Not Another Brick in the Wall: an Extensional Mereology for Potential Parts

Contents

0. Abstract

Part is not a univocal term. Uses of *parthood* and *composition* that do not obey any supplementation principle have a long philosophical tradition and strong support from contemporary physics. We call such uses *potential parts*. This paper first shows why potential parts are important and incompatible with supplementation, then provides a formal mereology for such parts inspired by the path-integral approach to quantum electrodynamics.

1. An Introduction to Potential Parts

Parthood may not be a univocal relation. Cotnoir and Varzi (forthcoming, p. 13) give these examples of ordinary language parthood talk:

(1) The handle is part of the mug.
(2) The speaker is a part of the stereo system.
(3) This half is your part of the cake.
(4) The cutlery is part of the tableware.
(5) This pile is part of the trash.
(6) The circle is part of the area.
(7) The vertices are part of the boundary.
(8) The bombing was part of the attack.

Cotnoir and Varzi's examples all plausibly meet Westerhoff (2004)'s condition that parts must be spatio-temporal and/or the unique results of a hypothetical decomposition.[1] Whether or not such a concept of parthood can be literally extended to abstract objects, it can at least be metaphorically extended to cover them, and following Kit Fine (2010) we can call that entire extended notion *integral* parthood. Here Fine is following the scholastic tradition, which distinguished various kinds of integral parthood coordinated with a disjunctive answer to Peter Van Inwagen (1995)'s Special Composition Question (SCQ).[2] Aquinas has his own technical term for these disjunctive answers to the SCQ, 'relations of order,' and summarizes the kinds of integral parthood as follows (1947, Q. 90, art. 3, ad 3):

> All integral parts have a certain relation of order to one another: but some are only related as to position, whether in sequence as the parts of an army, or by contact, as the parts of a heap, or by being fitted together, as the parts of a house, or by continuation, as the parts of a line; while some are related, in addition, as to power, as the parts of an animal, the first of which is the heart, the others in a certain order being dependent on one another: and thirdly some are related in the order of time: as the parts of time and movement.

These seem to cover (at least approximately) everything on Cotnoir and Varzi's list. Aquinas says that what is distinctive about such integral parts is that 'the whole is not present in each of the parts, either as to its entire power, or as to its entire essence, but that it is present to all of them together at the same time' (1947, Q. 90, art. 3, co.). Without getting mired in the details of powers and essences,[3] we can say that this distinctness of the parts is what makes them hypothetically decomposable from the whole. Since they are decomposable, they must be composed in virtue of something, and this at-least-metaphorical spatio-temporal connection is what Aquinas refers to as a relation of order.[4]

Nonetheless the concept of integral parthood does not exhaust the ways in which we speak of parts. David Lewis's assertion that 'There is no sense in which my parents are part of me, and no

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[1] Following the direction of Varzi (2007), one might regard Westerhoff's condition as just an informal statement of supplementation.

[2] For explanation of why the SCQ might admit of such disjunctive answers, see Hawley (2006).

[3] Though Sattig (2019) gives an accounting of how parthood and essence might be related.

[4] For more on the at-least-metaphorical connection here, see Wallace (2019).

sense in which two numbers are part of their greatest common factor' (1986) did not prevent Amy Tan from summarizing her book *The Joy Luck Club* by saying that 'my mother is a part of me' (Pastor, 2014), nor did it prevent Aristotle from saying that 'two is called in a sense a part of three' (1984a, V.25.1023b14). While Amy Tan may have been speaking metaphorically, Aristotle was not, instead allowing that two is in some sense *not* a part of three *only because two is not a factor of three* (Kretzmann, 1976). The scholastics attempted to meet these non-integral notions of parthood by offering two further options: *subjective* parts and *potential* parts. Subjective parts were an attempt to do justice to Aristotle's invocation of genus and species as parts of each other in *Metaphysics* V.25, and we need not quibble here with Lewis's contention that mereological language sheds little light on our intuitions about universals (1986). Potential parts, meanwhile, are cases where 'the whole is present, as to the entire essence, in each' (Aquinas, 1947, Q. 90, art. 3, co.).

The Thomistic view of potential parthood is much stronger than the mereology of potential parts given by Canavotto and Giordani (forthcoming). Canavotto and Giordani treat any non-heaplike *structured* sum (e.g. a completed puzzle)—what Fine (1994) calls *compounds*—as a potential whole. Pieces in a puzzle (Canavotto and Giordani's stock examples of potential parts) may not be actually separated in space, but they have actually separate existence; the essence of each piece is not the same as the essence of the whole puzzle. For Aquinas, by contrast, the difference between heaps/aggregates and structured sums/Fine's compounds is a difference between two *integral* parthood relations with different relations of order. Relative to integral parthood, potential parthood can seem like a confused notion:

> Potential wholes are curious items. They are particulars, not universals. Yet potential wholes are not composed out of their parts in the way that, for example, a house is composed out of bricks and wood. Indeed, the most commonly discussed kind of potential whole is a soul, and since souls are forms and forms are mereologically simple, they ought to be mereologically simple. That Boethius (following Aristotle) asserts that souls have parts is therefore initially quite puzzling (Arlig, 2015).

Of course to say that potential wholes have potential parts is precisely to say that they are *not* mereologically simple absolutely speaking; they are mereologically simple only in their lack of spatotemporal *integral* parts like puzzle pieces and bricks. Obviously these are meant to be two very different notions of parthood.

Potential parts in this strong sense have a pedigree beyond Aquinas and an importance beyond scholastic disputations about the soul. The idea of potential parthood goes back at least to Aristotle's rejection of the Empedoclean conception that elements come-to-be out of a mixture as 'a stone and a brick both come-to-be out of a wall—viz. each out of a different place or part' (1984b, II.7.334b1). In fairness to Lewis and Westerhoff's intuitions, Aristotle calls this 'combination' (σύνθεσις) as opposed to 'composition' (μίξις) where 'the constituents are preserved in small particles' (1984b, I.10.328a6-9). Nonetheless Aristotle uses the word *part* (μέρος) in just the way Aquinas defined as *potential*, averring that 'if combination has taken place, the compound *must* be uniform—any part of such a compound being the same as the whole' in its essence (1984b, I.10.328a10-11). As such, the elemental constituents with their distinct essences cannot '*persist actually*' in a mixture, but 'nor are they *destroyed*'—they rather exist 'potentially' (Aristotle, 1984b, I.10.327b23-30). This means that while mixtures 'are homogeneous homoeomeries' where 'every part is the same as the whole,' nonetheless 'what is mixed must have the potential to reemerge from the mixt' and 'the change involved in mixture is not total or complete' such that the elements continue to play an explanatory role in the properties of the mixture (Wood & Weisberg, 2004). Aristotle's elements in a mixture must be potential parts in a stronger sense than Canavotto and Giordani's puzzle pieces. Each puzzle piece certainly comes-to-be a detached or independent entity from a different place upon removal from the sum, even when that sum is structured as a completed puzzle. Similarly, each puzzle piece still actually exists as a piece when it is placed into the structured sum of the completed puzzle, even though it is no longer detached.

Furthermore, the physical applications of potential parthood are not purely antiquarian. Wood and Weisberg (2004) suggest that Aristotle's concerns about mixtures are of enduring importance for the metaphysics of modern chemistry. More broadly, Ladyman and Ross claim that the ‘metaphysics of domestication’ which ‘seeks to account for the world as “made of” myriad “little things” in roughly the way that (some) walls are made of bricks’ is ‘profoundly unscientific’ (2007, p. 5). If we are to preserve mereology’s present importance in science (Calosi & Graziani, 2014), we should provide a clear model of non-integral parthood.

2. The Physical Motivation for Potential Parts

Rather than attempting to address the broad questions of Wood and Weisberg or the sweeping claims of Ladyman and Ross, I will focus on a single case where scientific use of mereological terms requires a radically potential notion of parthood:

> So, suppose that there is a unique proton. Since a proton is constituted by two up quarks and one down quark held together by the strong interaction, we construe the proton as an actual entity composed by three potential proper parts (Canavotto & Giordani, forthcoming).

Many current undergraduate physics texts (e.g. Serway et al., 2008, p. 4; Rosen, 2009, p. 133; Rex & Wolfson, 2010, p. 622) do discuss protons and other hadrons as being composed of quarks.[5] Writing a more advanced undergraduate text, Michel Le Bellac (2011, p. 6) explains why these cannot be understood as ordinary integral parts:

> The crucial point is that these particles [the proton decay products] do not exist *ab initio* inside the proton, but are created at the instant the [decay] reaction occurs. It therefore appears that at some point it is not possible to decompose matter into constituents which are more and more elementary…the current idea is that a particle is elementary if it behaves as a point particle in its interactions with other particles. According to this idea, the electron, neutrino, and photon are elementary, while the proton and neutron are not: they are ‘composed’ of quarks. These quotation marks are important, because quarks do not exist as free states, and the quark ‘composition’ of the proton is very different from the proton and neutron composition of the deuteron. Only indirect (but convincing) evidence of this quark composition exists.

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[5] As Calosi (2018) suggests, even such simple and common statements do rely on controverted assumptions about how to interpret the quantum formalism, and (at-least moderate) scientific realism generally. This paper does not argue for those assumptions, but rather seeks to read such common scientific claims charitably, and asks what notion of parthood might apply if we take them seriously. Certainly a defender of the analyticity of supplementation for parthood could simply deny the relevant realist and interpretive assumptions, but this is a substantial cost for a mereological view to bear.

Given Canavotto and Giordani's definition of potential parts as entities that exist in structured sums, they interpret 'free' with respect to quarks in the same way as 'separate' with respect to puzzle pieces. The actual distinction between free and bound states, however, is that:

> Once nucleons are bound to a nucleus, energy-momentum conservation applies to the nucleus as a whole and the momenta of a pair of nucleons inside a nucleus are no longer restricted by [the conservation laws]. Interaction between two nucleons is 'off the energy shell,' or *off-shell* for short…if the sum of the momenta squared is not constrained by the kinetic energy of their relative motion (Wong, 1998, p. 100).

Bound quarks are thus always off-shell (Yndurain, 2007, p. 267), and the light quarks which make up protons are never free, so they are always off-shell (Grozin, 2005, p. 78). Such off-shell particles are called *virtual* because they can be given no realistic interpretation (Bunge, 1970; Fox, 2008): they represent non-local behavior (Schmidt-Böcking et al., 2005) and both their number and species are indeterminate (Weingard, 1982; French & Krause, 2006, p. 360). Quarks are clearly not integral parts of protons, since a proton's spatio-temporal footprint cannot be assigned among its quark constituents, and any hypothetical decomposition of the proton does not result in a set number of quarks of each species.

Nonetheless we should not abandon the idea that quarks are in some sense parts of protons, since the idea is connected to no less than four Nobel Prizes in physics. The 1943 prize was given to Otto Stern for his discovery that protons are not magnetically uniform, indicating that they are not point particles and charge is not distributed uniformly throughout their extension. Richard Hofstadter (1956)'s refinement of this result earned him the prize in 1961. These results count sharply against any account of protons as mereologically simple. Murray Gell-Mann (1964) proposed that treating hadrons as composed of quarks would explain the observed symmetries, for which he received the prize in 1969. Following theoretical work by Richard Feynman, Jerome Friedman, Henry Kendall, and Richard Taylor received the 1990 Nobel Prize for showing that patterns in the deep inelastic scattering of electrons by protons were best explained by point-like localization of those quarks (Riordan, 1992). These results are not disconsonant with Le Bellac's caution, however, since the point-like localization of quarks is only observed in deep inelastic scattering, which is a proton decay reaction. Yet it is unsurprising that physicists speak of protons as composed of quarks if protons are not mereologically simple and quarks help to explain their properties.

Physicists deal with this tension by treating protons ‘as a superposition of states with different, but fixed, number of partons [quarks and bosons]’ (Chýla, 2009, p. 91). Each of these basis states is treated as a possible configuration of the proton, and a distribution function assigns the properties of the proton (e.g. its charge and mass-energy) across the particles which make up the basis state, in accordance with the known properties of each type of particle and the conservation laws. Since the basis state can hypothetically be decomposed into the number of particles of each species which compose it, and those particles are spatio-temporal (they each have an assigned momentum, though subject to the usual quantum constraints), it is reasonable to treat those particles as ordinary integral parts of the basis state. This does not make the particles which compose the basis state integral parts of the proton, however, since each basis state, on its own, has the full mass-energy, charge, and magnetic moment of the proton.

The ‘standard shorthand’ that a proton is composed of ‘two up quarks and one down quark’ means that each and every basis state ‘has two more up quarks than up antiquarks, and one more down quark than down antiquarks’ (Strassler, 2011). These unpaired quarks are known as the *valence quarks* because their contributions to the proton’s ‘quantum numbers like charge, baryon number, isospin, and strangeness’ are not canceled out by corresponding antiquarks (Bugg, 2012, p. 4). Physicists reasonably use the language of parthood to discuss the explanatory contribution of valence quarks, especially since that contribution is spatially non-uniform, yet while the same *species* of valence quarks may be present in each basis state, nothing about the formalism allows us to treat them as literally the same particles.

One way forward is to engineer the concept of identity, as in French and Krause (2006). As French and Krause admit, however, no mereology has yet been developed which is compatible with their revised identity concept (2006, p. 278). Why develop a new concept of identity and new mereology, however, when new mereology on its own is sufficient? The mereological approach is suggested by physicists' practice, which often models the proton by assigning the contributions of the other partons to the valence quarks, known as *dressing* them into so-called *constituent quarks*, which are not standalone elementary particles (Povh et al., 2015, p. 223). This makes the constituent quarks integral parts of the proton, but at the cost of requiring that the constituent quarks themselves be composed of an indefinite number and species of particles. These can again be tamed by treating them as a superposition of basis sets, each of which has a fixed number and species of particles, but again those basis sets cannot be integral parts, since each on its own has the full mass-energy, charge, and magnetic moment of the constituent quark. Protons are not well treated as simples, since they have non-uniform extension, but their mereological complexity cannot be exhausted by integral parts.[6]

These issues are most sharply apparent in quantum chromodynamics (QCD) because models which treat hadrons as straightforwardly composed of their valence quarks have 'failed almost completely and given no predictions [of detailed properties] which have been verified by experiment' (Lipkin, 1983).[7] As Friedman, Kendall, and Taylor's 1990 Nobel Prize citation suggests, however, there is a profound analogy between QCD and quantum electrodynamics (QED) (The Royal Swedish Academy of Sciences, 1990). Sin-Itiro Tomonaga, Julian Schwinger, and Richard Feynman developed the dressing method in QED (for which they received the 1965 Nobel Prize) in order to explain an anomaly in the hydrogen microwave spectrum discovered by Willis Lamb (for which he received the 1955 Nobel Prize). Dressed particles are thus necessary in both QCD and QED, and in both cases they involve compositions of an indefinite number and species of particles (Bugg, 2012, p. 4). Taking composition-talk in physics seriously requires giving an account of parthood for dressed

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[6] Models which treat protons as extended simples or composed of integral parts might be useful idealizations in certain contexts, but they are inconsistent models which are both inadequate to the full range of contexts. They are thus best treated as idealizations of Weisberg (2007)'s third kind, which are useful but do not reveal the true structure.

[7] In fact, the 'straightforwardly composed' or *free quark* model works precisely when the quarks are taken to have infinite momentum (Chýla, 2009, p. 92), when by the Heisenberg Uncertainty Principle it would have infinitely uncertain position, and thus again cannot be an integral part.

particles, which cannot be done with the integral concept of parthood, which assumes that decomposition is spatio-temporal and unique.

3. A Model for Potential Parts

3.1 Informal Semantics: Dressed Electron Propagator as Mereological Model

A model of potential parts which responds to these motivations must give as much familiar mereological structure as possible without supplementation. Supplementation guarantees the distinctness of parts, allowing a whole to have a unique decomposition. By contrast, if overlap is total, then parts will avoid the spatio-temporal distinctness of bricks in a wall.[8] Potential parts must be unified into a whole not by some relation (like contact or functional integration), which would presume their distinctness, but by some shared essence which each possesses in its entirety.

Feynman's path integral formulation of quantum mechanics (2010), provides the tools to build a mereological model which meets these constraints. In Feynman's formulation the results of the familiar double-slit diffraction experiment are construed as electrons propagating through space by taking every possible path which satisfies the boundary conditions—the measured locations at the beginning and end of the paths (Zinn-Justin, 2005, pp. v, 35). The electron does not actually take every path (it is always in just one place when measured and otherwise would violate the conservation laws which govern the propagation of particles in space), yet the actual path, until measured, is a superposition of all the possible paths (Fox, 2008). Each possible path for an electron in weakly interacting fields can be given a heuristic representation as a Feynman diagram with a different interior topology but the same entering and exiting particles. Adding up all the contributions represented by the various Feynman diagrams is done by dressing the *bare propagator* to yield the *effective* (dressed) *propagator* (Carr, 2009, p. 71). This is the same dressing process that explains the Lamb shift in the hydrogen spectrum and the quark composition of the proton. Each

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[8] If supplementation holds, then when bricks are separated from a wall certain bricks have privileged relations to certain portions of the wall, namely those portions which they have as spatio-temporal parts that other bricks do not.

Feynman diagram represents a basis set, with the particles shown in the diagram as integral parts of that basis set, and the dressed propagator as a potential whole which is in a superposition of all the basis sets. When the dressed propagator is an electron, we should treat it as an ontologically serious entity, because electrons are among the strongest candidates for microphysical realism (Putnam, 1975). The other particles in the basis sets represented by the Feynman diagrams, however, cannot be integral parts of the electron because the best current experimental research indicates that electrons are truly elementary particles, lacking substructure (Brodsky & Drell, 1980) and hence integrally simple. Since the dressed propagator thereby shares its essence (actual entering and exiting particles) equally with all its possible realizations, which are not themselves actual but contribute to its actuality, the operation of summing Feynman diagrams can be taken as a model for mereological summing of potential parts.[9] Feynman diagrams can also be written for quarks and other partons in quantum chromodynamics (Chýla, 2009, p. 206), but they are considerably more complicated and have received less topological study.

3.2 Formal Semantics: A Join Semi-Lattice

The formal contribution of this paper is to generate a mathematical structure suitable for mereological semantics from the basis sets which compose a single dressed electron propagator in QED under the Standard Model (the formal results are given in **bold**). Each basis set is represented by a lawfully constructed Feynman diagram, and the rules for constructing Feynman diagrams in Standard Model QED are straightforward (Tanedo, 2010):

1. You can draw two kinds of lines, a straight line with an arrow or a wiggly line: You can draw these pointing in any direction.
2. You may *only* connect these lines if you have two lines with arrows meeting a single wiggly line. Note that the orientation of the arrows is important! You *must* have exactly one arrow going into the vertex and exactly one arrow coming out.
3. Your diagram should only contain connected pieces. That is every line must connect to at least one vertex. There shouldn't be any disconnected part of the diagram.

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[9] Further apparatus is required, however, for this mereological summation to match the quantitative summation done by physicists: no mereological account has been given of why higher-order perturbations have decreasing contributions to the whole.

We need only consider the topologically distinct diagrams yielded by these rules (Carr, 2009, p. 44). For a single dressed electron propagator, these rules yield the following valid topological moves (called *perturbations*) to generate increasingly complex Feynman diagrams (Carr, 2009, p. 49):

- At zeroth order (no loops), the bare electron propagator (Figure 1).

Figure 1: The Bare Electron Propagator

- At first order (one loop) and above:
    - the Hartree term (Figure 2).[10]

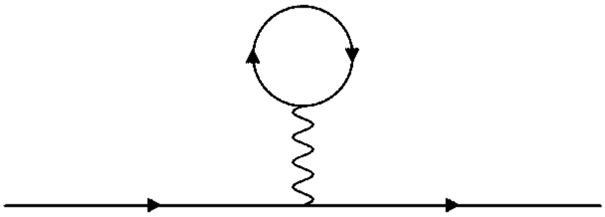

Figure 2: The Hartree Term

    - the Fock term (Figure 3).

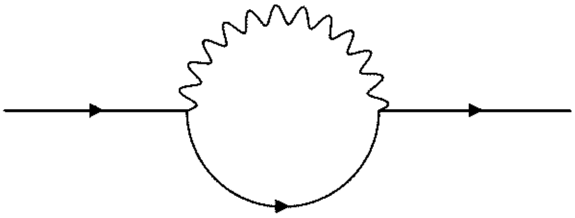

Figure 3: The Fock Term

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[10] The two arrows on the loop are an unfortunate artifact of the standard Feynman diagram generation software. More careful treatments use a single arrow to indicate that there is only one fermion line.

- At second order (two loops) and above, the *fermionic bubble*, or *polarization loop*, which does not exist at first order because there is no photonic line to interrupt with a fermionic loop (Figure 4).

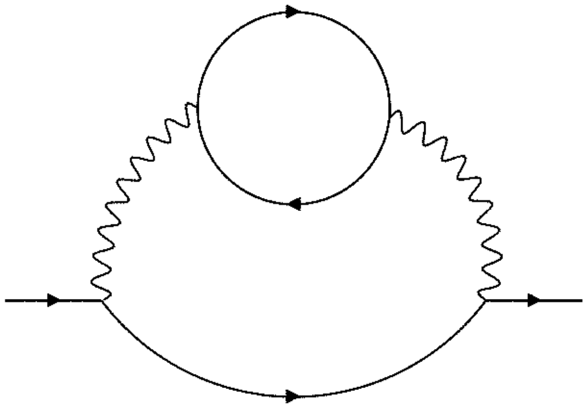

Figure 4: The Polarization Loop

Repeated applications of these topological moves yield 10 second-order diagrams (Figure 5), 74 third-order diagrams (Figure 6) and 706 fourth-order diagrams beyond the single zeroth-order and two first order diagrams (Prunotto et al., 2018).

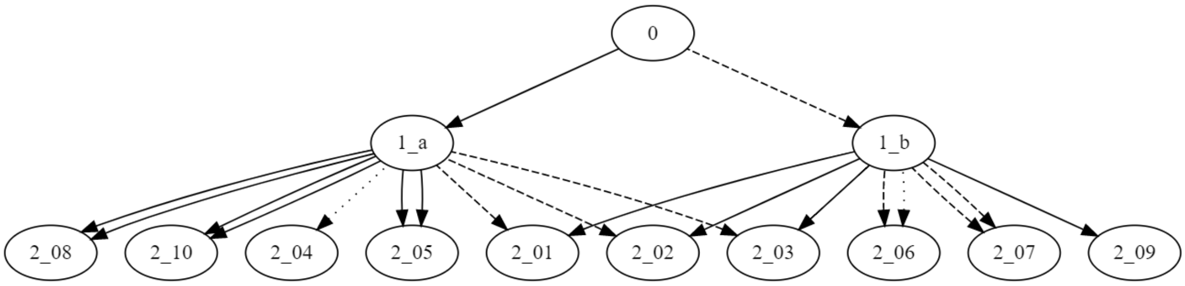

Figure 5: Generating the diagrams through second order by application of Hartree terms (solid), Fock terms (dashed), and Polarization Loops (dotted). Distinct series of perturbations often yield topologically identical results.

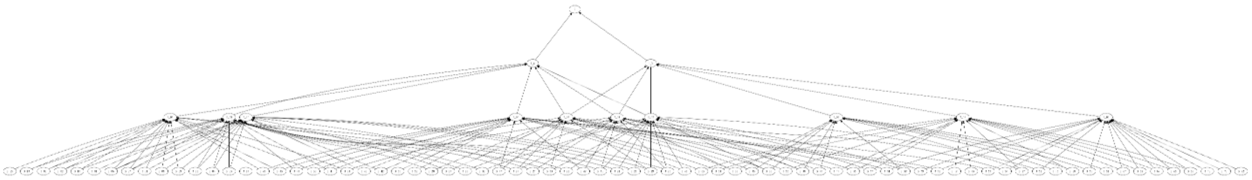

Figure 6: The diagrams through third order arranged as a join semi-lattice.

Prunotto, Alberico, and Czerski (2018) reproduce all of the second and third-order diagrams.

Because each perturbation introduces new segments to which one of the topological moves can be applied, these moves can be repeated infinitely, and in fact such infinite-order perturbations are often physically important (Carr, 2009, p. 37).

The Feynman diagrams for the electron propagator in Standard Model QED (and the basis sets they represent) therefore have a natural **weak partial-ordering on the perturbation relation**. Perturbation, construed as a binary relation between Feynman diagrams, is interpreted to mean that one diagram can be generated from another by valid topological moves. Since every dressed propagator has a zeroth-order bare propagator with the same topology, doing nothing is clearly a valid topological move which we can count as a trivial instance of perturbation, making the perturbation relation **reflexive**. Since all three non-trivial perturbations raise the order of the diagram (and no perturbation lowers the order of a diagram), perturbations which change the diagram can never restore it, so perturbation is **anti-symmetric**. Because valid moves are valid regardless of order, the perturbation relation is **transitive**.[11] The whole poset of Feynman diagrams and corresponding basis sets is generated by applying perturbation to the zeroth-order term, so that diagram is the **top** or **1**. Since the poset has a top, every subset has a least upper bound or **supremum**, and by anti-symmetry that least upper bound is unique (Partee et al., 1993, p. 278). Because the supremum always exists, the poset is a **join semilattice**, even though join is slightly tricky to interpret since perturbation does not have a well-defined inverse by which one can remove perturbations from a Feynman diagram.[12] We will say that the join of two diagrams (and corresponding basis sets) *x* and *y* is the highest-order diagram from which both can be generated by perturbation. Because this structure is relatively similar to the classical mereological model for integral parts (see Cotnoir & Varzi, forthcoming, p. 35), we can meaningfully interpret **parthood**

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[11] This does not imply that a single perturbation (a single valid topological move) is transitive, but rather the general operation of perturbation, by which a higher-order Feynman diagram is generated from a lower order one by a series of valid topological moves.

[12] If removal of perturbations from Feynman diagrams were well defined, the dual of this structure would be a junky meet semilattice of the integral topological parts of Feynman diagrams. The zeroth-order propagator would be the bottom, or nucleus, a part of every other diagram. These topological parts *of* diagrams would be integral parts in accord with Westerhoff (2004) because they are clearly spatial and, if their removal were well defined, the diagrams would be uniquely decomposable into them.

within it, saying that diagram *x* is part of diagram *y* just in case *y* can generate *x* by perturbation. The zeroth-order diagram has all of the others as parts, so it is the **universe**. As perturbation can continue infinitely, potential parts are **gunky**. This gunky join semilattice serves as a formal semantics for the model of potential parts.

3.3 Syntax: Mereological Axioms for Potential Parts

We have seen from the formal semantics of the proposed model that **potential parts satisfy the ordering axioms of classical mereology**. The classical definitions of proper parthood, overlap, underlap, and disjointness likewise require no modification. The proposed model for potential parts, however, cannot follow the classical axiomatization for decomposition. The classical remainder axiom and its less strict alternatives of strong and weak supplementation all entail that in cases where *x* is a proper part of *y* there must be some other part disjoint with *x* (Cotnoir & Varzi, forthcoming, pp. 25, 104, 111). In this model, however, **all objects overlap** because the various perturbations can be performed in any order and in an infinite sequence every order will occur, so there are no disjoint parts. This paper’s proposed model for potential parts is thus the pyramid model (Figure 5) from Cotnoir and Varzi that they deem mereologically incredible (forthcoming, pp. 127–128).

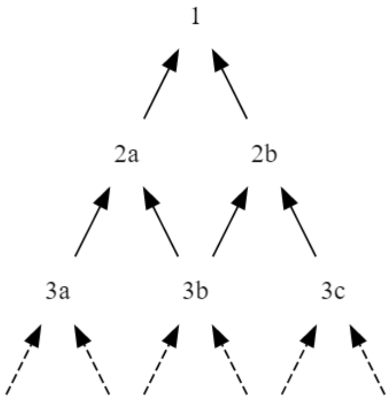

Figure 7: An extensional model that validates Strong Company but not Supplementation

This partial ordering cannot be considered as a genuine configuration of integral parts precisely because it is the configuration of potential parts, and both are not parts in the same sense. The appropriate decomposition axiom for this model is thus what Cotnoir and Varzi call **strong company**—for all *x* and *y*, if *y* is a proper part of *x*, then there exists a further part which is a proper part of *x* and not a part of *y* (forthcoming, p. 125).[13] Strong company is satisfied by potential parts since there are multiple non-trivial perturbations of any given diagram which each generate a different diagram of immediately higher order (distinct proper parts), and by anti-symmetry these diagrams of the same order are not parts of each other. Cotnoir and Varzi worry that models which satisfy strong company but where 'weak supplementation fails at every level of decomposition' are problematic because 'the removal of any proper part, at any level, will result in the annihilation of the wholes' (forthcoming, p. 127).[14] In this model of potential parts, however, such annihilation has a physical meaning: according to QED, an electron *just is* the particle which allows these perturbations, so if one of the perturbations is impossible, then that particle fails to exist. Despite using such a weak decomposition principle, however, no two distinct wholes have the same proper potential parts, because two diagrams which allow the same perturbations are topologically identical, so the model satisfies **extensionality of proper parthood** (see Cotnoir & Varzi, forthcoming, p. 27).

4. Conclusions About Potential Parts

Potential parthood finds natural applications in areas of science where composition seems to occur but Westerhoff (2004)'s condition that parts must be spatio-temporal and/or the unique results of a hypothetical decomposition is not met, so parthood cannot be understood in the usual integral way. The dressed electron propagator in the Standard Model of QED is a natural model for such a parthood relation, and it yields an extensional mereology with the classical ordering axioms and strong company as its decomposition axiom. This provides a much more natural reason to reject the analytic truth of weak supplementation than Smith (2009)'s approach, which relies on combining

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[13] Cotnoir and Varzi credit this nomenclature to Varzi (2007). Bynoe (2011) calls it "non-parthood supplementation" and defines it as "For all kinds of parthood, if y is a part of x then there's something, z, such that (1) z is a part of x, (2) z isn't a part of y, (3) z isn't y."

[14] Cotnoir (2018) characterizes this as a failure of the intuitive 'outstripping' conception of proper parthood.

time-travel thought experiments with a denial of extensionality. At both informal and formal levels, we have reason to regard integral and possible parts as different kinds of parts. Distinguishing these kinds of parts can avoid several difficulties for understanding QED that Passon et. al. (2019) trace to the misconception that virtual particles are ordinary, actual parts. Moreover, potential parthood need not be regarded as merely a recondite notion from scholastic faculty psychology.

This model of potential parthood provides a meaningful semantics for the claim that protons are composed of quarks. If those quarks are understood as elementary particles, then those particles are integral parts of basis sets, and those basis sets are in turn potential parts of protons. If those quarks are understood as dressed *constituent* quarks, then they are integral parts of protons, and have the basis sets represented by their perturbed Feynman diagrams as potential parts, which are in turn composed by elementary quarks and gluons as integral parts. Both possible readings of the quark composition of protons rely on the distinction between integral and potential parts.

A side benefit of such an account is that it may help to make peace among competing mereological intuitions. Those who do not share Ted Sider (1993)'s intuition that gunky integral parts are possible may nonetheless accept gunky potential parts. This, in turn, allows one to share Jonathan Schaffer (2003)'s wish for non-hierarchical levels of reality without embracing gunky integral parts in the actual world. On the other hand, those who deny proper integral parthood entirely, whether for mereological nihilism (e.g. Unger, 1979) or mereological anti-realism (e.g. Cowling, 2014) may nonetheless be able to accommodate some composition intuitions if they can be framed in terms of potential parts. Similarly, defenders of extended simples (e.g. Markosian, 1998; Simons, 2004; McDaniel, 2007) will have another distinction to wield.

Nonetheless there is further work to be done. Since potential wholes can be integral parts, a formal account should be given of how potential parthood in this sense interacts with the sense of parthood given in Canavotto and Giordani (forthcoming). Since quantum mechanics can be modelled with possible worlds rather than virtual particles, an account should be given of where and how this differs from the modal account of parthood given by Cotnoir (2013). There is also further work to be done in applying the model. One of the traditional applications of mereology is relating the masses of wholes to the masses of their parts (Cotnoir & Varzi, forthcoming, p. 76). Since dressing fermion propagators with only those higher-order diagrams that 'cannot be split into two by breaking a single fermion line' yields the self-energy, or mass, of the particle (Carr, 2009), bringing this distinction into the model would allow a mereological account of mass grounded on scientific rather than folk physics.

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