen, 1987: 30-31).[34]

[32] *Romeo and Juliet*; II, II: 1.2.
[33] Attributed to A. Lincoln. See *Reminiscences of Abraham Lincoln by distinguished men of his time, collected and edited by Allen Thorndike Rice (1853-1889).* New York: Harper and Brothers Publishers, 1909: 242.
[34] See also Van Inwagen (1990: 56-57).

On the face of it, the BSA seems fairly analogous to *Fastening*. In effect, it looks as a way of using physics to make *Fastening* more precise, to improve Van Inwagen's original formulation, as he himself would put it. This is because scattering states are exactly those states in which particular forces are responsible for "separating" components.[35]

The analogy is worth pointing out for different reasons. First because, to my knowledge, it has not been pointed out.[36] Second, if borne out, it can be used to reply to an objection due to Markosian (1998). Markosian writes:

> [I]n addition to the difficulties spelled out above for each of the versions of Fastenation, there is a general difficulty facing all these views. The general difficulty is that *we don't know what it means to say that some x-s are fastened together* (Markosian, 1998: 225, italics added).

In the light of this general objection, Markosian contends, the expression "the x-s are fastened together" should be taken as a primitive. And this is a great theoretical cost. But, if the analogy holds, perhaps we can simply reply that we *do know* what it means for the x-s to be fastened together: it means that they are in a common bound-state. And that latter notion can be defined as in (1).

Finally, the analogy is worth pointing out because Van Inwagen objects to *Fastening* on the grounds that it delivers unwanted results. If you and I shake hands and we suddenly become paralyzed we become fastened. Yet, according to Van Inwagen

> [O]ur paralysis has not added to the furniture of earth: it has merely diminished its capacity to be re-arranged. Therefore, composition is not, primarily, a matter of things being fastened to one another. This is not to say that there may not be some cases in which certain things come to compose something at the moment they become fastened to another another; it is to say that *the mere fact that they have become fastened is not a complete explanation of the generation of th new thing that they compose* (Van Inwagen, 1987: 31-32, italics added).[37]

Following Markosian (1998), let me call this the "Paralyzed Handshakers" objection. In the light of the analogy above, consider the following argument. Suppose a speck of galactic matter is caught in the gravitational well of the earth. Does this add to the furniture of the universe or merely diminished its capacity to be re-arranged? Is this the complete explanation of the generation of the new thing that the speck of matter and the earth compose?

[35] To be fair, it is not Van Inwagen's own notion of *Fastening*, for Van Inwagen requires fastened objects to be topologically connected.

[36] Neither McKenzie and Muller (2017), nor Waechter and Ladyman (2019) mention *Fastening*.

[37] See also Van Inwagen (1990: 58).

There seems to be a worry here. Let me phrase it this way. Either the BSA is relevantly similar to *Fastening* or it is not. If it is not, an account of the relevant difference is owed. If it is, then one has to address the Paralyzed Handshaker objection—or my galactic speck of matter variant. Either the objection was compelling in the first case, or it was not. If it was not, then we should have gone with *Fastening* all along. The BSA is *just* a way to make *Fastening* precise. However, one would need to motivate *why* the objection was not compelling. I know of no such discussion. If the objection was compelling against *Fastening* but it is not compelling against the BSA, then, once again, one needs to explain why, especially under the assumption at work here, namely that the BSA and *Fastening* are relevantly similar. Let me lay my cards on the table. I don't think that these difficulties are insuperable. As a matter of fact, I will suggest some strategies myself in the next section. Yet, it seems fair to say that more work needs to be done. This concludes my critical assessment of the BSA.

5 Mereological Pluralism

In the light of the above, one may wonder whether I think the BSA should simply be rejected. I am actually more sympathetic than one might infer from the arguments in the previous sections. Here I want to suggest different ways to look at the BSA—and other physics-based answers—that sidestep many of the worries raised above. I should be explicit upfront and confess that I will not provide an argument to the point that these are the *only* ways, the *best* ways, or the *correct* ways of looking at the BSA. I will limit myself to putting some suggestions on the table.

It is perhaps instructive to start by going back to the *entanglement answer* to the SCQ. As I briefly pointed out in §2, the entanglement answer and the BSA are not extensionally equivalent. The easiest way to appreciate it is to note that two entangled particles need not be in a bound state. Now, one can push the point that quantum mechanics need to treat (multi-particle)[38] entangled systems as composite systems to account for experimentally detectable correlations. In other words, one might treat entanglement as *sufficient* for composition.[39] This would provide an alleged physics-based counterexample to the BSA. It also seems that now we have two physics-based answers that deliver different results. I suggest that this is significant, and can be taken at face value. Perhaps the moral to be drawn from the discussion above is that physics provides us with *different ways to build wholes out of some components*, so to speak. Let me expand on this. As far as I can see, there are—at least—two different ways to develop the suggestion.

The first option is that we distinguish *simple mereological composition* from

[38]See Hasegawa (2012) for a case of one-particle entanglement. Note that this is not a problem for the proposal we are discussing here, for the proposal has it that entanglement is only *sufficient* for composition.

[39]For an argument see e.g. Schaffer (2010), and Calosi and Tarozzi (2014).

ψ*-composition* and we *define* the latter in terms of the former:

ψ-composition: A set S of material objects ψ-composes a further object x iff the members of S mereologically compose x and $\psi(S)$.

Mereological composition is necessary but not sufficient for **ψ-composition**. Different ψ will deliver different kinds of composition, different kinds of wholes and different kinds of parts. Suppose ψ is "being in a common bound-state".[40] Then we will get a notion of *Bound-composition*, a notion of *Bound-whole*, and a notion of *Bound-part*. Or, suppose that ψ is "being in an entangled state". Then we will get a notion of *Entanglement-composition*, a notion of *entangled-whole*, and a notion of *entangled part*.
This suggestion will not help answering the SCQ, for the SCQ is crucially understood in terms of *mereological* composition. Yet, it will help with some worries raised in §3. For one, depending on ψ, alignment with common-sense judgments should arguably not be considered a *desideratum* in the first place. Some such conditions are clearly beyond the scope of common-sense judgments. It will also help answering some worries about the formal profile of parthood relations. One can wholeheartedly accept that mereological parthood is indeed transitive, whereas the defined notion of ψ-parthood is not. But this is far from problematic. Whether ψ-parthood is transitive will depend on the exact ψ.[41] Finally, it should be noted that this can help to assuage—if not undermine—the Paralyzed Handshakers objection, or my speck of galactic matter counterpart. The worry was that the BSA seemed incapable to explain the "addition" to the furniture of nature, rather than the diminished capacity of rearranging some of its already existing items. In the case at hand, one would say that the BSA does provide an explanation of the fact that an already existing mereological sum becomes a new kind of whole, namely a *bound-whole*.

Now, the option I just discussed is a somewhat *conservative* option. There is a second, more radical one, that can be put forward. According to such an option, the arguments above suggest genuine *mereological pluralism*. Mereological pluralism is the view that

> [T]here are different *basic* ways in which one object may, intuitively, be part of another (Fine, 2010: 562, italics added).

Or, as McDaniel puts it:

> [T]here are many *fundamental* parthood relations (McDaniel, 2009: 254, italics added).

[40] Note that we will not recover the BSA as defined by McKenzie and Muller (2017). The proposal at hand is strictly speaking stronger then theirs, in that it entails theirs but is not entailed by it.

[41] This should be expected. Perhaps this is best appreciated in the context of set theory: the union of two transitive relations need not be transitive.

The thought here is that there are different parthood relations that *are not definable* in terms of mereological parthood.[42] This is where mereological pluralism departs from ψ**-composition** above, for the latter holds that any ψ-parthood relation is definable in terms of mereological parthood. As Fine points out, from the fact that pluralists hold that different notions of parthood cannot be defined in terms of mereological parthood, it doesn't follow that they cannot be defined at all. In effect, a way to do so is exactly the one I presented in §3.4. One can start with *different* operations of composition $\sum$ that cannot be inter-defined, and then go on to define different notions of **Component** and **Parthood***. In other words: one can endorse both *compositional pluralism* and *mereological pluralism*.

As far as I can see, this proposal will have the same consequences as the previous one *vis-à-vis* the SCQ, the alignment to common sense and, *mutatis mutandis*,[43] the response to the Paralyzed Handshakers objection. The question about the formal profile of different parthood relations is however more interesting, and it is worth spending a few words on it. On the one hand, one may hold the view that the different notions of parthood might not share the very same formal profile. In particular some of them might be transitive, some would not be. Bound-parthood can be then identified with McKenzie and Muller Direct Parthood, and failure of transitivity would not be problematic after all. On the other hand, one might simply insist that different notions of parthood might well have different formal profiles, and yet, *the partial ordering axioms are constitutive* of any relation that aspire to be a parthood relation. In this case, one should then insist that the way in which a bound-part is a part is not really given by Direct Parthood, but rather by its transitive closure, namely the relation that McKenzie and Muller define in Part. This is reminiscent of the discussion in Fine (2010) that focuses on an alleged notion of set-theoretic parthood:

> [I]ndeed, it may well be thought that the way in which a member is part of a set is given, not by the membership relation itself, but by the ancestral of the membership relation, where that is the relation that holds between x and y when x is a member of y, or a member of a member of y, or a member of a member of a member of y, and so on. The way in which a member is part of a set will then indeed be transitive, and the relation of member to set will merely correspond to the special case in which the object is *directly* part of the whole (Fine, 2010: 563).

It should be noted that the discussion above would not help McKenzie and

[42] Mereological pluralism has been investigated—and defended—in Grossmann (1973), Simons (1987), Armstrong (1997), Johnston (2006), Koslicki (2008), McDaniel (2009), and Fine (2010) to mention a few. The *locus classicus* for the opposite view, *Mereological Monism*, is Lewis (1991). A recent defense is in Lando (2017).

[43] For instance, given that mereological composition is not necessary for Bound-composition, there is no guarantee that there will be a pre-existing mereological sum in the case at hand.

Muller's case for **Parsimony**. Their claim was that they could prove transitivity of the notion of parthood that is at stake in the original SCQ. That is mereological parthood. And the suggestion at hand is exactly that bound-parthood is *not* mereological parthood.

As I pointed out already, I concede that the discussion above does not provide *a fully fledged argument in favor* of any of these two ways of looking at the BSA and other physics-based answer to questions of composition in general. I am afraid this deserves an independent scrutiny. It should be enough for now to have laid these possibilities on the table.

6 Conclusion

To take stock. The BSA represents a much welcome development in the debate on the physics and metaphysics of composition. On the one hand, I believe our metaphysics should be informed by empirical sciences. On the other hand, as I argued, at a closer look the BSA is less conservative and less simple than expected (or desired), its precision is arguably over-rated, and its ability to get some formal features of mereological parthood relation for free—that is, the formal features of the specific parthood relation that is employed in cashing out the original SCQ—is dubious. However, I also suggested different ways to look at the proposal—and at other relevant ones—which promise to have significant and fruitful ramifications. In particular, I suggested a less revisionary and a more revisionary understanding of the physics-based answer(s) in question. There is a sense in which both these understandings are card-carrying pluralist proposals.[44] It should in conclusion be noted that an overall pluralistic attitude towards composition in physics has been suggested, if not advocated, in a number of places, for instance Healey (2013) and Ceravolo and French(MS). An echo of such a general pluralistic attitude might be heard in this passage of Ladyman and Ross:

> [T]he wholes mentioned [in physics] (...) are hugely disparate and (...) we have no reason to believe that an abstract composition relation is anything other than an entrenched philosophical fetish (Ladyman and Ross, 2007: 21).

I don't share Ladyman and Ross's extreme skepticism towards the "abstract composition relation"—if this is meant to be mereological composition. Perhaps the disparity of the wholes that we are presented with in physics calls for some pluralism after all. Arguments in its favor will have to wait. We cannot do the whole work at once, only some parts.

[44] Though, admittedly, only one qualifies as genuine mereological pluralism.

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