Quantum Holism: Reconciling Extended Simples with Supersubstantivalism

## Abstract

I argue that the extended simples picture (ESP) is compatible with supersubstantivalism under the quantum holism model, and that reevaluating our limits on the ways an object may be located by fusing the two ontologies can benefit our understanding of modern physics. I first illustrate the explanatory utility of extended simples, using examples of superposition and entanglement. Second, I advocate the use of supersubstantivalism as a way to understand the interface between objects and spacetime, and argue that the ESP suitably fits into a supersubstantivalist interpretation of quantum field theory. In the last section, I propose quantum holism as a framework to reconcile supersubstantivalism with extended simples, and conclude that the causal relationship that interweaves material objects and spacetime render the two ontologies compatible. I will demonstrate that a combined ontology is useful for its parsimony, and for our understanding of quantum field theory.

## 1. Ways an object may be located: Extended Simples

Moving away from the assumption that simples must be physically small, or that all extended objects consist of multiple, spatially disparate parts, metaphysicians including Parsons (2003), Markosian (1998), and Simons (2004) have endorsed the possibility of spatially extended mereological simples.

There are mainly two viable conceptions of extended simples. First, there is the conception of extended simples as "spanners," as discussed in Lewis (1991) and McDaniel (2007). According to this conception, "an extended simple bears the occupation relation to exactly one extended spatiotemporal region, without bearing the location relation to any proper part of that extended region" (McDaniel 2007). This definition implies that extended simples are simples in virtue of covering a part-less region with homogeneous properties, and precludes the possibility of extended simples occupying more than a single extended region of spacetime.

Second, there is the conception of extended simples as “entended” or “multi-located” objects, defended in Parsons (2003)—this is the definition I will concentrate on. Parsons provides an account of extended simples with a concept he calls “entension,” or “the phenomenon of a material object being wholly located in multiple places.” He places this in contrast with “pertension,” the phenomenon of an object “being partly located in multiple places.” The temporal analogues to such location relations are endurance and perdurance, respectively, where endurance is the phenomenon of an object being wholly located at every instance of time at which it exists, and perdurance is the phenomenon of an object being partly located at every instance of time at which it exists. These entended objects, which I will call extended simples from here on for unity of terminology, need not have homogeneous properties; rather, they possess intrinsic, non-relational properties that can be described as the *distribution* of original qualities such as “heat” or “polka-dottedness.” When, for example, a single object is bright in one region and dark in another, it is the intensity of the “darkness” property that varies, and not the object itself. This possibility of a single simple having seemingly diverse properties will later prove useful in our discussion of quantum holism, where I will argue for the possibility of a single, extended simple manifesting itself as multiple material particles.

Markosian also contemplates a similar hypothesis of parthood and provides a more formal definition for the ESP. Under what he calls the Maximally Continuous View of Simples (MaxCon), an object is a simple iff it is maximally continuous — a maximally continuous object *x* being a “spatially continuous object with no continuous region of space *R*, such that the region occupied by *x* is a proper subset of *R* and every point in *R* falls within some object or another" (Markosian 1998). In other words, when there is a simple that extends across a certain continuous spacetime region *R*, all the points in the said region fall within the simple. I find this definition advantageous and will adopt it in the following discussions of extended simples, in that it opens the possibility for a simple to be 1) larger than a point spanning a single region of spacetime and 2) physically and metaphysically divisible. I think any definition of simples that does not permit variations in size or divisibility is unremarkable in the world of physics, as simples would be no different from the existing, rather outdated notion of indivisible atoms.

Having designated a formal definition of the ESP, I now defend the ontology's practical applications by examining its utility in modern physics.

### *1.1 Superposition*

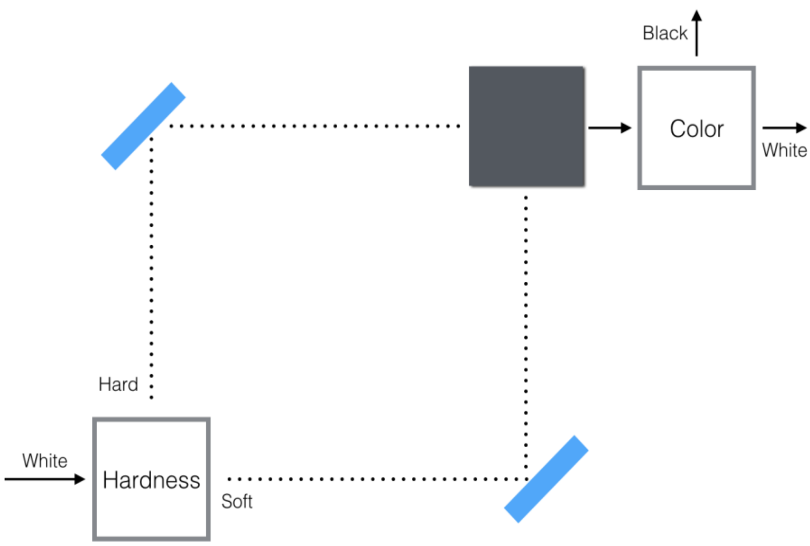


*Figure 1: Superposition illustrated*

Consider the familiar quantum setup (Figure 1) in which a "white" particle is placed in a hardness box with two apertures, hard and soft. The hardness and softness paths stemming from the apertures reconvene at some point, and the color of the particle is measured again. Experimental results confirm that the particle will always emerge from the white aperture, 100% of the time. However, when one places a wall in the softness path such that the particle can no longer traverse that path, the resulting probabilities change: the particle is measured white 50% of the time, and black the other 50%. This phenomenon in which the modification of one path seemingly influences another infinitely distant path and the experimental setup itself is dubbed "superposition," and though it is accepted as a fundamental principle of quantum mechanics, it still requires a philosophical explanation.

Parsons suggests that granted the orthodox von Neumann strategy, the particle's state of superposition can be attributed to either pertension or the ESP; that is, the particle may either be split into multiple parts that separately traverse the two paths, or be wholly located in both paths (Parsons 2003). He contends that the former account is more problematic for two reasons. First, the pertension hypothesis entails a single particle being split into two "half-particles," each of which travels down a single path. This poses a difficulty to the entire quantum setup, as it modifies the physical characteristics of the particle including its mass, charge, and spin, affecting its behavior and trajectory.

Second, the pertension hypothesis exaggerates the non-locality problem, and modifies the setup beyond our explanatory capabilities. Prior to the moment of collapse, all occurrences are deterministic and are governed by the dynamical equations of quantum mechanics, but the instant a single half-particle influences its respective detector instead of the other, an indeterministic choice is made. The ESP seems to satisfactorily alleviate these concerns, and adheres better to our existing knowledge of physics. Under the ESP, the whole particle (an extended simple) traverses both the hard path and the soft path, but only influences one of the detectors to collapse the state of superposition. Put simply, a particle would be considered a single, wholly located particle, rather than a fusion of two half-particles. Simons (2004) presents a similar argument for the ESP, stating that the moment the particle exits the first hardness box in Figure 1, the particle adopts "a new and furcate locus and the energies of the two legs sum to the total." Though this account may be inadequate in terms of its predictive capacity, in that it fails to clarify how, probabilistically speaking, the particle decides to influence one detector over another, it is still a more competent explanation than the pertension hypothesis, because it allows an object to cover disjointed regions of spacetime while still retaining its non-homogeneous or uncertain properties.

*1.2 Entanglement*

Quantum setups involving multiple particles, observers, or apparatuses require formalisms of entangled states, in which measurements carried out on a single particle inform the observer about the properties of other particles within the same system. In addition to superposition, entanglement is another quantum phenomenon that extended simples can usefully account for.

First, for ease of illustration, consider Bohm's formulation of the well-known EPR experiment (Einstein et al. 1935; Bohm 1951). In the experimental setup, two photons, Alice and Bob, propagate to the left and right of the *z*-axis, respectively. The photons are paired in a rotationally symmetric state such that if Alice, propagating to the left, is observed to be in one of two orthogonal polarization states x or y, then Bob, propagating to the right, is also observed to be in the same polarization state as Alice. In other words, they are entangled, and their correlated polarization states are always identical. Mathematically, the state vector of this setup can be written as follows:

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|x_1x_2\rangle + |y_1y_2\rangle)$$

This illustrates a superposition of the two states in which i) Alice is *x*-polarized and Bob is *x*-polarized, and ii) Alice is *y*-polarized and Bob is *y*-polarized. When Alice and Bob are put side by side at the center of the system and are fired to their respective polarization filters at either end of the apparatus, the state of superposition given by the above equation dictates the following probabilities:

Pr(Alice is observed to be x-polarized & Bob is observed to be y-polarized) = 0

Pr(Alice is observed to be x-polarized & Bob is observed to be x-polarized) = 0.5

Pr(Alice is observed to be y-polarized & Bob is observed to be x-polarized) = 0

Pr(Alice is observed to be y-polarized & Bob is observed to be y-polarized) = 0.5

From the perspective of the observer, who observes the polarization state of Alice at the left end of the apparatus, these probabilities are counterintuitive; prior to communicating with another observer who observes the polarization of Bob from the left end, she would think that the photons are polarized randomly, such that they generate a random binary sequence of *x*-polarization and *y*-polarization outcomes. Due to entanglement and its consequent coordination of randomness, however, the two observers will find that their observations are always identical, and that the determination of the polarization state of one photon will eliminate the uncertainty associated with that of the other photon. That is, the moment Alice reaches its observer, the measurement of its polarization automatically and instantaneously informs Bob's observer of Bob's polarization state, regardless of how far apart the two observers are. As with our case study in superposition in Sect. 1.1, entanglement also gives rise to "spooky action at a distance," or non-locality, for which physics cannot account.

Interpreting entanglement under the ESP may effectively address the concerns of non-locality. Recall that following Parsons from Sect. 1.1, the ESP is willing to accommodate non-homogeneous properties, and considers the diverse characteristics of an object to be manifestations of variations of a single property. In the specific case of entanglement, one could view the entire system of two particles as an extended simple, and consider Alice to be the *x*-polarized manifestation of the property "polarization," and Bob to be the *y*-polarized manifestation of it.

I think this perspective removes the need for explanations involving non-local behavior, elucidating the bizarrely coordinated randomness we call entanglement. To motivate this view, we can look to the strong correlation between the two photons that gives us good reason to believe that they are extended elements of a single object. If the basic characteristics of an object are governed by its underlying relationship with another object, it invites the question of whether the two objects are separate to begin with, particularly given that conceiving them as separate obliges us to resort to non-local accounts. Much like Parsons's entension hypothesis applied to superposition, extended simples help account for entanglement by treating it as a relationship between two components of the same simple, as opposed to two entirely different entities. Considering a multiple-particle system as one object effectively eliminates any "spooky action at a distance"; one particle no longer influences another particle a thousand kilometers away, but instead influences a spatially disparate part of *itself*. Indeed, it is easy, even in the non-quantum context, to imagine one region of an object informing the observer about another region of the same object. For example, given a single object called the Earth (which I designate as a simple), the knowledge that Part A of the Earth is dark immediately informs to us that Part B on the opposite side of the Earth is currently bright. The situation of entanglement is similar, in that the knowledge about one portion of the system—say, Alice—tells us about the other portion of it, Bob. Thus, conceiving of a multiple-particle apparatus as a single body under the ESP provides an alternative explanation for non-locality that is certainly more intelligible and less costly than accounts that resort to non-local interactions.

## 2. Supersubstantivalism

### *2.1 Motivating supersubstantivalism*

The Newtonian theory of substantivalism and the Leibnizian theory of relationalism have maintained a long-standing rivalry on the issue of how to interpret the relationship between material objects and spacetime—and on whether spacetime exists at all. Relationalism, an ontology that defines and locates objects solely based on their relations with other objects, presents a different take on location than substantivalism, an ontology that involves material objects as well as the spacetime manifold upon which the objects are pinned.

Following a relationalist perspective (an ontology of material bodies and the relations grouping them together), our traditional conception of spacetime becomes merely a means of expressing the spatiotemporal relations between objects. Locating an object, therefore, is not an act of pinpointing where the object is situated on a larger expanse of spacetime, but rather an act of describing the position of that object in relation to other objects. Put geometrically, the concept of "coordinates" cannot assume the existence of a background *xyz*-vector space; coordinates would more appropriately be interpreted as an object's distance from another object located, for instance, 100 meters away.

Relationalism is clearly a parsimonious ontology with some pre-theoretical appeal, as it reduces the universe to a group of material objects and removes spacetime as a necessary component. Consequently, however, it may also place more rigid restrictions on its modal properties compared to an ontology that includes an underlying geometrical structure of spacetime. Following the verificationist criterion of Leibniz's principle of the identity of indiscernibles, the relationalist would argue that there is no difference between World A and World B in which all material bodies in World A were moved five meters to the right, as the spatiotemporal relations between the bodies remain the same. Thus, for the relationalist, the set of modal properties of objects are limited to their particular relations in a given world, and exclude the possible configurations of objects in Euclidean space. Relationalists may not find this problematic—such conceptual possibilities could merely be counterfactual situations that are not reflective of the actual structure of the world—but it is yet unclear how undesirable relationalism's account of possibilities is.

In contrast to relationalism, substantivalism "pins" objects onto a single spacetime fabric. One of the core commitments of substantivalism is that spacetime is a fundamental constituent of reality, and that there is an "occupation relation" by which material bodies occupy certain regions of spacetime. This has traditionally been accepted as the most scientifically sound ontology, due to its treatment of spacetime as a series of unextended points and its compatibility with Minkowski spacetime (Walker-Dale 2013). Substantivalism has also been considered useful for developments in quantum field theory as physicists experiment with traditional Minkowski space quantum field theory (QFT) as well as QFT in curved-spacetime, both of which treat space and time as entities in their own right.

But despite substantivalism's snug fit into our conventional (and perhaps future) notions of physics, the theory certainly has ontological limitations as well. For one, the inevitable "occupation relation" forces us to adopt mysterious connections between objects and space that are explicable only by coincidence. The fact that all material bodies require spacetime in order to be instantiated, or that bodies are perfectly harmonious with the spacetime regions that underpin them, provides mounting evidence that there is some sort of relationship between objects and spacetime. In order to justify this relation, substantivalism has to invent a brute, gratuitous interdependence between objects and space.

A more recently suggested middle ground between relationalism and substantivalism is supersubstantivalism (SS), which argues for a monistic ontology that identifies objects as *parts* of spacetime itself. While this theory inherits the concept of a spacetime manifold from substantivalism, it is akin to relationalism in that it posits the monistic hypothesis that material objects are part of, or even equivalent to, their corresponding spacetime regions. It is an ontology that parsimoniously explains all that we want material objects and spacetime to account for.

Schaffer, a notable proponent of SS, provides several arguments illustrating SS's superior explanatory capabilities (Schaffer 2009). Besides its ontological parsimony, SS also offers a straightforward explanation for the perfect harmony between the geometrical and mereological properties of objects and those of spacetime regions (an area in which substantivalism is lacking). More broadly, in describing the interface between spacetime and objects, the supersubstantivalist would leave a lot less room for coincidence than the substantivalist, who explains phenomena such as the monopolization of spacetime and the materialization of objects through coincidence or the occupation relation. I believe these are good reasons to prefer SS over relationalism or dualistic substantivalism.

### *2.2 Supersubstantivalism in Quantum Field Theory*

Beyond escaping the troubling occupation relation, SS is also a preferable ontology in discussing quantum field theory (QFT), a physical framework that strongly suggests the existence of "fields" of spacetime and the absence of material bodies.

Fields have proven essential in accounting for the electromagnetic characteristics of objects, and have helped resolve the limitations of the formalism of quantum mechanics. The property of having discrete and quantized physical quantities, considered uniquely applicable to particles, were transferred to fields. Fields would be considered packets of energy subject to granularity and quantum probability, rather than continuous electromagnetic fields.

More specifically, QFT treats particles as excitations of their underlying physical field, and dub them "field quanta." The energy of these quanta are directly related to the frequency of the field surrounding them, and such differences in energy potentials between particles in turn form the field, indicating an interdependence between the two substances. As Weinberg suggests, "A quantum field theory is a theory in which the fundamental ingredients are fields rather than particles; the particles are little bundles of energy in the field" (quoted in Schaffer 2009). Following this definition, if we identify fields as space, and particles as mere excitations of the fields around them, the substance dualist (the substantivalist) would be misinterpreting the nature of spacetime. Fields would be the only real substance, and the supposed "matter" we see would be created and destroyed by the fields themselves. It follows naturally that a monistic ontology such as SS would be more appropriate for QFT. Indeed, Schaffer claims that by adopting a monistic supersubstantivalist framework, "fundamental physics does not need to explain why, for instance, the geometrical properties of material objects are a perfect fit for the geometrical properties of the spacetime regions they occupy…. There is the spatiotemporal manifold, and the fundamental properties are pinned directly to it. Nothing more." Earman further affirms that "modern field theory is not implausibly read as saying the physical world is fully described by giving the values of various fields, whether scalar, vector, or tensor, which fields are attributes of the spacetime manifold M" (Earman 1989). As such, if all matter is reducible to spacetime, and the concept of particles is interchangeable with excitations in fields, a substantivalist model hardly seems worthwhile, and QFT seems suggestive of a monistic, supersubstantivalist ontology of spacetime.

*2.3 ESP in Quantum Field Theory*

The plausibility of the supersubstantivalist interpretation of QFT may prompt us to reconsider QFT in the context of the extended simples picture that I endorsed in Sect. 1. I have argued that SS is useful for explaining the fact that material objects (particles) and spacetime (fields) are inextricably tied such that particles are brought into existence by excitations of fields, and that differences in the energy potentials of particles determine the properties of their surrounding field. It seems appropriate, then, to hypothesize that objects and spacetime are elements of one, extended simple called the universe, whose spacetime component influences and creates its object component (much like the way Alice influences Bob in the example of entanglement).

This view is compelling given the MaxCon definition of extended simples that I adopted, which states that when there is a simple that is said to be extended across a certain continuous spacetime region *R*, all the points in the said region fall within the simple. Based on this definition, if we let the region *R* be the area encompassing the field, and the "points in the said region" be the particles that the field gives rise to, we can define an extended simple consisting of the field and its particles. This allows the particles to not only "fall within the simple," but also to be causally coupled with their underlying field, in accordance with the supersubstantivalist view of QFT.

## 3. Reconciling ESP with SS: Quantum holism

*3.1 Arguments for the Incompatibility of ESP and SS*

There is a smooth congruence of extended simples and supersubstantivalism in QFT, but the two theories are nonetheless traditionally considered incompatible, or at least have not been fused together as a singular ontology. In this section, I examine some popular objections to the compatibility of ESP and SS before presenting quantum holism as a framework to reconcile the two ontologies.

In arguing for the supersubstantivalist view, Schaffer dismisses extended simples, calling it an "exotic possibility" and going as far as to state, "I think extended simples are impossible, or at least, given unrestricted decomposition, the impossibility of extended simples is immediate." This objection is grounded in the premise that SS presumes the possibility of "unrestricted composition and decomposition," which treats "gerrymandered and discontinuous regions all the same" and posits that "for any plurality of spacetime regions, there is a region that fuses them" and that "for any extended spacetime region, there are sub-regions that fission it" (Schaffer 2009). This is an understandable concern, since the act of fusing multiple spacetime regions or fissioning an extended region implies the existence of divisible parts, which is, prima facie, impermissible per the definition of an extended simple.

Such an objection is reminiscent of the "conceptual parts" objection that Parsons responds to in his discussion of the entension hypothesis, which argues that extended objects must have parts if we are "able to conceive of those parts separately, even if the parts themselves are inseparable" (Parsons 2003). Essentially, the objection draws on the distinction between physical parts and conceptual parts, and contends that even if objects are not physically divisible, they may be conceptually divisible, which sufficiently renders them complex objects rather than extended simples. Markosian (1998) seems to accept this distinction, admitting that "it is apparent that anything with some extension will have *conceptual parts*, even if it doesn't have *metaphysical parts*." While this fortunately does not contradict his MaxCon definition of extended simples, I agree with Parsons that the conceptual parts distinction is unnecessary, and can be overcome using the concept of intrinsic, non-relational properties discussed in Sect. 1. That is, if we consider conceptually distinguishable properties to be variations of a single quality, we have no reason to believe that conceptually separate parts comprise different objects. Parsons illustrates, "I can intelligibly say "I am looking at the morning star and not at the evening star" — but this doesn't show that the morning star and evening star are not identical, or that they must be distinct parts (temporal parts perhaps) of Venus" (Parsons 2003). He may respond to Schaffer's concern by undermining the necessity (but not necessarily the feasibility) of fusing or disassembling spacetime regions, and stating that despite the conceptual separability of regions, extended objects can still be simples.

Admittedly, however, Parsons' answer to the conceptual parts objection is inadequate, because the principle of unrestricted composition and decomposition does not always reside in the conceptual realm, and may well be about the actual physical separation of objects. I believe that this objection requires adopting the quantum holism framework, which *causally* interweaves all objects in the universe into one extended simple.

*3.2 Quantum holism: Unifying the ESP and SS*

Quantum holism is a theory motivated by the necessity to provide a common ground explanation for quantum phenomena. Ismael and Schaffer (2016) expand on Hume's inference that "if entities *a* and *b* are necessarily connected, then *a* and *b* are not distinct existences," and suggests that we accept a "Source Inference" principle, which states "If non-identical entities a and b are modally connected, then either (i) a grounds b, or (ii) b grounds a, or (iii) a and b are joint results of some common ground c." In other words, if two entities are modally connected, there must be some sort of causal connection between the entities, or a common cause that results in both of them. Common ground explanations, which ground parts in wholes to inductively identify common partial grounds for objects that exhibit modal connections, can be essential in our search for the most basic units of nature.

One can identify the need for a source inference (or common ground) explanation in the quantum phenomenon of entanglement. Revisiting the EPR setup I used to justify the ESP, particles in a system may be jointly constrained by certain probabilities so that it is possible to predict the properties of one particle given information about those of the other. Science and philosophy are faced with a roadblock when trying to provide a physical explanation for *how* entanglement occurs, or how particles that may be lightyears away from each other exhibit such coordinated randomness. We have identified three distinct theories that could supply this explanation: non-locality, the EPR "hidden variables" theory, and nonseparability. The first two theories, however, are conventionally considered implausible. First, non-locality, which assumes the presence of instantaneous, superluminal causation, directly belies special relativity's principle of locality—a conflict we have not yet resolved. Second, the hidden variables theory, which postulates that quantum mechanics is incomplete and that there must be intrinsic states encoded in the particles' quantum state descriptions, has been demonstrated through multiple empirical experiments to be an implausible explanation (Aspect 1982, Freedman 1972). The final explanation, nonseparability, is the idea that the two particles share a modal connection that provides us more information about Alice and Bob than can be found in them individually: the system of the two particles amounts to more than the sum of its parts. Nonseparability seems to be the best explanation for entanglement, and the most accurate characterization of particle behavior according to quantum mechanics. If we dismiss nonseparability and regard the Alice + Bob system as being grounded in its individual components rather than in a holistic modal connection, we can only describe the individual features of Alice and Bob and leave unexplained their mutual dependence governed by coordinated randomness. Indeed, nonseparability, in which wholes ground parts (i.e. the principle that if Alice has *x*-polarization, then Bob also has *x*-polarization, and if Alice has *y*-polarization, Bob also has *y*-polarization), seems to be the only explanation that can fully save the phenomenon of entanglement. From here, we can extract a theory of quantum holism: "in a nonseparable quantum system, non-identical events *a* and *b* are modally connected" (Ismael & Schaffer 2016).

I will not be discussing the specific ontologies that the relevant literature considers to treat spacetime as a whole, but it is important to note that broadly, quantum holism views the components of entangled systems as shared manifestations of a common ground, and suggests that *the entire universe* might be a single entangled entity. This argument is based on two observations: first, entangled states are mathematically generic, meaning that if there is a wave function governing the cosmos, it is entangled. Second, given that there would have been entanglement created at the initial expansion of the universe, and that the evolution of Schrödinger's equation preserves entanglement, "every particle in the universe must become entangled with every other" (Penrose 2004). The quantum holism hypothesis, which usefully elucidates entanglement, can accommodate both extended simples and SS as fundamental ontologies.

First, it is evident in the formulation of quantum holism that all material objects are intertwined via a common ground state of entanglement. Put differently, if we are to ground parts through wholes, all material objects should be treated as components of one, entangled object that encompasses the whole material cosmos. Furthermore, because pertension is not a viable hypothesis in situations of entanglement following Sect. 1.2, this massive object must be an extended simple composed of multiple particles, rather than an object including several *pertended* particles. I should clarify that in this context, the term "extended simple" is not used in its typical mereological or geometrical sense of being physically extended across a spacetime region, but is used in a *causal* sense of being tied together by a single, causal explanation. Such a causal formulation of extended simples is equally useful as physically extended simples, in that the purpose of adopting the ESP in physics mainly comes from its capacity to account for coordinated, mysterious interactions (such as superposition or entanglement) between supposedly non-identical objects. Acknowledging a common causal connection between objects sufficiently achieves this purpose, since the causal explanation allows particles to influence one another outside of the constraints of locality, akin to the way particles influence each other as parts of a physical extended simple. An object thus has to satisfy two conditions to be considered an extended simple: all components of the object must be causally interconnected, and should not exhibit causal connection with any other object. We can repurpose Markosian's MaxCon view of extended simples and arrive at the following definition:

> *x* is a maximally continuous object iff *x* is a causally connected object with no continuous region of space, *R*, such that (i) the region occupied by *x* is causally grounded in *R* and (ii) every point in *R* is modally connected to another object that is not *x*.
>
> Necessarily, *x* is a simple iff *x* is a maximally continuous object.

Using this definition, we are finally able to reconcile the ESP with SS. Recalling Sect. 3.1, I think the possibility of causal, holistic extended simples provides an effective response to Schaffer's objection against incorporating extended simples into the supersubstantivalist ontology. Since quantum holism characterizes the entire cosmos as being interwoven by entanglement, "unrestricted composition or decomposition" would not affect the object's scope in any significant way. Even if one were to synthetically combine or separate objects, the extended simple can still be preserved, since the state of entanglement that grounds them cannot be modified or removed and the objects would retain a causal connection. Hence, under a quantum holism model, neither the conceptual nor the physical separability of objects can be a reason to reject the possibility of extended simples.

This is not to say, however, that it is pointless or impossible to consider objects in a causally separable light. In fact, from a macroscopic frame of reference, thinking of all objects as part of an expansive extended simple might strain the definition of causation and overcomplicate the relations between objects. For instance, there would be no value in saying that a barometer and my hair are an extended simple originating from a common ground simply because the wind can cause both of them to move. If we were to conceive of material bodies in this way, perhaps all objects would exhibit causal connections in one way or another, in which case the definition of causation would become too broad and the causal ties would not be useful for tracing back to a single common ground. Thus, what I am proposing is not the renunciation of all distinctions between objects, but rather a shift in perspective when considering the most fundamental units of spacetime on a quantum scale. Embracing a holistic, causally extended model of material particles and integrating it with the underlying spacetime through a supersubstantivalist framework is not only parsimonious, but can also have practical consequences in our understanding of quantum phenomena such as entanglement and quantum field theory.

Once we accept the ESP as a viable way of understanding spacetime, we can notice the straightforward compatibility between the ESP and SS; SS, which claims that spacetime and matter are one substance, can be aided by the ESP, which unifies all material objects—specifically those on an atomic or subatomic level—into one extended simple. I offer two arguments in support of adopting this combined ontology.

1. Parsimony

Thus far, I have considered three hypotheses to characterize the interface between spacetime and materials: the hypothesis that all material objects (i.e. particles) are separate entities, each with its own properties independent from those of other objects; the pertension hypothesis, which states that one object has multiple parts that are located in spatially disparate regions of spacetime; and the extended simples hypothesis, which states that one object is wholly located, or extended, in numerous spacetime regions and is not conceptually separable. The first theory takes the arrangement of material objects at face value, using distinctive properties and spacetime locations to define separate objects. It is clearly less parsimonious than the second and third theories, as it assumes the existence of more objects without adding explanatory value, does not account for entanglement, and resorts to brute connections between objects in place of nonseparable grounds.

Then in comparing the entension and pertension hypotheses, one should assess the need for substances to be complex rather than extended, as well as the role of separable parts. The primary role of physically and conceptually separable parts is to account for the varying properties that objects exhibit. Diverse properties, however, are not an adequate warrant to adopt the pertension hypothesis; the entension hypothesis supports the same phenomenon using distributional properties that vary in intensity. It is unnecessary to concoct boundaries between parts. Combining this picture with SS, we end up with a model that unites all material bodies by considering them entended and by equating them to spacetime. This is a maximally parsimonious theory of spacetime, as it explains the interface between material objects and their underlying spacetime field while still maintaining a monistic ontology.

2. Quantum field theory

QFT is already a good reason to adopt supersubstantivalism, as it theorizes that particles are reducible to field excitations. Why then, could a common ground explanation that integrates supersubstantivalism with ESP be beneficial for our understanding of QFT?

Consider an electron moving through its electromagnetic field. Its movement causes a disturbance in the electromagnetic field, and as a corollary, disturbs nearby electrons as well. Heathcote writes, “Since the disturbance is a form of energy it must be quantized, and given that this is what is referred to as a long range force it can be deduced that the quantized disturbance of the electromagnetic field is a zero mass particle, namely the photon. Photons therefore are the means by which electrically charged particles interact” (Heathcote 1989).

With this proposition in mind, we can picture spacetime as consisting of fields that constantly simmer with ephemeral photons, or "virtual particles" that exchange disturbances with other particles. These virtual particles that emerge from disturbances caused by particles, act as forces between objects and can account for all causal influences, indicating that particles originating from the field are fundamentally connected in a causal fashion. Intuitively, this common ground justifies not only the supersubstantivalist view that matter is equivalent to spacetime, but also the extended simples view that particles share a causal connection as components of an all-encompassing simple.

Thus, far from being an exotic possibility, the ESP complements SS, and is a helpful model in explaining quantum phenomena such as entanglement and superposition, as well as quantum field theory.

As an overall summary, I have attempted to defend both the extended simples picture and the supersubstantivalist framework by means of case studies in modern physics, and have suggested that contrary to popular belief, the two ontologies complement each other. I have proposed thinking of extended simples in a causal sense based on the theory of quantum holism, and have rationalised a plausible fusion between the ESP and SS. I believe that this new, synthesised ontology may help shed light on new developments in physics, and in particular, mysterious quantum phenomena.

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