Tropes – the Basic Constituents of Powerful Particulars?

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[penultimate draft, published in Dialectica 65: 3 (2011)]
[issued in agreement with the Editorial Board of
dialectica and Blackwell Publishing]
[The definitive version of the article with the final corrections is available at
wileyonlinelibrary.com.]

ABSTRACT

This article presents a trope bundle theory of *simple substances*, the *Strong Nuclear Theory* [SNT] building on the schematic basis offered by Simons's (1994) *Nuclear Theory* [NT]. The SNT adopts Ellis's (2001) *dispositional essentialist* conception of simple substances as *powerful particulars*: all of their monadic properties are dispositional. Moreover, simple substances necessarily belong to some natural kind with a real essence formed by monadic properties. The SNT develops further the construction of substances the NT proposes to obtain an adequate trope bundle theory of powerful particulars. The SNT allows for co-located powerful particulars. However, every powerful particular is necessarily co-located with its constituent tropes, which determine its causal powers. Every constituent trope of substance *i* is part of a trope aggregate (the *n-bundle* or *c-bundle*) that forms an individual figuring in the basic spatio-temporal relations. The location of these individuals determines the location of individual tropes. Since they are necessarily co-located with substance *i* when they exist, every trope *t* of *i* is necessarily co-located with *i* when it exits. Every simple substance has nuclear tropes necessary to it. It belongs to certain primary natural kind K because its nuclear tropes belong to certain distinct determinate kinds.

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1. Introduction

Dispositional Essentialism in the form defended by Ellis (2001) and Ellis & Lierse (1994) offers us a conception of the dynamic nature of reality well integrated into a Neo-Aristotelian substance ontology. According to *Dispositional Essentialism*, all fundamental objects are *powerful particulars*: objects are particular substances and, necessarily, members of some natural kind K (electron, down-quark,…). Moreover, as members of natural kind K they necessarily have a set of monadic *dispositional properties* (specific mass, charge, spin, etc.) determining their causal powers. Consequently, as a member of given natural kind, any powerful particular necessarily possesses a set of causal powers. According to *Dispositional Essentialism*, it is essential to a dispositional property (e.g., the mass of 1 kg) possessed by object *a* to specify a generic natural kind of causal processes (gravitational attraction by a 1 kg object) that *a* undergoes in certain circumstances. If there are powerful particulars belonging to certain natural kinds in certain determinate locations, they necessarily take part in certain basic causal processes (e.g., attract each other gravitationally).

The dispositional essentialist ontology is attractive for several reasons. Nature is considered as essentially dynamic. The intrinsic properties of fundamental objects are identified by means of the causal powers they bestow on objects. Objects are not passive, but are bound to be involved in causal processes due to their essential nature. The fundamental objects subdivide into certain definite *a posteriori* discovered natural kinds, which accounts for the fact that there is only a limited number of the different kinds of fundamental objects. As a consequence, there is a limited number of the different kinds of mutually interacting fundamental causal powers and fundamental causal processes in which objects occur.[1] According to Ellis, the fundamental processes (such as gravitational attraction and electric repulsion) are as are the fundamental properties and natural kinds, discovered and identified by *a posteriori* research (especially by physics).

Ellis (2001) introduces a rich Neo-Aristotelian "six-category" ontology.[2] In addition to primitive substances, individual property and relation accidents, substantial and property kind universals, he postulates primitive processes and dynamic (i.e., the process kind) universals. All of these kind universals are hierarchically organized reflecting such an

[1] All fundamental causal processes are assumed to be physical processes and a result of the acting of some of the basic causal powers.

[2] Strictly speaking, the fundamental ontological categories are not limited to six because Ellis (2001, 74) accepts both property and relation accidents and the corresponding kind universals.

organisation of natural kinds. According to Ellis (2001, sec. 2.3), the kind identities are best explained by means of the respective kind universals, but he briefly considers the possibility of accounting for the kind identities by means of a trope ontology.

The idea of replacing the Neo-Aristotelian ontology with a trope theory (or, trope bundle ontology) is attractive for two reasons. First, the trope ontology introduces only two fundamental categories of entities (monadic and relational tropes) instead of the four categories of the Aristotelian "ontological square" (substances, accidents and the respective kind universals) also accepted by Ellis. If we can implement such a reduction of the fundamental categories without reducing the ontological explanatory power, it leads to *qualitative economy* (i.e., fewer required fundamental categories of entities).[3] Qualitative economy amounts to fewer basic principles and different kinds of formal relations in the construction of an ontological system. For instance, Neo-Aristotelians introduce primitive formal relations of instantiation that connect substantial kind universals and their instances. If the trope theory has the same explanatory power as the Neo-Aristotelian position, it is a more credible alternative because its acceptability is not dependent on the acceptability of these further formal relations.

Second, the Neo-Aristotelian ontology seems to introduce *redundant postulations*. An ontological system introduces a redundant postulation if two distinct entities of the system (of whatever category) can separately account for the existence of the same entity or the same trait of reality. Instead of picking up distinct entities, redundant postulations seem to reflect alternative ways of categorizing reality, alternative structures of entities. Any adequate ontological system must try to eliminate them.[4] We can give two *prima facie* examples: s*ubstances* and *property tropes* of substances are considered as mereologically disjoint entities. Further, Ellis introduces both *property tropes* essential to

[3] The term *qualitative economy* (qualitative parsimony) was made popular by Lewis (1973, 87). Qualitative economy is a relational feature of an ontological category system: of the two ontological category systems having the same explanatory merits, a qualitatively more economical system introduces fewer primitive categories of entities than the less economical system.

[4] As the present case shows, the qualitatively less economical system (Neo-Aristotelian ontology) may lead to redundant postulations, which the more economical system (i.e., trope theory) eliminates. Nevertheless, the demands for qualitative economy and avoidance of redundancy are distinct. An advocate of an ontological system (Neo-Aristotelian ontology) must try to eliminate redundant postulations *before* the study of the comparative merits of the system. She can propose the elimination of (some of) the redundant postulations but it is not clear whether such elimination can be carried out (cf. note 5). Besides, some less economical systems (e.g., factualist ontologies) reject the primitive categories a more economical system (trope theory) accepts. Thus, there are no extra categories that could generate redundancy relative to the more economical system.

certain kinds of substances and *kind universals* to determine the essential features of substances.[5]

The task of the present article is to construct a trope bundle theory of *simple substances*, i.e., powerful particulars. *Simple substances* are substances that do not have further substances as their proper parts. This article is a part of a larger undertaking of constructing the *dispositional essentialist trope ontology*, i.e., a dispositional essentialist conception of reality according to which all fundamental entities are property and relation tropes. It replaces Ellis's Neo-Aristotelian theory.

In section 2, we attempt to determine the central traits of powerful particulars relevant to their trope theoretical construction. First, powerful particulars must possess certain basic features Ellis assigns to them. Second, we argue, following sortal essentialists, that a powerful particular cannot be bare but must belong to some necessary natural kind K determining its identity conditions. We call the most specific necessary natural kinds the *primary kinds* of substances.

The trope bundle theories come in several different variants. In section 3, we examine whether any of the main rival trope theories can be used in building a trope bundle theory of powerful particulars. However, both *Independence Theories* (Williams, 1953, Campbell, 1990) and *Saturation Theory* (Denkel, 1996, 1997) turn out to be inadequate. We argue that powerful particulars are best construed by developing further Peter Simons's (1994) *Nuclear Theory*. *Nuclear Theory* has two important advantages in comparison with the other trope theories: first, it introduces nuclear tropes that determine the (counterfactual) identity conditions of a powerful particular and the primary natural kind to which it belongs. Second, since tropes are parts of a substance due to their rigid dependence on the nuclear tropes, *Nuclear Theory*, unlike its rivals, allows for distinct but co-located powerful particulars.

Nevertheless, *Nuclear Theory* has two main defects: first, the construction of substances is too permissive and substances can be formed solely by the tropes falling under a single determinable (mass tropes, for instance). Second, unlike any other trope theory, *Nuclear Theory* allows that the tropes determining the features of a substance are spatio-temporally dispersed. We argue, however, that the tropes determining the causal powers of a powerful particular can exist only when the powerful particular exists and are necessarily spatially co-located with the powerful particular when they exist. In section 4,

[5] Lowe (1998, 142-143) proposes the identification of a substance and its essential tropes, which, in the context of Lowe's Neo-Aristotelian system, comes close to the elimination of the latter.

we construct the *Strong Nuclear Theory* of simple substances (i.e., powerful particulars) [SNT], which avoids these main defects. First, the SNT guarantees the diversity of the different kinds of tropes constituting a simple substance. Second, the SNT entails that each trope constituent of a powerful particular exists only when the powerful particular exists and is necessarily co-located with the powerful particular at each moment of its existence.

The construction of the dispositional essentialist trope ontology contains three additional tasks, which we leave for further work. They all stem from the explanatory functions the dispositional essentialist ontology assigns to the different kinds of entities.[6] First, the trope ontology must eliminate the need to introduce *property kind universals* and *dynamic kind universals* that form a hierarchical structure (Ellis 2001, 70ff.). Second, the SNT admits that there is an objective division of substances into natural kinds and that the latter have an important role in the determination of the identity conditions of substances. Therefore, we must spell out the structures of entities determining the kind identities between objects (i.e., substances) without introducing *substantial kind universals*. As natural kinds are not identified with separate mind-independent entities, we have to present a trope nominalist conception of substantial natural kinds. Finally, we must clarify the relationship between *substances* and *processes* in a way that avoids redundancy.

2. Powerful particulars in dispositional essentialist ontology

Ellis adopts *a posteriori* realism with respect to natural properties and natural kinds. He identifies natural properties considered as universals with *determinate kinds of tropes*. Corresponding to an exact similarity between objects (e.g., in respect of mass) there exists a class of exactly similar tropes (e.g., 1kg tropes) instantiated by objects, which is picked up by a determinate kind universal (of being a mass trope of 1kg). According to *a posteriori realism*, all exact similarities between objects are discovered by *a posteriori* research, by physics in particular.[7] Let us stipulate that objects *a* and *b* share a feature F if

[6] In this article, we mean by "metaphysical explanation" two things: first, spelling out the *category features of entities* such as the category features of tropes listed in the beginning of section 3, the formal relations the entities of a given category bear to the other entities, or the identity conditions of the entities of some category, second, accounting for the various traits of reality by means of the entities of the given category system: e.g., accounting for the causal powers of objects by means of their trope constituents (the ontological explanatory functions assigned to the entities of a given system) (cf. Oliver (1996); Swoyer (2000); Ellis (2001, sec. 2); Keinänen (2005, sec. 2.4) for the second kind of explanation).Typically, both kinds of explanations are meant to reveal metaphysically necessary truths about entities.

[7] Cf. Armstrong (1978) for an influential defence of *a posteriori* realism. Ellis (2001, 84ff.) too adopts *a posteriori* realism with respect to determinate properties of objects: the exact similarities between objects are

and only if *a* and *b* are exactly similar in respect of some determinable D. It seems that the empirically discovered intrinsic features of the fundamental objects are physical quantities (such as mass, electric charge, spin or quark colour charge) and dispositional features of objects (cf. Ellis 2001, 115; Mumford 2006, 475ff.). Thus, all intrinsic similarities between fundamental objects are similarities in respect of the causal powers the objects possess.

Ellis's *Dispositional Essentialism* has two main pillars. The first is the *strict dispositionalist* (cf. note 9) conception of natural properties that determine dispositional features of objects: a dispositional property kind universal (kind of property tropes) specifies a generic natural kind of processes, which the objects instantiating the property necessarily undergo in certain circumstances.[8] If certain initial conditions hold, a property trope of a deterministic disposition (e.g., mass trope t_1 of M in the presence of another mass trope t_2 of M' in certain distance D) necessarily triggers a determinate kind of causal process (gravitational attraction by force F to a determinate direction). Thus, dispositional properties necessarily bestow on objects certain definite causal powers (e.g., to attract certain other objects gravitationally).[9]

According to the second main thesis of *Dispositional Essentialism*, every substance necessarily belongs to *some* natural kind. Each natural kind K has a *real essence* constituted by the necessary intrinsic properties of a substance belonging to kind K.[10]

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discovered by *a posteriori* research and property tropes as well as the property universals of the corresponding determinate kind are introduced to account for such exact similarities between objects.

[8] It is customary to characterize the dispositional essences of the dispositional property universals by means of the *stimulus-manifestation counterfactual conditionals* (cf. Bird 2007, ch.2, 3; Eagle 2009, sec. 3.2). Ellis (2001, 130) too gives a characterisation by means of a necessary conditional that links the events of the causal and the effect kinds. However, the purpose of such conditionals is to describe the different kinds of fundamental processes (e.g., electric repulsions) produced by the instantiations of the basic causal powers (electric charges) in variable circumstances.

[9] Following Hendry & Rowbottom (2009), *strict dispositionalism* ("strict dispositional essentialism") claims that the instantiation of dispositional property P entails a group of stimulus-manifestation conditionals that remains the same in every possible world. By contrast, *weak dispositionalism* allows for a slight variation of the stimulus-manifestation conditionals the instantiation of a dispositional property implies in different possible worlds. Ellis advocates *strict dispositionalism* but uses natural kinds of processes to specify the essences of dispositional properties. Thus, we must qualify the above strategy to define *weak dispositionalism* in the context of Ellis's theory. The best way to develop "a *weak dispositionalist style*" variant of Ellis's position is to assume that the exact values of certain natural constants (e.g., the gravitational constant) are contingent. As a consequence, which specific kind of causal processes of a certain generic kind are triggered by certain basic dispositional properties in certain distance from each other varies in the distinct possible worlds. This variant of Ellis's position is consistent with the other pillar of Ellis's Dispositional Essentialism (i.e., that each powerful particular must belong to some natural kind with a specific kind essence) but its exact consequences must be studied on some other occasion.

[10] Ellis (2001, sec. 1.4) introduces the *causal notion of intrinsicness* that is different from the standard notion discussed, e.g., by Kim (1982) and Langton & Lewis (1998). According to Ellis, intrinsicness is a (second-order) relation between properties and things possessing the properties, not a formal property of properties: a property *P* is possessed intrinsically by object *a* if and only if *a* would display *P* in the absence of any accidental forces that might otherwise affect the properties that would be displayed by *a*. In the following pages, we will not discuss Ellis's notion any further. We will concentrate our attention on the fundamental

While such essential properties can determine a structure (or structural features) of a complex substance and be categorical, all properties necessary to a certain kind of fundamental substance are dispositional because all intrinsic features of fundamental substances are (Ellis 2001, 31-32, 115; 2002, 47). Both natural properties and natural kinds of objects are known *a posteriori* and we may change our conception of the correct natural kinds. According to our current knowledge, the best examples of natural kinds are the kinds of physical micro-particles (electron, down quark, etc.).[11]

According to Ellis's *Dispositional Essentialism*, the objective and mind-independent division of substances into natural kinds is determined by the kind universals which the substances instantiate. Each substantial kind universal K collects the properties forming the real essence of natural kind K. No elimination or reductive analysis of substantial kind universals is considered possible. Further important characteristics of substantial natural kinds are, first, that the distinct natural kinds differ in some intrinsic properties forming their real essences and, second, that such natural kinds form a hierarchy.[12] Typically, a higher (or more general) kind (e.g., atoms, leptons) possesses a real essence, which must be supplemented by further properties to reach the real essence of an *infima species* (e.g., specific atom isotopes, down quarks, electrons) (Ellis 2001, 77-78).

All fundamental substances are *powerful particulars*, which have only intrinsic dispositional features and fail to have any structural features.[13] Since each powerful particular *a* must be an instance of *some* substantial kind universal K, *a* must instantiate a real essence constituted by the monadic dispositional properties (e.g., some specific mass, electric charge, spin) essential to *some* K. Ellis does not accept the stronger claim that powerful particular *a* must possess a real essence (of some kind K) necessary to *a* constituted by (some of) its intrinsic dispositional properties. His reasons are twofold: first, some powerful particulars may very well change the natural kind to which they

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objects, i.e., powerful particulars. We may assume that the basic quantitative features of powerful particular *i* are both intrinsic in the sense of being possessed by *i* independent of the existence of any other *object* that is not a proper part of *i* (i.e., in the standard sense) and possessed intrinsically by object *i* (in Ellis's sense).

[11] By contrast, Ellis (2001, 21, 32) does not consider the biological species as single natural kinds because the members of a biological species need not share any set of standing intrinsic features. Instead, Ellis maintains that the biological species are clusters kinds, i.e., clusters of mutually similar natural kinds.

[12] See Ellis (2001, 19-21) for a list of the central features of the substantial natural kinds. A different kind of list of such features is given by Bird & Tobin (2008, 5-6).

[13] Structural features (e.g., determinate shapes) are not dispositional (in Ellis's sense) because it is not necessary to an object possessing such a feature to be involved in certain kinds of causal processes in certain circumstances.

belong without ceasing to exist.[14] Second, the identity of a substance depends primarily on its temporal and causal history and we may wonder whether any intrinsic properties are necessary to a substance (Ellis 2001, 238-239).

Before considering these arguments further, it is instructive to note that Ellis's categorial scheme and certain other recent Neo-Aristotelian schemes differ both structurally and in motivation. Both Ellis and the other contemporary Neo-Aristotelians postulate substantial kind universals to determine kind identities between objects (cf., e.g., Lowe 2009, ch.2, ch.9-10). However, three further functions not considered by Ellis are often given to substantial kind universals. First, substantial kind universals are postulated to rule out *bare particulars*, i.e., substrata without necessary properties.[15] Second, substantial kind universals are supposed to determine the identity and counting conditions of their instances. Third, substantial kind universals are introduced as referents of natural kind terms. We are assumed to acquire the identity and counting conditions of objects by means of the natural kind terms applying to them (Lowe 2009, ch.2; 1998, ch.2-3). These further functions are all associated with the alleged ability of substantial universals to determine the *de re* necessary properties of individual substances. Intuitively, the identity and counting conditions are determined (in a large part at least) by the necessary intrinsic features of substances.[16]

Ellis's powerful particulars are (as Neo-Aristotelian substances) wholly distinct from their property tropes. However, Ellis's scheme lacks any element or explicit principle that would rule out *bare particulars*. Substantial kind universals cannot do the job in his system because they do not determine *de re* necessary properties of *individual substances*. By contrast, according to Lowe (1998, ch.8), the identity conditions and essential features of substances are given by the most specific ontological categories (living organisms, special kinds of material objects, persons, etc.) into which substances are subdivided. Categories are known by means of *a priori* metaphysical investigation. In Ellis's system, kind universals can deliver only what Lowe (1998, 183-184) calls the

[14] Ellis's (2001, 238) example of an object changing a natural kind is an atom which loses one of its electrons in β-emission. Another possible example of an object that changes its natural kind is a proton that transforms into a neutron through the process of electron capture.

[15] Lowe (2009, 4-5, 14-15). In Loux's (1978, ch.9) "Substance-theory of Substance" substantial universals both diversify their instances and bestow on their instances certain essential features. The paradigmatic advocates of *bare particulars* (such as Bergmann (1967)) claim that particulars do not have any *necessary properties* while maintaining that particulars must have *some* properties.

[16] For instance, certain kinds of parts arranged in a certain way or, alternatively, a functional organisation of parts is (perhaps) most often considered to be essential to a complex substance. A complex substance remains in existence as long as its structural features or functional organisation are preserved, cf. Lowe (1998, ch.7-8) for such an account.

"*sortal persistence conditions*" of a substance: the kind universal *electron* determines the properties electron *E* must retain in order to remain an electron. In principle, *E* could gain, e.g., a completely different mass or electric charge, but remain the same object.

According to Ellis's first argument, we must allow for the possibility of kind change. However, the examples of substances changing a natural kind Ellis presents are complex substances (such as atoms losing an electron by β-emission). They seem to continue their existence through kind change because of retaining their necessary proper parts. Powerful particulars are *simple substances*, which do not have any substances as their proper parts. The examples of powerful particulars changing a natural kind are more contestable. However, one might claim that when a proton turns into a neutron by β^+-decay, one of its quark constituents, namely, an up quark, remains in existence but changes its natural kind, i.e., turns into a down quark. Further conceivable examples of simple substances changing a natural kind are found among quarks and leptons.[17] Whether these specific physical events are in fact changes of a natural kind by a single substance or, rather, cases of destruction and re-generation is a question that cannot be decided here; answering it belongs to the metaphysics of physics. However, there might be good reason to distinguish between the changeable natural kinds and the natural kinds necessary to substances. Consequently, the possibility of kind change does not offer us sufficient reason to consider *all* natural kinds contingent to their instances.

Ellis presents further reason to remain sceptical of the claim that any natural kind (and its kind essence) is necessary to its instances: according to him, the essences of particular substances are determined by their causal and temporal history, not by their intrinsic features. Thus, substances might well be *bare particulars*, which do not have any necessary intrinsic properties. However, *sortal essentialists* (cf. Wiggins 1980, 2001; Lowe 1998, 2009) have argued, in our opinion convincingly, against the possibility of bare particulars. We can present their argument with the help of two separate theses. First, each natural object (or, substance) must have certain identity conditions associated with the permanent natural kind to which it belongs. The identity conditions of a substance are

[17] According to physics, there are natural events in which a more massive quark (e.g., a bottom quark) is replaced with a less massive quark (e.g., an up quark) and a more massive lepton (e.g., a muon) is replaced with a less massive lepton (an electron). Either kind of events might be considered as containing a single micro-particle changing its natural kind. By contrast, there are no known events in which a single quark (or lepton) continues its existence and can be considered to be transformed into a micro-particle which is not a quark (or lepton).

determined by its permanent intrinsic features[18] and it cannot change these intrinsic features while remaining in existence. If the fundamental physical micro-particles are natural objects (as we have assumed), they are simple substances having determinate identity conditions associated with some natural kind.[19] The identity conditions of a simple (or a comparatively simple) substance are determined by its permanent dispositional features. Without help of the permanent intrinsic features it seems to be impossible to decide which specific change is sufficient for the destruction of the substance.[20]

Second, the *identity conditions* of a substance determined by certain of its permanent intrinsic features are also *necessary to the existence of the substance*. Let us call the natural kind of a substance associated with its identity conditions the *primary kind of a substance*.[21] Thus, each substance necessarily belongs to its primary kind. This second thesis of *sortal essentialism* is independent of the first and criticised by Mackie (2006, ch.8). The gist of Mackie's criticism is that sortal essentialists have not given sufficient reason to consider the identity conditions of a given object (associated with some sortal) necessary to the object. We can defend the second thesis as follows: the necessary intrinsic features of a substance provide the only clear unified explanation of how a substance can be (in counterfactual situations) and develop in all future situations (cf. Lowe 2007, 765-766). If a substance exists, it has certain temporal and counterfactual identity conditions determined by its necessary intrinsic features. The primary kind is necessary to the substance and the latter cannot be a bare particular.

Lowe's (1998) above proposal to determine the identity conditions manages to rule out bare particulars in the Neo-Aristotelian context but it claims that substances divide into *a priori* identifiable sub-categories. By contrast, according to Ellis's

[18] However, in order to distinguish between two objects having the same identity conditions, we also need to have recourse to the spatio-temporal location and the causal history of each object.

[19] It is a matter of dispute whether physical micro-particles are natural objects in this sense or some kind of non-individuals (i.e., entities without determinate identity conditions). According to the so-called standard interpretation of quantum mechanics, superposed electrons, for instance, lack synchronic and diachronic identity conditions, cf. French & Krause (2006) for further discussion.

[20] Consider leptons and quarks taken up in note 17. If we, e.g., maintain that up quarks are destroyed and replaced with down quarks, we assume that masses and electric charges of quarks contribute to determining their identity conditions: quarks cannot lose these intrinsic features and remain in existence. However, if quarks can change their specific quark kind, then they must be able to change their mass and charge. Still, there are intrinsic features (such as the quantum of spin) they must retain. Since a micro-particle (e.g., an electron) possesses *some* intrinsic features determining its identity conditions, we can say that it is destroyed in a drastic enough change (e.g., the event of electron-positron annihilation).

[21] While the objects belonging to the (possible) sub-kinds of the *primary kind* share their identity conditions, each primary kind is the highest natural kind whose instances share their identity conditions. The natural kind terms corresponding to primary kinds are called the *ultimate sortals*, i.e., the most general sortal (or, natural kind) terms assigning to objects certain determinate identity conditions, cf. Mackie (2006, 132).

Dispositional Essentialism, both the lower and the higher sub-kinds of substances are natural kinds identified *a posteriori*. As it is difficult to specify any sub-categories of substances to which powerful particulars would belong by means of *a priori* metaphysical investigation, Lowe's proposal is not appealing. From the trope theoretic perspective, "*bare particulars"*, which need to be ruled out, are an unnecessary by-product of the Neo-Aristotelian categorial scheme.

Instead of postulating primitive substances and complex substances built from the primitive substances, the trope theorist can suggest the following basic approach. First, there are complex substances, which are complexes of simple substances. Complex substances belong to natural kinds due to their intrinsic, mainly structural features. Which of such features are necessary to some complex substance must be dealt with separately. Second, powerful particulars (i.e., simple substances) are certain kinds of bundles of property tropes. The constituent tropes of a powerful particular determine the natural kinds to which the powerful particular belongs. They can form different kinds of structures to accommodate the possible distinction between the tropes necessary to a powerful particular and the tropes forming a real essence of a contingent natural kind. In section 4, we formulate a trope bundle account of simple substances that accords with this proposal, while the theory of complex substances must be left for further work.

3. The trope bundle theories of substance

According to *trope theorists*, substances (i.e., concrete objects) are bundles (or groups) of property tropes.[22] Tropes are assumed to be *concrete* (i.e., spatio-temporal) *particulars*. Moreover, tropes possess certain category features usually assigned to concrete particulars that function as basic entities of a categorial scheme.[23] First, tropes are *particular*, i.e., they exist only as single units and in a single unscattered spatio-temporal location. Second, tropes have certain definite identity conditions. Thus, it is fully determinate which two tropes are identical with each other. Moreover, tropes have identity of their own, independent of the identity of any further entity. Third, it is determinate how many

[22] In what follows, I use the term "trope bundle" for any group of tropes that fulfils some specific conditions. Hereafter I use the term "trope theory" exclusively for the *trope bundle theories of substance*. Thus, I will not consider the *substratum trope theories* advocated by Martin (1980), LaBossiere (1994), Molnar (2004) and Heil (2006). Moreover, the trope theories considered here in detail (i.e., *Nuclear Theory* and *Strong Nuclear Theory*) maintain that only *simple substances* are trope bundles, while *complex substances* are constituted by simple substances.

[23] Examples of the concrete particulars having the same category features assumed by some metaphysicians are *substances*, *perdurant objects* and *processes*.

property tropes there are in some definite location, i.e., tropes are countable.[24] Fourth, tropes are *categorially simple*: each trope is either simple, i.e., it does not have any proper parts, or all of its proper parts are further tropes (i.e., entities of the same category).

As *particular properties* tropes are assumed to have two interesting further features. First, tropes can occur as spatio-temporally co-located (i.e., compresent) with each other. Second, the nature of each trope is to determine a single feature of the thing possessing that trope. A trope is often identified with a single particularised feature of the thing possessing the trope. [25] Unlike a concrete object (which has many different features), a trope thus possesses a thin nature (cf. Simons 2003, sec.6). Several recent trope theorists claim that tropes belonging to some determinate kind (e.g., two distinct 1 kg tropes) are exactly similar due to being the tropes they are. Hence, they refrain from introducing further entities (such as determinate kind universals) to account for the exact similarities between property tropes. Since each trope *t* already possesses a particular nature, e.g., a nature of a 1 kg trope, two exactly similar tropes suffice to determine their exact similarity without help of any further entity.[26]

Trope theories fall under two, fundamentally different subgroups with respect to how they constitute substances. According to *Independence Theories* (Williams 1953; Campbell 1981, 1990), tropes are independent existents ("junior substances")[27]: each particular trope t_1 can exist independently of the existence of any particular trope t_2 that is not a proper part of t_1.[28] In principle, each particular trope *t* can occur alone, without being accompanied by a trope wholly distinct from *t*. Concrete objects are groups of mutually spatio-temporally co-located (i.e., *compresent*) property tropes. Rather than forming a further category of entities concrete individual objects are constructions out of groups of compresent tropes. *Independence Theories* deliver a very straightforward analysis of *ontic predication*: trope *t* is a property of object *s* if and only if *s* has *t* as its compresent part.

[24] By contrast, modes, which are particular properties assumed by Lowe (1998), *need not be* countable nor *need they have* determinate identity conditions.

[25] In some cases, there *might be* good reason to maintain that a single trope determines more than one dispositional feature. As noted in section 2, the fundamental dispositional features (e.g., masses and electric charges) specify a set of causal processes in which the object possessing the feature is necessarily involved in variable circumstances. An object having a *gravitational mass* also has an equal *inertial mass*, which is a disposition to produce a certain kind of acceleration to certain direction on the basis of the net force applied to the object. Instead of postulating both *inertial* and *gravitational mass tropes*, the trope theorist *can* propose that each mass trope determines two different dispositional features of an object, i.e., its gravitational and inertial mass.

[26] This view of trope resemblance, which is also adopted in this article, is defended, e.g., by Maurin (2002) and Simons (2003).

[27] The term "junior substance" for tropes is coined by Armstrong (1989).

[28] Substances are *strongly independent particulars*, i.e., they are not strongly rigidly dependent on any entity (cf. note 32).

Separate individual tropes are limiting cases of ontic predication, i.e., objects that possess exactly one property, while normally an object is as a matter of contingent fact constituted by several co-located property tropes.[29]

According to *Dependence Theories* (Simons 1994, 1998; Denkel 1996, 1997), tropes are dependent existents, i.e., they cannot exist alone but only as accompanied by wholly distinct property tropes and in substance-forming bundles. Substances form a *derived category of entities*: a group of tropes fulfilling certain ontological principles necessarily constitutes a substance.[30] Denkel constructs substances out of tropes by means of the formal relation of *generic dependence* and the relation of *spatial co-location*. The determinate tropes falling under certain determinable (e.g., mass tropes) must be "saturated" by exactly one trope falling under each of the certain distinct complementary determinables (charge tropes, etc.) co-located with the tropes at issue. Substances are groups of co-located tropes saturating each other completely, i.e., bundles of co-located tropes in which all generic dependencies of the tropes occurring in the bundle are met.[31] Therefore, substances are independent existents. Denkel rules out mutually co-located objects. If and only if trope *t* is a spatially co-located part of object *i*, *t* is a property of *i*.

Simons constructs *simple substances* solely by means of the formal relations of (strong) *rigid* and *generic dependence*.[32] First, each simple substance *i* contains two or more nuclear tropes rigidly dependent on each other or a single nuclear trope. The nuclear tropes are necessary to *i* and determine to which kind K *i* belongs. Possible examples of nuclear tropes are determinate quantity tropes (a determinate mass trope, charge trope, etc.) necessary to a simple substance (e.g., electron). Second, as tropes of a substance of kind K the nuclear tropes *may be* generically dependent on further tropes falling under

[29] For the *independence theorist* the distinction between abstract (tropes) and concrete particulars (ordinary objects) is epistemic rather than metaphysical: an entity is abstract, if it is got before the mind by an act of abstraction, i.e., "by concentrating attention on some, but not all, of what is presented" (Campbell 1981, 477-478).

[30] *Category C* of *complex entities* is *derived* if and only if two conditions hold. First, the entities belonging to *C* are formed by certain kind of groups of the entities belonging to some further *categories*. Second, the more basic entities necessarily form the groups at issue because they must fulfil certain definite conditions (e.g., existential dependencies): if any of the more basic entities exist, they necessarily constitute entities belonging to derived category *C*.

[31] Although Denkel considers saturation as a primitive internal relation, saturation can be analysed by means of generic dependence and spatial co-location, cf. Keinänen (2005, 352-369) for a detailed presentation of Denkel's theory.

[32] Let "$\leq$ " be a relation of improper parthood between distinct entities (cf. Simons (1987, 112) for the definition) and "E!" the predicate of (singular) existence. Trope *e* is *strongly rigidly dependent* on trope *f*, if SRD(e, f) $\equiv \neg(\Box \text{E!f}) \wedge \Box((\text{E!e} \rightarrow \text{E!f}) \wedge \neg(\text{f} \leq \text{e}))$ holds. Trope *x* of kind P is strongly generically dependent on trope *y* of kind R, if SGD (P(x), R(y)) $\equiv \Box \forall x \Box (Px \rightarrow \Box (\text{E!x} \rightarrow \exists y (Ry \wedge \neg(y \leq x)))) \wedge \Diamond \exists x Px \wedge \neg \Box \forall x Rx$ holds. Cf. Simons (1994, 294 ff.) for further discussion.

determinables $D_1, \ldots, D_n$.[33] There must be a trope falling under each of the determinables $D_1, \ldots, D_n$ (one-sidedly) rigidly dependent on the nuclear tropes. Intuitively, these further tropes constitute the outer sphere of contingent properties of a substance (e.g., the quantities accidental to a microparticle), while the nuclear tropes constitute the properties necessary to a substance. In Simons's theory, tropes are made constituents of a substance by their rigid dependence on the nuclear tropes and each trope must be a constituent of some substance. Substances are independent existents because the "existential needs" (i.e., rigid and generic dependencies) of tropes are met by the tropes constituting a substance. However, Simons's theory differs from all other trope theories by not requiring that a substance has its tropes as its mutually co-located parts.[34]

Although *Independence Theories* provide us with a straightforward analysis of ontic predication, they are inadequate. In the context of developing a trope bundle theory of powerful particulars, suffice it to mention two main reasons.

First, assuming the truth of *Independence Theories*, we cannot give any (empirical or metaphysical) explanation for the behaviour of the tropes of the basic physical quantities. We cannot spell out why they always are in compresent bundles that constitute a powerful particular belonging to some natural kind K (a certain kind of microparticle). Since tropes are in compresent bundles as a matter of contingent fact, one might expect that the explanation is empirical and given by science (e.g., by physics) (cf. Schaffer 2003, 134). However, the individual tropes are not investigated by scientific experiments and scientists have not proposed any laws of nature on the behaviour of individual tropes. Rather, in empirical study, the investigation is focused on the inventory of different kinds of objects (e.g., micro-particles) and their behaviour. We cannot even identify the tropes the independence theorist introduces by standard empirical means.[35] Thus, one is entitled to expect that the explanation is *metaphysical* rather than directly *empirical*: there should be metaphysical principles spelling out why tropes, which are the analytic primitives of an ontological system, form natural objects. *Independence Theories* explicitly deny the existence of such principles: all tropes are claimed to be in compresent bundles that form natural objects as a matter of contingent fact having no explanation, by

[33] The "may" is here *epistemic*, i.e., we may or may not find tropes generically dependent on the tropes falling under these determinables.

[34] Cf. also Simons (2000, 148-149). Several commentators (e.g., Hoffmann & Rosenkrantz (1994, 77), Denkel (1997, 600-601) and Maurin (2002, 150ff.)) make the false claim that the tropes introduced by Simons are necessarily mutually co-located parts of objects.

[35] Assuming that the individual tropes the independence theorist introduces can form "conjunctive compresences" (cf. Campbell (1990, 67, 85-88)), we cannot identify the tropes determining some specific feature of an object. Cf. Keinänen (2005, 296ff.) for a more detailed argument.

cosmic chance. By contrast, all available theories regulating the behaviour of tropes rule out the free floating tropes by means of (rigid or generic) existential dependencies.

Second, we have assumed that powerful particulars and their constituent tropes are *endurants*.[36] We cannot defend this claim within the limits of this paper. *Independence Theories* do not spell out how tropes form comparatively stable natural objects (of some natural kind). According to *Independence Theories*, the compresent tropes forming an object at some time T have a complete freedom to have any kind of location at some later moment T'. Since objects do not have any necessary tropes, a natural object formed by a trope bundle at some time T can well be considered to continue its existence as an individual trope at some later moment T'. Alternatively, we can legislate that if certain distinct tropes are destroyed, also the object the tropes form ceases to exist. Apart from such stipulations, the independence theorist does not have any means of delivering the *temporal identity conditions* of powerful particulars, i.e., when a simple substance is destroyed and replaced by some distinct substance(s). He cannot construct natural objects having certain identity conditions (independent of our stipulations) out of property tropes.

Unlike *Independence Theories*, Denkel's *Saturation Theory* rules out the free-floating individual tropes. However, *Saturation Theory* does not spell out why each substance as a trope bundle necessarily belongs to some natural kind.[37] Nor does *Saturation Theory* avoid the second difficulty of *Independence Theories*. Since no trope is essential for the survival of a substance, the substance can be considered to change all of its mutually co-located trope constituents but continue to exist as a spatio-temporally continuous entity. Alternatively, we might legislate that the destruction of some definite trope is sufficient for the destruction of the substance. Independent of this kind of stipulations, we do not have any objective means of deciding when a simple substance is destroyed.

According to *Saturation Theory*, if trope *t* is co-located with substance *i* (at some time T), *t* is a property of *i*. Thus, *Saturation Theory* rules out distinct but mutually co-located powerful particulars. However, the possibilities of co-location of powerful particulars are constrained by their causal powers (e.g., electric charges). There seems to be

[36] For the present purposes, we can use the term "endurant" for the concrete particulars that can exist longer than instantaneously but do not (usually) divide into temporal parts, cf. Keinänen and Hakkarainen (2010) for a more advanced characterisation. Processes and events are standard examples of concrete particulars that divide into temporal parts ("perdurants"), while the status of objects is contestable (cf. Hawley 2001).
[37] However, Denkel's (1996, 192, 223-226) idea of *essential saturation* might perhaps be used in constructing objects as bundles of mutually saturated tropes that necessarily belong to some natural kind. However, this idea does not solve the two further problems of *Saturation Theory*.

mutually co-located powerful particulars.[38] As *Saturation Theory* rules out the spatially co-located simple substances, it cannot offer us an adequate trope bundle theory of powerful particulars.

By contrast, Simons's *Nuclear Theory* introduces tropes necessary to a substance, which both determine the natural kind to which each powerful particular *i* belongs and the (counter-factual) identity conditions of *i*. Tropes are tied to powerful particulars by rigid dependence and the co-located powerful particulars are allowed for. Thus, of the above trope theories, Simons's *Nuclear Theory* seems to give the best trope bundle analysis of powerful particulars.

Nevertheless, *Nuclear Theory* has several serious problems. First, *Nuclear Theory* allows that substances are constituted solely by the nuclear tropes. However, it does not specify what kinds of nuclear tropes can constitute such a substance. In principle, a substance can be formed solely by the mass tropes necessary to the substance. As single nuclear tropes are allowed for, a single determinate trope, e.g., a 1 kg trope necessary to a substance can already form a substance. Second, we may suppose for the sake of argument that powerful particulars are constituted by the tropes falling under several distinct determinables. *Nuclear Theory* does not rule out two or several tropes falling under the same determinable (e.g., several mass or charge tropes) that function as constituents of the same powerful particular at the same time. Tropes appear to be identified as properties of different kinds of fundamental substances.[39] If two or more tropes falling under the same determinable can be constituents of the same powerful particular (at the same time T), it seems to be impossible to specify how many tropes falling under the same determinable (e.g., charge tropes) may determine the single feature (the electric charge of –e) of powerful particular *i* at T.

The third set of difficulties result from the fact that the formal relations of rigid and generic dependence do not constrain the *spatio-temporal locations* of tropes in any manner. Consequently, according to *Nuclear Theory*, each trope *t* has a location independent of the location of each other trope. Each individual trope can have a *spatio-temporal location* of its own and the tropes constituting a substance can be spread to a

[38] Neutrinos passing the visible matter and the quark constituents of matter affect each other only by weak interaction and gravitation. It seems that a large number of neutrinos can be (instantly) co-located with the quarks without interacting with them. Another, more contestable example of co-located powerful particulars is two superposed electrons in an atomic shell.

[39] We can distinguish between two exactly similar tropes, first, on the basis of their (possibly) distinct spatio-temporal location, and second, on the basis of that they are properties of different kinds of fundamental substances. No direct recourse to any particular substance *i* is needed.

larger area of *space-time*. The co-location with substance *i* is neither *sufficient* nor *necessary* for tropes to be properties of *i*. The most the advocate of *Nuclear Theory* can assume is that the tropes constituting a substance (or, the nuclear tropes at least) are usually as a matter of contingent fact compresent with each other (cf. Simons 2000, 148).

The first two difficulties of Simons's theory can be largely removed by modifying Simons's original construction and constraining it further by means of formal relations (cf. theses [SN2] – [SN4] in the next section). Nevertheless, the third difficulty is decisive. Tropes are introduced to determine the intrinsic dispositional features of powerful particulars (i.e., their causal powers). The causal powers of powerful particular *i* are *local*: they have a centre of influence which is necessarily the same as the centre of influence of the powerful particular. The substance (i.e., powerful particular) possessing these causal powers is necessarily co-located with its causal powers. Consequently, the tropes determining the causal powers must be co-located with the powerful particular. If the tropes possessed by a substance were spatio-temporally dispersed, they would determine the causal powers of spatio-temporally dispersed powerful particulars.[40] A substance constituted by the spatio-temporally dispersed tropes would be constituted by *distinct* spatio-temporally dispersed existentially dependent powerful particulars.

Hence, *Nuclear Theory* is inadequate in *metaphysical explanation* (cf. note 6): it fails to deliver any adequate analysis of the relation between powerful particulars and their constituent tropes (i.e., ontic predication). It cannot account for the intrinsic causal powers of an object by means of its property tropes. Similarly, the two first difficulties showed that *Nuclear Theory* does not furnish tropes with a sufficiently rich set of category features in order to construct natural objects by means of them.

Nevertheless, *Nuclear Theory* has several interesting features. First, each trope *t* is made a constituent of substance *i* by its rigid dependence on *i*. Because compresence with *i* is not sufficient for trope *t* to be a proper part of *i*, several co-located substances are allowed for. Second, each substance *i* has *nuclear tropes* rigidly dependent

[40] According to quantum mechanics, two physical micro-particles (e.g., superposed electrons) can be spatially separated from each other but in entangled state (Maudlin 2007, 56-57). Assume that the quantum eigenstates of the system formed by the two electrons refer to the features of these electrons (cf. Teller 1986, 77). If the electrons are in entangled state, it can be indeterminate which of them have a specific feature – e.g., spin up or spin down in the z-direction. However, if measured, the one of the electrons turns out to have its spin up and the other turns out to have the opposite spin (spin down). Still, these electrons are two powerful particulars with the distinct centres of influence. Their *property tropes* are necessarily co-located with them. As does Teller (1986, sec. 4), we can consider the entangled spin-state of these two electrons as a non-supervenient relation inhering in them and introduce a corresponding relational spin-state trope, which is strongly rigidly dependent on both of the electrons.

on each other necessary to *i*. Nuclear tropes have three important functions. As the first function, nuclear tropes determine the (counter-factual) identity conditions of substance *i*: substance *i* exists only if its nuclear tropes exist.[41] As the second function, nuclear tropes work as a "substratum" on which the tropes belonging to *i* are rigidly dependent. As the third function, nuclear tropes determine the (primary) kind K to which substance *i* belongs. As properties of a substance of kind K the nuclear tropes are generically dependent on certain further tropes. The nuclear tropes are generically dependent on certain further tropes on the basis of the kind of the substance in which they occur as constituents. Hence, unlike Denkel, an advocate of *Nuclear Theory* is not committed to the claim that the substances containing tropes falling under certain determinable D (e.g., mass tropes) must contain tropes falling under certain fixed determinables.[42]

Nuclear Theory offers us a promising schematic basis for the construction of a trope bundle theory of powerful particulars. Mutually co-located powerful particulars are allowed for. The explanation of why larger material objects cannot have the same spatio-temporal location is given by means of the causal powers of their constituent powerful particulars, no metaphysical explanation is required.[43] Nuclear tropes both collect the tropes of a powerful particular and determine its identity conditions as a certain kind of object. In the next section, we construct a trope bundle theory of powerful particulars on the schematic basis offered by *Nuclear Theory*. As the main task, we must construct a trope theory which both makes a powerful particular necessarily co-located with its constituent tropes and preserves the central virtues of *Nuclear Theory*.

4. The Strong Nuclear Theory of simple substances

In this section, we present the *Strong Nuclear Theory* of powerful particulars, which is a further development of Simons's (1994) *Nuclear Theory*. In the *Strong Nuclear Theory* [SNT], simple substances are first constructed by means of the formal relations of rigid and

[41] Intuitively, substance *i* continues its existence as long as its nuclear tropes do. Simons's (1994, 567-568) own statements suggest that the nuclear tropes determine also the *cross-temporal identity conditions* of the substance. However, since the nuclear tropes of *i* can be, according to *Nuclear Theory*, temporally separate from each other and the contingent tropes of *i*, we cannot guarantee that substance *i* continues to exist as long as its nuclear tropes do.

[42] *Pace* Molnar (2003, 50-51), an advocate of Nuclear Theory is not committed to the thesis that the tropes belonging to certain fixed *determinate kinds* must co-occur in trope nuclei. Rigid dependencies connect only individual tropes and the exactly similar tropes can be constituents of different kinds of trope nuclei.

[43] For instance, two solid macro-objects (such as stones) cannot occupy the same spatial location due to the attractive and repulsive electro-static forces between their sub-atomic parts determined by the positive and negative electric charges of the parts (nucleons and electrons). Since solidity and impenetrability already have a physical explanation (in terms of properties of the constituent parts), any metaphysical explanation leads to explanatory and ontological redundancy.

generic dependence. This basic construction of substances presented in [SN1] – [SN5] imposes further restrictions on the tropes constituting a substance in order to avoid the first two difficulties of *Nuclear Theory*.

The spatio-temporal location of a powerful particular and its constituent tropes is determined by further theses [SN6] – [SN8]. Instead of individual tropes, the SNT claims that certain trope aggregates that are parts of a substance (e.g., the aggregates of the nuclear tropes of a substance) figure in the basic spatio-temporal relations. Depending on the favoured theory of space-time, the trope aggregates are either the sole *relata* of spatio-temporal relations (*Space-time Relationalism*) or the basic spatio-temporal relations connect them and space-time points (*Space-time Substantivalism*).[44] Individual tropes have their locations derivatively as constituents of some trope aggregate. The spatio-temporal relations between individual tropes turn out to be *grounded internal relations*: they are *upwardly grounded* (or, determined) by the spatio-temporal relations between the trope aggregates.

Before spelling out these ideas in more detail, we present the basic construction of powerful particulars by laying down theses [SN1] – [SN5] of the *Strong Nuclear Theory*:

> [SN1]: Any powerful particular, *i*, contains at least one nuclear trope. If it contains more than one nuclear trope, then the nuclear tropes are strongly rigidly dependent on each other.[45] The nuclear tropes are necessary to *i* and determine the primary kind K to which *i* belongs.
>
> [SN2]: Let $D_1,\ldots, D_k$ be a group of the distinct highest determinables, i.e., determinable kinds of tropes. Each nuclear trope of *i* necessarily falls under some of the determinables $D_1,\ldots, D_k$. There is at most one nuclear trope falling under each of these determinables.

[44] Cf. Sklar (1974) for detailed characterisations of these rival ontologies of space-time. An alternative and a more neutral name for *Space-time Substantivalism* is "(Space-time) *Primitivism*" (cf. Nerlich 1991). The basic difference between these positions is that *Relationalism* attempts to analyse space-time in terms of (actual and possible) relations between entities in space-time, while *Substantivalism* rejects such an analysis.
[45] Cf. note 32 for the characterization of *strong rigid dependence* and *strong generic dependence*. Henceforth, I use the terms "rigid dependence" (rigidly dependent) and "generic dependence" (generically dependent) exclusively for *strong* rigid and generic dependence. A *nuclear trope* is either a trope not rigidly dependent on any other trope or it is rigidly dependent only on the tropes rigidly dependent on it.

[SN3]: Any trope *t* of a powerful particular of kind K is *generically dependent sde*[46] on the tropes falling under each of the determinables D_1,…, D_k.

[SN4]: Assume that powerful particular *i* of kind K has two or more nuclear tropes. There must exist tropes falling under each of the determinables D_1,…, D_k *rigidly dependent sde*[47] on the nuclear tropes of *i*. Each such trope is a part of some trope aggregate that is a part of *i*. Substance *i* does not have any other constituents.

Assume that substance *i* of kind K has a single nuclear trope. The above holds with the exception that there are no tropes falling under the same determinable D as the nuclear trope rigidly dependent on the nuclear trope.

If there is a nuclear trope of *i* falling under determinable D, there are no further tropes falling under D rigidly dependent on the nuclear tropes of *i*.

According to [SN1], each powerful particular *i* must have nuclear tropes, which determine the *primary kind K* to which *i* belongs. By using the notion of *primary kind*, the *Strong Nuclear Theory* leaves open the possibility of lower natural kinds of powerful particulars, in which the kind membership is partly determined by the tropes contingent to a powerful particular.

According to [SN2], each nuclear trope of a powerful particular necessarily falls under some highest determinable, i.e., belongs to the corresponding determinable kind. Examples of the determinable kinds of the tropes possessed by powerful particulars are determinables of certain basic physical quantities such as mass, electric charge and quark colour charge.[48] There cannot be more than one nuclear trope falling under a single highest determinable. According to [SN3], each trope *t* possessed by a powerful particular of kind K (irrespective of whether *t* is a nuclear trope) is *generically dependent sde* on the tropes falling under certain distinct determinables D_1,…, D_k. Depending on whether there

[46] The characterisation of *generic dependence* (cf. note 32) rules out self-dependencies, the generic dependencies of entities on themselves. The purpose of the term "*generically dependent sde*" ("self-dependencies excluded") is to make this restriction explicit.

[47] Similarly, the purpose of the term "*rigidly dependent sde*" (self-dependencies excluded) is to make explicit that rigid dependencies obtain only between distinct entities.

[48] The fundamental quantitative features of objects, which are all lowest determinates of determinables, are features of simple objects (i.e., powerful particulars) such as electrons and quarks.

are nuclear tropes to occupy all of the determinable kinds $D_1,\ldots, D_k$, clause [SN3] does or does not make the nuclear tropes generically dependent on the tropes outside the nucleus.

Finally, [SN4] guarantees the diversity of the different kinds of tropes constituting powerful particular *i* of kind K: there must exist tropes falling under each of the determinables $D_1,\ldots, D_k$ *rigidly dependent sde* on the nuclear tropes of *i*. In a limiting case, powerful particular *i* of kind K contains only nuclear tropes and the condition is fulfilled by the nuclear tropes. In many cases, a powerful particular has some contingent tropes.[49] There cannot be contingent tropes of *i* falling under a determinable of some of its nuclear tropes.

Theses [SN1] – [SN4] suffice to give the *necessary conditions* for a trope being a part of a powerful particular: if trope *t* is a part of simple substance *i*, then *t* is rigidly dependent on the nuclear tropes of *i* or *t* is the sole nuclear trope of *i*. In order to provide the *sufficient conditions*, we add a further thesis:

> [SN5]: Trope *t* is a part of powerful particular *i* if and only if either *t* is the only nuclear trope of *i* (and *t* is not rigidly dependent on any trope) or the nuclear tropes of *i* are the only tropes on which *t* is rigidly dependent.

According to [SN5], trope *t* is a part of simple substance *i* if and only if *t* is its only nuclear trope or rigidly dependent only on its the nuclear tropes. Thus, [SN5] rules out that the tropes rigidly dependent on two or more nuclei are parts of a single substance. The relation of parthood in [SN5] is *atemporal*, i.e., not relativized to time. All tropes fulfilling the condition are parts of a substance in this basic sense: "the temporary parthood" of contingent tropes is analysed in terms of this basic notion of parthood and their spatio-temporal location relative to the location of the substance in the SNT.[50]

On the basis of [SN1] – [SN5], we have already laid down the conditions according to which tropes are parts of substance *i*. In order to constrain the spatio-temporal location of tropes, we add a further thesis:

[49] A possible example of a contingent trope of a powerful particular is a trope of the direction of spin of an electron or a colour charge trope possessed by a quark.

[50] According to the SNT, trope *t* is a temporary part of substance *i* if and only if *t* is a part of *i* (in the atemporal sense), and *t* is a part of a *c-bundle* (cf. below) whose temporal location is a proper part of the temporal location of *i*. Cf. Keinänen and Hakkarainen (2010) for further discussion.

> [SN6]: Assume that powerful particular *i* of kind K is constituted solely by its nuclear tropes falling under determinables $D_1,\ldots, D_k$. The powerful particulars of this specific type are among the minimal entities instantiating the basic spatio-temporal relations.

Powerful particular *i* of kind K, which contains only nuclear tropes, is among the minimal entities instantiating the basic spatio-temporal relations. The basic spatio-temporal relations determine the spatio-temporal location of *i*. As the constituent tropes do not instantiate the basic spatio-temporal relations, they do not have any independent location. The spatio-temporal location of this kind of substance determines the spatio-temporal location of its constituent tropes. Therefore, the relation of compresence between the constituent tropes is *upwardly grounded* in the following straightforward way:

> [P1]: The relation of compresence Ct_1t_2 between tropes t_1 and t_2 is an *upwardly grounded internal relation* if the following conditions [1] – [3] hold:
> [1]: Tropes t_1 and t_2 are rigidly dependent on substance *i*;
> [2]: Necessarily, if t_1 exists, t_1 is a proper part of *i*, and, necessarily, if t_2 exists, t_2 is a proper part of *i*;
> [3]: The existence of tropes t_1 and t_2, and the spatio-temporal relations between substance *i* and the other substances (or, trope bundles, space-time points) entail that Ct_1t_2.

Thus, necessarily, if tropes t_1 and t_2 exist, substance *i* exists *and* t_1 and t_2 are proper parts of *i* (conditions 1 and 2 of [P1]). Moreover, the spatio-temporal relations between substance *i* and the other entities determine the spatio-temporal location of substance *i* and its constituent tropes. Consequently, the constituent tropes of *i* are compresent with each other (condition 3). As a concrete entity substance *i* necessarily has *some specific* spatio-temporal location. Thus, necessarily, if tropes t_1 and t_2 exist, they are compresent with each other.

The best known *grounded internal relations* are determined by the monadic properties of objects.[51] For instance, if both *a* and *b* have a mass of 1kg, their masses

[51] Cf. the discussion of grounded internal relations by Campbell (1990, 100ff.). While reserving the term "internal relation" for *ungrounded internal relations*, Campbell uses the term "founded external relation" for grounded internal relations.

determine the *grounded internal relation* of being equal in mass between *a* and *b*. The grounded internal relation is not any further entity (e.g., a relational trope instantiated by *a* and *b*). Rather, the mass tropes of *a* and *b* suffice to determine that *a* and *b* are equal in mass and make true the corresponding relational predication. We can identify the relation of mass similarity between *a* and *b* with the interpreted relational predicate (or relation concept) applying to *a* and *b* due to their mass tropes.[52]

Moreover, the basic relations connecting certain entities determine grounded internal relations connecting certain (the same or further) entities. It is easy to find examples of *grounded spatio-temporal relations* determined by certain basic spatio-temporal relations. The general idea is that we need to postulate only certain basic relations in order to determine the spatio-temporal location of certain entities, the entities composed of them, or their existentially dependent proper parts. The instantiation of the basic relations entails that the same or the further entities are in certain further spatio-temporal relations.

First, if certain basic spatio-temporal relations (e.g., relational tropes connecting objects or objects and space-time points) determine the spatio-temporal location of objects, they determine further spatio-temporal relations (i.e., grounded internal relations) connecting objects.[53] Second, according to most trope theorists, the individual tropes are the entities that instantiate the basic spatio-temporal relations. Thus, a trope theorist is entitled to maintain that the spatio-temporal relations between the individual objects are *downwardly grounded* by the spatio-temporal relations between their necessary trope constituents.[54] By contrast, according to [SN6], powerful particulars formed solely by the nuclear tropes are among the minimal entities instantiating the basic spatio-temporal relations. The basic spatio-temporal relations determine the locations of the constituent

[52] Since the question of whether the supervenient items are genuine constituents of reality (i.e., entities) has not given any clear answer, we will not use the notion of supervenience in clarifying the status of internal relations. According to Campbell (1990, 37ff.), supervenient items (e.g., grounded internal relations) are mere "pseudo additions" to our ontology, no new being is involved. However, as all internal relations are mereologically disjoint from their foundations, we cannot both accept them as entities and maintain that they are *no addition* to our ontology, cf. Simons (2003, sec.6).

[53] To take a simple (or, simplified) example of a *grounded spatial relation*, we may assume that the distance m between *a* and *b* is determined by a relational trope of m instantiated by *a* and *b*. Moreover, the distance m between *b* and *c* is determined by a further relational trope of m. The distance between *a* and *c* (e.g., 2m) is a *grounded spatial relation* determined by these relational tropes and further relational trope(s) fixing the relative locations of objects *a*, *b* and *c*. See Maurin (2002, 163ff.) and Simons (2003) for a more detailed characterisation of relational tropes.

[54] In the case of downward grounding, the existence of the necessary tropes of substance *i* entails that *i* exists and the existence of the necessary tropes of substance *j* entails that *j* exists. Moreover, the spatio-temporal relations between the necessary trope constituents of *i* and *j* entail that *i* and *j* are in certain grounded spatio-temporal relations to each other.

tropes of (this kind of) powerful particulars and *upwardly ground* all spatio-temporal relations between the constituent tropes.

Thus, if we accept the idea of upward grounding presented in [P1], we have the following positive result in the SNT: the tropes of a powerful particular formed solely by the nuclear tropes are necessarily co-located with each other and the powerful particular. The constituent tropes of every simple substance satisfy [P1: 1] and [P1: 2]. Condition [P1: 3] holds because simple substances constituted by the nuclear tropes are among the minimal entities instantiating the basic spatio-temporal relations.

We would need a still more general result, i.e., that *every property trope t* of powerful particular *i* is necessarily co-located with *i* when it exists. There are three *prima facie* alternative ways to account for the location of a contingent trope. According to the first alternative, the spatio-temporal location of contingent trope *t* of substance *i* is determined by the location of *i*. The second alternative is that each contingent trope *t* is an entity that figures in the basic spatio-temporal relations and has an independent location. Finally, one might introduce the primitive formal relation of *inherence* to ground the location of contingent trope *t* of substance *i*.[55] Since *t* inheres in *i*, *t* is a property of *i* and necessarily co-located with *i*.

We must reject all of these alternatives. The first two are clearly unsatisfactory. First, there is no contradiction in assuming that substance *i* cannot change its contingent tropes but there are *prima facie* examples of simple substances changing their contingent tropes (cf. note 49). It seems that each contingent trope *t* of substance *i* can have a *spatio-temporal location* different from the location of *i*. Therefore, the spatio-temporal location of *t* cannot be grounded by the spatio-temporal location of *i*. Second, as we argued in the previous section, a trope that is a property of a simple substance is necessarily spatially co-located with the substance. Thus, if contingent trope *t* is a property of simple substance *i*, *t* is necessarily co-located with *i* when *t* exists. Consequently, *t* cannot have a location entirely independent of the location of *i*. Therefore, contingent trope *t* is not a good candidate for an entity that instantiates the basic spatio-temporal relations.

Finally, we cannot introduce the primitive formal relation of inherence to solve the problem at hand. *Rigid* and *generic dependence* and *mereological relations* (such as parthood) are paradigmatic examples of *formal relations*. Given that entity *e* exists, its

[55] E.J. Lowe (2006, 34ff.) has recently suggested that inherence (in his terms, *characterisation*) is a primitive formal relation. A mode (i.e., a particular property) stands in the relation of characterisation to a definite substance *i*, which entails that the mode is both existentially dependent on *i* and necessarily co-located with *i*.

existential dependencies and mereological relations to the other entities must be fixed. Formal relations are not further entities to their *relata* but entities are in formal relations due to their existence – when we specify a given entity, we must also specify the formal relations it bears to the other entities.[56]

We can present the inherence of a trope in a substance as follows: if trope *t* inheres in substance *i*, then *t* is a proper part of *i*, *t* is rigidly dependent on *i* and *t* is necessarily co-located with *i* when *t* exists. Hence, instead of a single formal relation of inherence, there seem to be three components (*rigid dependence*, *proper parthood*, and *necessary co-location*) in terms of which we can analyze inherence. Inherence is not a good candidate for a *primitive formal relation* because we can analyze it further.

Because of its third component (i.e., the necessary co-location), inherence is not a credible candidate for any kind of formal relation (primitive or defined). Trope *t* and substance *i* possessing *t* have their spatio-temporal locations contingently. We must introduce *some* spatio-temporal relations to ground both of their locations. The relation of spatial co-location between trope *t* and substance *i* must be grounded by the relations determining the spatio-temporal location of the trope, on the one hand, and the substance, on the other. As we must introduce further entities (e.g., relational tropes) to ground the location of trope *t* and substance *i*, we must introduce further entities to ground the inherence of *t* in substance *i*. All formal relations hold on the basis of the existence of their *relata* but we must introduce further entities such as relational tropes to ground inherence. Consequently, inherence is not a formal relation.[57]

None of the three alternative ways to ground the location of contingent tropes is acceptable. Thus, we must take a closer look at the location of tropes. For that purpose we can introduce three principles that constrain the spatio-temporal location of tropes:

> [TL1]: The nuclear tropes of powerful particular *i* are necessarily compresent and the spatio-temporal location of the aggregate of its nuclear tropes determines the spatio-temporal location of the powerful particular.

[56] In the context of the SNT, we can assume that *formal relations* (1) are *ungrounded internal relations*, i.e., the existence of entities *e* and *f* entails that they are in formal relation *F*, i.e., that *Fef* and (2) two entities are in a formal relation due to their structural characteristics (cf. Smith & Mulligan 1983) or similarity. Formal relations specify how a given entity *e* exists as a constituent of the world (mereological relations), how *e* can exist as a constituent of the world (existential dependencies, combinatorial relations) and ungrounded similarities between distinct entities (or entity pairs).

[57] However, according to the SNT, the relational tropes grounding the spatio-temporal location of the nuclear and contingent tropes also ground the inherence of trope *t* in substance *i*. Hence, we need not introduce any *new relational entities* to ground the inherence. Cf. Keinänen and Hakkarainen (2010, sec. 3).

[TL2]: By contrast, the contingent tropes of powerful particular *i* are neither necessarily compresent with *i* nor with each other.

[TL3]: Necessarily, each trope *t* contingent to substance *i* occupies an area of space-time that is a (proper or improper) part of the area occupied by *i*.

Both [SN6] and principles [TL1] – [TL3] are independent of theses [SN1] – [SN5] but they are all reasonable. First, if substance *i* must instantiate trope *t* permanently, the spatio-temporal location of *t* and *i* is necessarily the same: their temporal location is the same and (as a property of *i*) *t* is necessarily spatially co-located with *i* when it exists. Thus, according to [TL1], the spatio-temporal location of each powerful particular *i* is determined by the location of its nuclear tropes. No powerful particular can change its nuclear tropes during the time of its existence. Powerful particulars formed solely by the nuclear tropes form a special case of [TL1]: they are necessarily compresent with their constituent tropes. Second, if substance *i* can gain or lose trope *t*, which *i* possesses at some moment, the temporal location of *t* is a proper or improper part of the temporal location of *i*. However, the non-permanent tropes of powerful particular *i* are necessarily co-located with *i* when they exist. According to [TL2], each powerful particular *can* change its contingent tropes and such tropes *can* vary independently of each other. Therefore, each contingent trope must occupy an area of space-time that is a (proper or improper) part of the area of space-time occupied by the powerful particular ([TL3]).

In order to satisfy principles [TL1] – [TL3], we make the following two assumptions: first, the aggregate of the nuclear tropes of each simple substance (let us call this aggregate the *n-bundle*) forms an *individual* that instantiates the basic spatio-temporal relations. In some cases, such a trope aggregate constitutes the entire substance (cf. [SN6]). Second, the trope aggregates constituted by each single trope contingent to some simple substance *i* and the nuclear tropes of *i* (let us call such a trope aggregate the *c-bundle*) form further *individuals* which instantiate the basic spatio-temporal relations:

[SN7]: In addition to the substances fulfilling the conditions of [SN6], the following two kinds of trope aggregates are individuals that instantiate the basic spatio-temporal relations:

[1]: The trope nucleus of each powerful particular *i* (the *n-bundle*). The spatio-temporal location of the nucleus of each powerful particular *i* determines the spatio-temporal location of *i*.

[2]: Each trope bundle formed by the nucleus of some powerful particular *i* and single trope *t* one-sidedly rigidly dependent only on the nuclear tropes of *i* (the *c-bundle*).

First, *n-bundle*s instantiate the basic spatio-temporal relations. The *n-bundle* of each substance *i* is a minimal entity instantiating the basic spatio-temporal relations. The spatio-temporal location of the *n-bundle* determines the spatio-temporal location of the nuclear tropes of *i*. Thus, the nuclear tropes of *i* fulfil the conditions of [P1] relative to the *n-bundle* and are necessarily compresent with each other and the *n-bundle*. Hence, the compresence between the nuclear tropes is an upwardly grounded internal relation in the sense of [P1].

Second, in order to ground the spatio-temporal location of contingent tropes, condition [SN7: 2] states that each *c-bundle* (i.e., the trope aggregate formed by contingent trope constituent *t* of substance *i* and the nuclear tropes of *i*) is among the entities that instantiate the basic spatio-temporal relations. The spatio-temporal location of the *n-bundle* of substance *i* already determines the spatio-temporal location of the nuclear tropes. Hence, they do have a determinate location. Contingent trope *t*, which is the further constituent of a *c-bundle*, does not have independent location. Instead, the spatio-temporal location of the *c-bundle* in which *t* occurs determines the spatio-temporal location of trope *t*. Contingent trope *t* is necessarily compresent with its *c-bundle* and they are in exactly the same spatio-temporal relations.

According to the SNT, exactly three different kinds of trope bundles constitute *individuals*. First, each bundle of tropes rigidly dependent only on the nuclear tropes of a substance is a *simple substance* (cf. [SN5]). Second and third, certain kinds of parts of a simple substance, namely the *c-bundles* and the *n-bundles*, are individuals that instantiate the basic spatio-temporal relations. They all have a unique construction. The *n-bundles* (i.e., the trope nuclei of substances) are aggregates of mutually rigidly dependent tropes and the *c-bundles* are trope aggregates formed by each contingent trope *t* of substance *i* and the tropes on which *t* is rigidly dependent (i.e., the nuclear tropes of *i*).

While substances having contingent trope parts are *mereologically inconstant* (i.e., they can change their proper parts), the *c-bundles* and the *n-bundles* are

mereologically constant (i.e., they cannot change their proper parts) as trope aggregates.[58] Each *n-bundle* is mereologically constant because the spatio-temporal location of the *n-bundle* determines the spatio-temporal location of its constituent tropes. We must introduce a further principle to secure the mereological constancy of the *c-bundles*:

> [SN8]: The interval of time in which a *c-bundle* of substance *i* is located is a proper or improper part of the interval of time in which the *n-bundle* of *i* is located.

According to [SN8], the temporal interval each *c-bundle* of *i* occupies is a proper or improper part of the temporal interval occupied by the *n-bundle* of *i*. As a consequence, each *c-bundle* is *mereologically constant*: if a *c-bundle* exists at time T, each of its proper parts must also exist at T. First, the location of the *c-bundle* determines the location of contingent trope *t*. Thus, if the *c-bundle* exists at T, trope *t* must exist at T. Second, if the *c-bundle* of substance *i* exists at time T, its constituent *n-bundle* and the nuclear tropes of *i* must exist at T (by [SN8]). The temporal locations of the *c-bundle* and the *n-bundle* of substance *i* are co-ordinated. Since [SN8], i.e., the co-ordination of temporal locations, guarantees the mereological constancy of every *c-bundle*, a *c-bundle* is a trope aggregate.

The temporal location of every *c-bundle* of substance *i* relative to the *n-bundle* of *i* is fixed by [SN8]. Moreover, the fact that a *c-bundle* is a trope aggregate has an important consequence with regard to its spatial location relative to the *n-bundle*. Since each *c-bundle* is a trope aggregate having the nuclear tropes as its constituents, the spatial location of the *c-bundle* of *i* must include the spatial location of the nuclear tropes, i.e., the area of space the *n-bundle* (of substance *i*) occupies is a proper or improper part of the area of space occupied by the *c-bundle* at each moment of their existence.[59]

The spatio-temporal location of the *c-bundle* determines the spatio-temporal location of contingent trope *t*, which is a proper part of the *c-bundle* together with the nuclear tropes. Hence, the location of trope *t* relative to the *n-bundle* is exactly the same as the location of the *c-bundle*. First, the interval of time a contingent trope *t* of substance *i*

[58] The *n-bundles* and the *c-bundles* satisfy the thesis of *Strong Mereological Essentialism* (SME) as trope aggregates (cf. Simons 1987, 272). See Simons (1987, 177 ff.) for a comprehensive presentation of modal temporal mereology.

[59] As Parsons (2007, 213) argues, all concrete entities satisfy the following principle of *Expansivity*: the *spatial location* of the whole is as least as inclusive as the *spatial location* of its (proper or improper) parts. Since tropes and their *c-bundles* and *n-bundles* are concrete entities, they satisfy *Expansivity* with respect to their spatial location.

occupies is a proper or improper part of the interval of time that the nuclear tropes of *i* occupy. Second, the area of space the nuclear tropes of *i* occupy is a proper or improper part of the area of space contingent trope *t* of *i* occupies when *t* exists.

We can argue further that a *c-bundle* of substance *i* must be spatially co-located with the *n-bundle* of *i* at each moment in which they both exist. To this point, we have assumed that tropes as well as simple substances (powerful particulars) can occupy some definite, extended area of space-time. Commonsense macro-objects have definite boundaries (relative to the other macro-objects), size, shape and extended location. Powerful particulars (e.g., quarks, electrons, and the more complex physical objects they constitute) arranged in certain spatial locations determine the boundaries of the macro-object they constitute. Every powerful particular has a centre of influence of its causal powers as a centre of its spatial location. It seems to be consistent with the current physics that powerful particulars (e.g., quarks and leptons) occupy the minimal regions of space.[60] Alternatively, we can propose that a powerful particular has an *approximate size* determined by its intrinsic causal powers and the causal powers of the other powerful particulars in its proximity.[61]

Assume the latter. The trope constituents of powerful particular *i* determine its intrinsic causal powers but we cannot assign to the tropes at issue any definite size. Unlike the powerful particular, its trope constituents do not have a set of intrinsic causal powers, on the basis of which we could assign to the tropes a size. Rather, each trope *t* has a centre of influence, which is the same as the centre of influence of the causal powers trope *t* determines**.** The spatial location of a trope is identical with its centre of influence at each time of its existence. On the other hand, if each powerful particular has the minimal

[60] Both quarks and leptons are referred as "point particles" because they do not have any detectable size, cf., e.g., Eisberg & Resnick (1985, 277, 667). Assume that powerful particulars have the minimal spatial extent. Instead of considering such powerful particulars as point-sized, it seems reasonable to claim that space-time is quantized (in such case) and that the minimal regions of space powerful particulars occupy have certain (non-punctual) size, cf. Braddon-Mitchell & Miller (2006).

[61] According to Harré (1970, ch.11), each simple substance, which he calls "a point centre of influence", has "a surface" determined by the net attractive and repulsive forces between the substance and the other point centres of influence. The intrinsic features of the point centres of influence are causal powers and the causal powers of the point centres of influence determine the attractive and repulsive forces between the point centres. We can propose a similar explanation to the approximate size of a powerful particular: the size of a powerful particular is determined by its causal powers determining the net attractive and repulsive forces between the powerful particular and the other powerful particulars (with certain causal powers) in its proximity. (Here, we omit the complications resulting from quantum phenomena and the wave-like nature of micro-particles.) We distinguish between powerful particulars and their centres of influence (i.e., spatial locations). Here, we have only assumed that each powerful particular has a "centre of influence", a (not necessarily point-like) centre of the location of its causal powers.

spatial size, it has its centre of influence as its exact location. The spatial location of its trope constituent is again identical with the centre of influence of the trope.

Since the basic spatio-temporal relations determine the spatial location of the *n-bundle* of substance *i* and each *c-bundle* of *i* at every moment of their existence, they determine the centre of influence of these tropes and trope bundles at each moment of their existence. First, the basic spatio-temporal relations determine the centre of influence of the *n-bundle*, which is the same as the centre of influence of the nuclear tropes. Second, the basic spatio-temporal relations determine the centre of influence of each *c-bundle* and contingent trope *t* of substance *i*, which is its further constituent. As the spatial location of a *c-bundle* of *i* must include the spatial location of the *n-bundle*, the centre of influence of a *c-bundle* of substance *i* must include the centre of influence of the *n-bundle* of *i*.

The centres of influence of tropes and trope bundles are spatial locations of tropes. They have the minimal spatial size (i.e., are minimal regions of space) and might be point-like.[62] If they are points of space, they do not have different sizes. If they are not point-like, we can still assume that the centres of influence do not have different sizes.[63] The centre of influence of a *c-bundle* of *i* must contain the centre of influence of the *n-bundle* of *i* as a part (at each moment of the existence of the *c-bundle*) but the latter is not a proper part of the former. Thus, a *c-bundle* of *i* and the *n-bundle* of *i* have exactly the same centre of influence when they exist. As a consequence, each contingent trope *t* of *i* and the nuclear tropes of *i* are spatially co-located with each other when they all exist.

Hence, the area of *space-time* each *c-bundle* of substance *i* occupies is a proper or improper part of the area occupied by the *n-bundle* of *i*. The basic spatio-temporal relations determine the spatio-temporal location of each *c-bundle* and the *n-bundle*, but the locations of these trope aggregates are closely co-ordinated. First, each *c-bundle* is a trope aggregate containing the *n-bundle* of *i* as its proper part and the latter has at least as extensive temporal location as the former (by [SN8]). Second, since the *n-bundle* of *i* is a proper part of a *c-bundle* of *i*, these trope aggregates must have exactly the same centre of influence (i.e., spatial location) at each moment in which they both exist. Finally, the spatio-temporal location of each contingent trope *t* is determined by the location of its

[62] Here, we omit the possibility that space(-time) does not contain minimal regions or space-time points but can be divided into smaller and smaller regions "all the way down". However, it seems that we can argue also in this case that the centres of influence do not have different sizes, although the argument is more complicated.

[63] If the centres of influence are not point-like, space-time is quantized and not divisible into point-like parts. The centres of influence have the minimal spatial size and there is a single minimum unit of length ("Planck length") determining their size, cf. Braddon-Mitchell & Kristie (2006).

c-bundle and co-ordinated in exactly the same way as the location of the *c-bundle*. Consequently, contingent trope *t* of substance *i* must be co-located with *i* at each moment of *t*'s existence.

In order to complete the *Strong Nuclear Theory* of powerful particulars, we assume two further theses:

> [SN 9]: Necessarily, every property trope *t* is a part of some powerful particular *i*, i.e., it is either the sole nuclear trope of some simple substance *i* or rigidly dependent only on the nuclear tropes of *i*.
>
> [SN 10]: Simple substances are trope bundles in which all of the rigid dependencies of their constituent tropes are fulfilled. Therefore, they are *strongly independent particulars*.

According to [SN9], every property trope is a constituent of some powerful particular. Thus, all *property tropes* are constituents of simple substances. The features of complex substances are determined either by the trope constituents of powerful particulars or by the relational tropes connecting two or more powerful particulars.[64] Simple substances are by their construction trope bundles closed under the formal relation of rigid dependence. Therefore, simple substances are not strongly rigidly dependent on any further entities, i.e., they are strongly independent particulars ([SN 10]). By contrast, they can be strongly generically dependent on certain further entities, relational tropes for instance.[65]

Finally, in order to make sense of contingent natural kinds, the SNT can introduce *secondary natural kinds* of simple substances. Instead of an explicit description of the modifications we must make, we briefly describe how the secondary kinds can be constructed in the SNT. The basic idea is as follows: a group of tropes rigidly dependent on

[64] The first alternative requires that the intrinsic features of a complex substance are determined by the features of its constituent powerful particulars. In order to account for the "emergent features of a complex substance" (i.e., the features of a complex substance not determined by the features of its parts), we might be obliged to introduce tropes rigidly dependent on two or more powerful particulars, which are *relational tropes* (cf. Keinänen 2005, sec. 4.3.6).

[65] According to Simons's (1998, 243-244) version of the *Conditioning Principle* cf. Simons (1987, 322) for more discussion), if the "existential needs" of whatever strength of the tropes belonging to a group of tropes, such as rigid or generic existential dependencies, are satisfied by the tropes belonging to that same group, the complex formed by this group of tropes is an independent existent. Moreover, Simons applies the principle to the simple substances constituted by the existentially dependent tropes and considers substances as independent existents. However, it seems reasonable to apply the *Conditioning Principle* only to *rigid dependencies* and consider substances as *strongly independent particulars*, which accords with Simons's own general characterisation of substances.

each other but contingent to substance *i* forms a kind essence of substance *i* belonging to the secondary kind together with the nuclear tropes of *i*. In order to allow for such contingent kind essences, we must modify [SN5: 2] and permit that mutually rigidly dependent contingent tropes are constituents of simple substance *i*. Moreover, in order to explain the natural unity of the mutually rigidly dependent contingent tropes, we must assume that a group of such tropes is like a single contingent trope with respect to its spatio-temporal location. The required modifications of [SN7] and [SN8] are straightforward. If the *infima species* are the secondary natural kinds, a simple substance can change its secondary kind by changing the contingent tropes partly constituting the (particularized) kind essence of the secondary kind.

5. Conclusion

The *Strong Nuclear Theory*, which consists of theses [SN1] – [SN10], preserves the three main functions *Nuclear Theory* assigns to the nuclear tropes. With the help of these functions, the SNT constructs an adequate trope bundle theory of powerful particulars. First, the SNT makes a powerful particular necessarily co-located with the tropes determining its causal powers but allows for mutually co-located powerful particulars. Certain definite tropes are parts of substance *i* due to their rigid dependence on the nuclear tropes of *i*. Moreover, each constituent trope *t* of powerful particular *i* is necessarily a part of a trope aggregate (a *c-bundle* or *n-bundle*) determining its spatio-temporal location. These trope aggregates form individuals that instantiate the basic spatio-temporal relations. Since they are necessarily co-located with substance *i* at each moment of their existence, a constituent trope of *i* is also necessarily co-located with *i* at each moment of its existence. However, as a trope is a part of a powerful particular by virtue of its rigid dependence on the nuclear tropes, the co-location with a substance is not sufficient for a trope being a part of the substance. Consequently, the SNT allows for distinct but mutually co-located powerful particulars.

Second, the SNT specifies the temporal and counterfactual identity conditions of powerful particulars. The *n-bundle* of powerful particular *i* and the nuclear tropes constituting the *n-bundle* are parts of *i* at each moment of *i*'s existence - the nuclear tropes are necessarily compresent with *i*. Substance *i* exists only if its nuclear tropes exist and when the nuclear tropes exist. Thus, the nuclear tropes determine the counterfactual and the temporal identity conditions of powerful particular *i*.

Finally, according to the SNT, all powerful particulars are necessarily instances of natural kinds. They necessarily have some set of distinct causal powers. The nuclear tropes determine the primary kind K to which powerful particular *i* belongs. Since each powerful particular *i* must have nuclear tropes, *i* must belong to some definite primary kind K. As a member of K, substance *i* necessarily possesses tropes belonging to certain distinct determinable kinds. As dispositional properties these property tropes furnish powerful particular *i* with certain distinct causal powers. In order to accommodate the possibility of kind change, the SNT can introduce naturally unified contingent tropes to determine the membership of a simple substance in a (possible) secondary (or contingent) natural kind.

Thus, the nuclear tropes collect the trope constituents of a powerful particular and determine its necessary intrinsic features. The SNT rejects *primitive substances* and *substrata* as redundant postulations. Moreover, as a *trope nominalist* position, the SNT rejects substantial kind universals. Simple substance *i* is a member of certain primary kind K because it possesses nuclear tropes that belong to certain determinate kinds. It might be a member of the secondary (i.e., contingent) natural kind because it possesses, in addition to the nuclear tropes, naturally unified contingent tropes belonging to certain further determinate kinds. Thus, as a by-product of the trope bundle theory of power particulars, the SNT specifies the structures of tropes determining certain central kind identities between powerful particulars, namely, the kind identities between the powerful particulars belonging to the most specific (or nearly the most specific) natural kinds.[66]

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[66] For comments on the earlier drafts, I would like to thank the editors and five referees for dialectica as well as Damiano Costa, Jani Hakkarainen, Antti Keskinen, Philipp Keller, Olli Koistinen, Tapio Korte, E.J. Lowe, Fraser MacBride, Arto Repo, Gonzalo Rodriguez-Pereyra, Peter Simons, Valtteri Viljanen, and audiences in the University of Geneva, University of Tampere and University of Turku.

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