PROCESS-BASED ENTITIES ARE RELATIONAL STRUCTURES. From Whitehead to Structuralism

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Abstract: The aim of this work is to argue for the idea that processes and process-based entities are to be modelled

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as *relational structures*. Relational structures are genuine structures, namely entities not committed to the existence of basic objects. My argument moves from the analysis of Whitehead's original insight about process-based entities that, despite some residual of substance metaphysics, has the merit of grounding the intrinsic *dynamism* of reality on the holistic and relational characters of process-based entities. The current model of process ontology requires genuine *emergence* and this, in turn, requires organizations, i.e., emergence *in* organizations. Another view about processes rely on a *structural* specification of processes. I suggest that the two views can be made compatible by the help of a specific sort of structures, namely relational structures. The appeal to the mathematical theory of genuine structures, category theory, reveals the formal plausibility of this convergence. According to this formal approach, genuine structures are essentially dynamic entities for they are relational, namely, as well as organizations, they are not existentially committed to particulars.

1 Introduction

Process ontology is that realist naturalism that strongly opposes to the view traditionally called *substance metaphysics*.[1] Substance metaphysics is articulated in a

[1] I am a little ambiguous in the use of the term "ontology" and "metaphysics", but the naturalist spirit of the philosophy of processes pushed me in this direction. I lean on Cocchiarella's [18, p. 2] when he writes that the Metaphysics itself has usually been divided into ontology and cosmology, where

- Ontology = the study of being as such, and whose goal is to discover the laws connecting the categories of entities and the entities in them with one another;
- Cosmology = the study of the physical universe at large, and whose goal is to discover by observation and ex-

variety of interpretations but it is ultimately based on the assumption that (A1) exists an ultimate and *fixed* bottom domain of mutually *isolated* substance(s) or object(s) with their own characteristics. From the formal standpoint this view is realized by any theory that assumes (A2) the existential commitment to extensions or to objects in isolation.[2] Sometimes interpreted as bits of matter, i.e., atoms (materialism), sometimes more generically as particulars, i.e., individuals or tropes (nominalism), such substances are thought as the metaphysical substratum of extrinsic or external properties and relations, according to a more or less implicit object-property (or substance-attribute) *dualism*. Such a dualism is mirrored in the specific formal language employed to represent and regiment the theory: the language of predicate logic.

On the contrary, process ontology consists in the attempt to give a dynamic account of being and, for this reason, the primary focus is to provide an explication of the process of *constitution* of all entities. In this sense, clearly, process ontology cannot suppose or must not be committed to the existence of a basic do-

periment the laws connecting the cosmological categories (causality, space-time ... etc.) and their constituents with one another.

But in the case of theories dealing with the very process of constitution of entities, it seems to me that the distinction between ontology and cosmology (and therefore that between ontology and metaphysics) is even more blurred, to a certain extent almost systematically.

[2]The distinction between the singular and the plural form depends respectively on the pluralist or monist character of the substance metaphysics.

main of particulars. After all, the purpose is exactly that of explaining the constitution and construction of entities of whatever sort. So, process ontology claims that reality is essentially process-based, namely that entities are *dynamic* in the sense of coming into existence in virtue of processes.

My first concern (Sect. 2) is that of analyse the fundamental character of process-based entities according to Whitehead's original insight.[3] Here I focus on the way the dynamism of process-based entities is articulated and that spots these entities in sharp opposition with substances: as a consequence of the process of their constitution, entities are intrinsically *relational* or depending on their environment and *holistic* or in some sense emergent. Nonetheless, Whitehead's proposal conveys of some substance metaphysics residual that forces him to interpret entities as particulars (events). This point will be made clear too.

However, of great interest is the fact that Whitehead's dynamic analysis of reality solicits the employment of some genuine introduction of novelty as essential and this echoes genuine *emergence*. So, Sect. 3 is devoted to evaluate the plausibility of such a notion. This depends, I argue, on two strictly related issues, one deeply *metaphysical* and a second essentially

[3] In contemporary times, process ontology finds its first main thinker in A. N. Whitehead and his philosophical works, especially those of 1920 and of 1929, [50] and [49] respectively. In particular, Whitehead's philosophical masterpiece, *Process and Reality. An essay in cosmology*, is a series of lectures, the Gifford lectures given in 1927-28 and later revised and published in 1929, where the process account has been explicitly and systematically deepened.

formal: the first consists in making Kim's argument against emergence as harmless, while the second consists in the acknowledgment of the formal limitations of a set-theoretic model of emergence and of the related notion of *supervenience*. Both are grounded on the (implicit) acceptance of the characteristic assumption of substance metaphysics (A1) and (A2) respectively.

As a consequence, in Sect. 4, I discuss the compatibility of the two best candidates for modelling dynamic entities as emergent and essentially relational: *organizations* and *structures*. The idea is to make organizations and structures somehow compatible. I argue that the structural setting and the organizational model formally converges by means of a specific kind of structures, *relational structures*. The appeal to the formal theory of structures, category theory, makes clear that genuine structures are essentially dynamic entities and that in particular they match with organizations not just for a matter of formal stipulation.

I conclude with some words about the empirical falsification of the assumptions of substance metaphysics (A1-A2) that plays a relevant role for grounding the proposed model or process-based entities.

2 Whitehead and the dynamic constitution of entities

Process ontology seems to provide a very natural account of becoming, not only because based on the premise that *being is dynamic*, but especially for "the dynamic nature of being should be the primary focus

of any comprehensive philosophical account of physical reality" [44]. Whitehead's great philosophical contribution consists exactly in not limiting his analysis to the simple evidence of the becoming of nature.[4] In this section I first discuss the naturalist origin of Whitehead's approach and, then, the characterisation of the dynamic constitution of process-based entities. Lastly I discuss some criticism of particularism addressed to Whitehead's proposal.

2.1 The naturalist origins of process ontology

The metaphysical proposal based on processes was started and explicitly developed in contemporary times by A. N. Whitehead in *Process and Reality* [49], who was inspired by a genuine naturalism, as it is widely known. Whitehead's view on processes is due to the strong dependence on the complete reassessment of the hypotheses of modern science that occurred between the end of the XIX century and the first half of the XX. At the heart of the paradigm shift from substances to processes there is the challenge to scientific materialism and mechanicism, today called otherwise *physicalism* [45],[5] implicit in the articulation of modern science,

[4]The claim that *becoming is illusory* is obviously linked to the notion of *reversibility* (even of time) and in opposition to a properly evolutionary view (see [10]). Reversibility, in turn, is linked to the notion of *reducibility* of an entity (property) to more fundamental one(s) (previously existing), as the *mechanistic* or static conceptions affirm, and in opposition to *British emergentism*.

[5]"Physicalism is the thesis that everything is physical, or as contemporary philosophers sometimes put it, that everything supervenes on the physical. [...]. Indeed, on one strand to contemporary usage, the terms 'physicalism' and 'materialism' are

i.e. the Galileian-Newtonian physics. The ontological reference of this physics consists in the existence of material substances (atoms or bits of matter) as immersed in the mechanical and inert vacuum (in isolation) and even collectively governed by statistical laws (causal regularities).

At the basis of Whitehead's critical revision is the thesis according to which material substances are not all that there is: that disjoint or isolated substances or material objects are just mere *abstractions* that neglect the involvement of the physical relations among such material constituents in the characterisation of any concrete entity or physical system. In particular, to illuminate Whitehead's metaphysical reflections was the scientific revolution represented by formulation of the Electro-magnetic Theory earlier, and the Quantum Theory later. It is the former that puts as first the emphasis on the relational and holistic notion of *field of force*(s) as ontologically basic – what essentially characterizes electro-magnetic phenomena is that while they could be related to specific vector quantities in each specific point of space, at the same time "at all points" they express "one definite physical fact" [48, p. 29], i.e., the field of electro-magnetic forces. With the latter, instead, the notion of *quanta of energy* entered in the physical vocabulary: material particles, with the rise of Quantum Mechanics (QM), became quanta of their relative field.[6]

interchangeable" [45].

[6]QM is historically the first Quantum Theory but not the only. A successive one, Quantum Field Theory, makes Quantum Theory compatible with Special Relativity.

Still at that time, with the rise of the General Theory of Relativity (GR) of 1916 and its successive empirical confirmation in 1919, space-time also became apparently something similar to a field.[7] Thus, it was exactly in that effervescent period that the possibility of a general interpretation in terms of processes of physical systems of all domains – from the micro-world of atomic and sub-atomic particles, to the cosmic-world of galaxies – became conceptually plausible and desirable: physical systems as fields are *relational wholes*, although concretely scattered throughout the cosmos. The materialist view became, then, superficial and unsound in Whitehead's eyes, exactly because it gives to material substances of any scale an *absolute* interpretation,[8] abstracting from the (physical) relations and connections in which they are actually immersed.

All this led Whitehead to strongly criticize that ontological position called *dualism*. Indeed, as a mere consequence of that abstraction, physicalism is inevitably forced to interpret the relations among material substances in two alternative ways: either ontologically, as belonging to a second, but irreducible, primitive domain;[9] or epistemically, namely making them ontologically irrelevant despite their opposition to individual substances, resulting that they have epiphe-

[7]Since space-time geometry and its metric is no more external to the material world and fixed but, rather, it varies depending directly on the distribution of matter/mass.

[8]Indeed, the adjective "absolute" comes from the latin "absolútum" that means "isolated", "ties-free". From this, it comes the idea that substances are absolutely individuable or univocally characterisable.

[9]Think of, for example, Descartes' dualism.

nomenal status.[10] Both alternatives suppose an irremediable *formal* dualism ultimately encoded in the term-predicate distinction characterising the language of classical predicate logic. This language, characteristic of set-theoretic or extensional formal theories, is still nowadays widely applied for the formal modelling and representation of ontological theories, process ontologies included but with very poor and misleading results.

The field of relations in which a particle is immersed, therefore, was the naturalistic basis for the original development of Whiteheadian thesis of reality as a dynamic process and for his strong opposition to the modern substance-attribute dualism, left implicit at the mere level of language by materialism and nominalist metaphysics.

2.2 Processes and the dynamic constitution of entities

The essential idea of Whitehead's *Process and Reality* is to provide the basis for a dynamic explication and constitution of all natural entities. These are often called "actual occasions" or "actual entities", and are conceived as new ontological units which allegedly come into existence by means of the integration of the growing together of the available ontological amount of the Universe at each (evolution) state. So, actual entities construe, repeat, and reinforce certain patterns called "eternal objects" and each one becomes itself an

[10]Think of, for example, empiricism or to nominalist ontologies: the classical versions based on individuals as well as the variant based on trope.

eternal object that enters in the formation of further new actual occasions, and so forth. This is an iterative-like procedure of novelty introduction and of entity formation, from given entities. In this context, the interpretation of actual occasions cannot be univocal or fixed: the term "actual entity" ranges from sub-atomic particles to human persons; sometimes substituted for "atom" in the extended meaning of being an indivisible entity, because holistic.

Whitehead's motto is *becoming is the constitution of being* (see [49, p. 23]): the way something *becomes* is the way something *is*. This means, on the one side, that the existence of entities is secondary or subordinate to the process of their constitution, in the sense that their actual existence is understood in terms of their constitution; while, on the other side, even that any actual entity is always in disposition to become something else, that every actual entity is always *a potential* for the formation and integration of a further entity.[11] Each entity is, thus, as system of correlations with other entities, what Whitehead calls a "phase" (perhaps a pattern), and the passage from a given phase to an increased one is what underlies the asymmetrical (entropic) evolution of nature.

That all actual entities are generated and obtained by means of a *process of entity constitution* is clear. What is not clear is how the process is performed. Such a process is twofold, namely articulated as the

[11] In analogy with the Aristotelian ontology (see [27]), the process-based constitution of dynamic and contingent entities passes through the reciprocal (dual) correlation of act and potency (see [49, p. 40]).

interaction of the (sub-)process of *concrescence*,[12] and the process of *transition*. By means of *concrescence* "many things acquire an individual unity in a certain relegation of each item of the many to its subordination in the constitution of the novel one" [49, pp. 211] while by the *transition* it is explained the passage "from phase to phase, each phase being the real basis from which its successor proceeds toward the completion of the singular novel thing" [49, pp. 215]. Thus, processes are not entities at all, at least in the sense of substances, but, rather, according to this picture they seem to be acts, oriented actions, operations. The process of concrescence may be seen as an *act* of integration or structural unification of many isolated entities. It is the operation that makes any concrete entity as a *novel one*, a holistic process. Whitehead is clear when he attributes to the concrescent entity the introduction of some relation of subordination defined over the whole one and its many constituents.[13] The process of concrescence, then, takes a group of entities and makes them as parts of the novel one by means of their integration (condensation). The process of transition, instead, may be seen as the *act* or operation that immerses each new actual entity among that group of

[12] Whose etymological root is the Latin intransitive verb (3rd conjugation) concresco, concrescis, concrevi, concretum, concrescĕre: 1. to grow together, to form; 2. to condense, to congeal, to solidify, to coagulate, to harden, to stiffen; 3. (c. + ablative case, c. + *ex* or *de* + ablative case:) be composed of.

[13] The intuition seems to be the following: once the novel entity is formed, its constitutive parts are no longer existing on their own but are just parts of the new existing one because although they are formally identifiable in the whole as separable entities they are no longer separate entities.

many items that took part in the constitution of the former one. The transitional process is essential for it gives and creates the basis for the constitution of any further concrescent. By transition, indeed, any new entity is always made available to (is in disposition for) the formation of a new and further entity.

The abandon of the rigid and static view of beings as substances is condensed in the *Reformed Subjectivist Principle* (RSP) here articulated, again, as the two sides of the same coin [49, pp. 166-167]:

(RSP_a) "[I]t belongs to the nature of a 'being' that it is a potential for every 'becoming"';

(RSP_b) "The way in which one actual entity is qualified by other actual entities is the 'experience' of the actual world enjoyed by that actual entity, as subject."

Interestingly, the terms 'experience' and 'subject' do not seem to bring an epistemic interpretation. Rather, actual entities are the ontological subjects of the experience (influence) of that relevant part of the universe that contributes to their own constitution. In this sense RSP is not only an expression of the intrinsic dynamism of nature (RSP_a), but it is even an expression of the intrinsic relational character of all entities (RSP_b) according to which nothing is *per sé*, but each entity is constitutively in relation with all things [49, pp. 148]. Not incidentally, Whitehead refers to RSP as "merely an alternative statement of the principle of relativity" [49, pp. 166].

So, Whitehead has the merit of revealing how *holism* and *relationalism* are concepts strongly interwoven in the sense of being dynamically convergent toward the constitution of entities. Process-based entities are dynamic entities exactly in the sense of being holistic (concrescent) on the one side, and relational on the other, for their intrinsic constitution. Namely, on the one side, any entity gets its own *internal* and concrescent (holistic) organization: Whitehead writes that "[t]he concrescence of each individual actual entity is *internally* determined" [49, p. 27] while, on the other, once formed, the individual actual entity is always immersed in what was the previous ontological phase (domain), that plays now the role of an 'external' environment 'experienced' by that entity as different subject.

2.3 Criticisms to Whitehead's account

Notwithstanding the emphasis on the relational and holistic (concrescent) character of process-based entities, Whitehead's proposal seems to present a great limitation which would apparently contrast, if not actually contradict, the dynamic position outlined so far. The common impression is that such a limitation, in case not being recognised, stressed, isolated and then eliminated, risks to negatively influence the contribution that process philosophy can in principle give to scientific research and, consequently, to its own self-understanding as a naturalist ontology.

Indeed, many current accounts of process ontology diverge considerably from Whitehead's. An example is Seibt's *General Process Theory* (GPT) [43]. Seibt

insists in specifying GPT as *non-Whiteheadian*. The core of the divergence is the way process-based entities are conceived. Accordingly, they are thought as *general* entities precisely because they are "non-particular individuals", to mention Seibt's expression. She complains of Whitehead's account for it reveals a strong commitment to a certain *particularism*, more or less explicit, since his work on the concept of nature [50]: Whitehead pends towards an events-like interpretation of entities. Campbell, along the same lines of thought, confirms Seibt's complaint: "being events, they are still particulars" [15, p. 63]. The consequences of the divergence are so profound that the criteria of individuation of process-based entities can no longer depend on some empirical spatio-temporal factors and/or, formally, on the classic theory of individuality (of particular individuals) encoded by the Leibniz Law [25]. Rather, Seibt binds the individuation of process-based entities on *what they do* or on their specific *operational behaviour*:

> We can replace the particularist conception of individuals with a view of individuality that focuses not on location but on 'specificity-in-functioning' in the widest sense of 'functioning'. [43, p. 484]

An analogous point has been raised by Rescher. Rescher stresses that it is fundamental to acknowledge that "processes have patterns and periodicities that render them in principle repeatable" [40, p. 10], both in space (ubiquitous) and in time (diachronic).

Rescher is addressing the attention to the "commonality" of a "structure of some sort" as what characterises processes-based entities in a way that makes them independent from the conditions of their concreteness and, at once, not in conflict with these [40, pp. 10-11]. Rescher's *structural* account of processes is fairly consistent with Seibt's and will be of my interest later. Another approach to processes that is worth to mention is Campbell's and Bickhard's [6, 7, 15, 16]. They provide an *organizational* reading of processes and process-based entities. Their view, in particular, comes from their analysis of emergence as a recognized essential property of process-based entities: accordingly, the very locus of emergence are organizations. The reason is that organizations, as such, lack of a base of particulars *from* which the new wholes emerges, i.e., an emergence base.[14] And, of course, organizations are structural entities.

Of a completely different opinion is E. Zemach, when claims that both events and processes are characterized as particulars or entities that are subject of some spatio-temporal characterisation [51]. Accordingly, both events and processes are bound in time dimension in the sense that they spread their several parts in the flowing time. Their difference consists just in their relation to space: the former are bound in space too, while processes are spatially located as wholes. Interesting, Zemach claims that processes are "often confused with" events [51, p. 236] and maybe this can be

[14]The next section is devoted to the metaphysical concept of emergence and the related notion of supervenience.

the main consequences of Whitehead's particularist interpretation.[15]

However, it seems out of discussion that Whitehead's interpretation of process-based entities entails a certain residual of substance metaphysics. Campbell refers Whitehead's inability to keep substance metaphysics at a distance, as due to a certain correlation between the *actual* mode of existence of concrete entities and his adherence to the atomist model: "he believed that the discrete character of the new quantum mechanics of his day did require processes to have an atomic constitution" [14, p. 458, fn. 6]. The culprit would be Whitehead's "insisting that what is actual is atomic" [15, p. 3] and, indeed, Whitehead commitment to atomism is declared: "the ultimate metaphysical truth is atomism" [49, p. 35]. Nonetheless, at least to some extent, Whitehead seems to be aware of the apparent contradiction between the atomist model and the process account. In fact, he tries to resolve the contrast in many occasions like when he claims that "atomism does not exclude complexity and universal relativity" [49, p. 36], suggesting to interpret any atom as "a system of all things" [49, p. 36].

Notwithstanding his compatibilist attempt, the point is to understand whether such a residual of particularism affects a consistent account of the introduction

[15] Actually Zemach distinguishes as the fourth ontology one made of pure continuants (PCs), namely entities that are independent with respect to specific spatio-temporal characterisations. PCs, then, are called *types* and – he adds – they were considered to be universal or abstract or formal entities (see [51, pp. 239-240]). This would made types to be very similar to our processes.

of novelty by concrescence (emergence). The culprit seems to be the atomist assumption of a bottom base of atoms to which the process of concrescence is applied, and that makes the concrescent entity to come *from* a concrescence base that is easily definable in terms of some extension, namely in terms of a fixed collection of basic objects. Whitehead articulates the most general setting of the process of entity constitution, the *The Ultimate Metaphysical Principle* (UMP) [49, p. 21], in terms the following three conditions:

(i) The process of concrescence applies to a group of "disjunctive 'many"' objects in mutual isolation, now the *concrescence base*;

(ii) The process of concrescence gives back a "novel entity" as the unitary "synthesis" or 'the togetherness of the 'many"', namely a system of objects essentially in some relation, the concrescent entity;

(iii) The concrescent entity is "other" and further than the many of the concrescence base but, once formed, it is included among them at the same ontological level: "The many become one, and are increased by one"; this is the process of transition.

MPU is thought to explain how "the passage from disjunction to conjunction" is performed by means of processes but, however, there are still present some theoretical problems with this account. On the one side, it seems that the "passage to conjunction" in-

volves the introduction of some relation or holistic characterisation in order to gather together, in the new whole, the group of many atoms (in mutual isolation). But relations or holistic characterisations among the members of the concrescence base are not and cannot be at the same level of the members of the base, for they introduce some novelty in that base. This commitment to the concrescence base seems to reveal a certain dualism between the concrescence base and the concrescent entity – at least a formal dualism between terms for objects and predicates for relations or sets or collection of some sort – and it needs to be resolved in some way. On the other side, this dualism seems to be "fooled", to say, by the process of transition that expands iteratively the original domain – point (iii). The idea seems to be that, despite the formal dualism base-concrescent, the ontology is a one-level or flat ontology, namely one given in a first-order language and whose typical example is nominalism. But problems with nominalism are widely known [23] and, moreover, nominalism is in explicit contrast with the process account, inasmuch it is the formal counterpart of atomism.

3 Beyond Whitehead

The introduction of novelties is a fundamental aspect of process ontology, an inherent expression of the dynamism of being and of the evolutionary nature since Whitehead's formulation. There are no doubts about the genuine ontological role of the introduction of nov-

elty: each concrescent entity is in some ontological sense *irreducible* to its many constituents, because it comes into existence as a new further whole *from* them and, then, enters in the ontological constitution of the successive one.

Displayed in these terms, the concept of concrescence echoes the more widespread concept of genuine *emergence*: emergent systems are those (physical) systems that come into existence and display new causal (physical) powers, namely specific of the emergent.[16] Another concept, often related to that of emergence, is that of *supervenience*, and supervenience is usually assumed as being involved when to explain emergence in addition to the notion of (epistemic) *irreducibility*. The appeal to supervenience is used to make inoffensive the ontological commitment to emergents, inasmuch it conveys a position of non-dualism.[17] In this section I articulate the current debate about these notions in rather analytic fashion.

3.1 Emergence form and the exclusion argument

In recent times, J. Kim provided a clearer account of the notion of emergence [32, p. 21] to which he refers as emergence of *higher-level properties*, i.e., prop-

[16]The philosophical debate on emergence is very actual and fruitful in all fields of research, from fundamental physics to neuroscience, from philosophy of nature to philosophy of mind [5, 30], more recently [4, 17, 20, 34, 19, 37].

[17]The specific role played by the relation of supervenience was that to explain the emergent collective (holistic) behaviors of more complex (collective) systems, without the appeal or commitment to such holistic properties (or universals). See [47] for a neutral taxonomy of many views on emergence.

erties characterizing a *higher-level* system, *from* the properties of some *lower-level* system that determines the ontological basis of the former. In a latter work ([33]) Kim provides an argument against genuine emergence, sometimes called the *exclusion argument* and some others the *preemption argument*. The argument is supposed to prove that emergent systems (properties) cannot have efficacious causal powers further than those of their base, on pain of the violation of the causal closure of the physical domain, namely the idea that emergents do not belong to some further ontological and physical realm.[18] As a consequence of this argument, Kim is inclined to weaken the idea of genuine emergence from the outset, preventing any positive account of the emergence of (physical) causal powers, providing a negative articulation of emergence in terms of *supervenience* and *irreducibility*: "They tell us what emergence is not" [33, p. 557]. The alleged robustness of the arguments together with his (reductive) naturalism lead Kim to conclude that two are the "important" and "unresolved" items that "remain on the emergentists' agenda":[19]

[18]The original thesis about emergence was by British Emergentism and accounted for emergents as irreducible and causally efficacious. Actually the term "emergence" was introduced prior to the British Emergentists. This picture is genuinely committed to emergents as ontologically irreducible to the physical realm in the sense that the physical realm does not saturate the ontology. Emergentism, on the contrary, has the burden to prove that emergents are physically efficacious, namely is committed to the idea that the physical realm saturate the ontology and that emergents are physically efficacious.

[19]Here it is British Emergentism. Up until his 1998 book [31], Kim assumed that emergentism is British Emerentism.

> The first is to give emergence a robust positive characterization that goes beyond supervenience and irreducibility. The second is to come face to face with the problem of downward causation.[20] [33, p. 559]

Emergence and *downward causation* (*DC*) are so strictly related that the exclusion argument tackles genuine emergence in the extent it provides a counter model of *DC*. *DC* supposedly consists in a peculiar sort of causal relation, from a holistic or higher-level or macro-system to one or more of lower-level or micro-system(s) called *basal condition*(s); *DC* is an effective desiderata of all emergent systems, for it is the property of macro-systems to have causal powers on the basal condition in a way that enables the macro to physically and ontologically *control* the micro – i.e., (self-)controlling or self-organised systems.[21]

Before going to the argument, let me clarify the reductive spirit of Kim's negative approach to emergence. Regarding supervenience, this relation is thought as that component of emergence that provides the ontological dependence of the emergent from its base (see [33, p. 550, changed notation]):

Proposition 3.1. *Supervenience/determination. A*

[20] Downward causation is criteria for genuine emergence, according to Kim. Kim is correct insofar as 'downward' can be made sense of. But the vertical hierarchy that this calls upon is not necessarily manifest. This is, it is not a metaphysical a priori articulation. For this reason, many thinkers still appeal to supervenience.

[21] Downward causation is not necessarily internal to the system's hierarchical and unfolding levels, as the next diagram stresses. See the original introduction of the term in [11, 12].

macro-property M supervenes to (or is determined by) micro-properties or basal conditions $B_1, \ldots, B_n$ ($n \in \mathbb{N}$) if and only if whenever anything x has $B_1, ..., B_n$, x necessarily has M.

In addition, the emergent is ontologically dependent on its base in a univocal way, for supervenience works as a *covariant* relation between the base and the emergent [33, p. 550, changed notation]:

Proposition 3.2. *Supervenience. If a property M emerges from properties $B_1, ..., B_n$ then M supervenes on $B_1, ..., B_n$. That is to say, systems that are alike in respect to basal conditions $B_1, ...B_n$ must be alike with respect to their emergent properties.*[22]

Nothing new: this is the idea that supervenient entities are ontologically dependent on and formally determined by their basal conditions. However, there is an evident mismatch in the way supervenience determines "the behaviour of the whole" all along Kim's work of 2006 [33]. On the one hand, Kim tells us that the emergent property supervenes on properties *and* "structural relationships characterising its components" while, on the other hand, emergence and supervenience are clearly defined as relations *from/on* non-structural entities. The formal account of basal conditions in the propositions above is, rather, *just* in terms of the several constituents x and their relative properties $B_i, ..., B_j$. As a consequence, the bottom

[22]Supervenience is usually, but not always, defined in the other direction: M is supervenient on B if there can be no difference in M without there being difference in B.

level results as made of mere aggregates and not as arranged in *one* system with its own ontological status [16].[23] The reductive character of Kim's approach becomes fully explicit when the other component of emergence, that of "ireducibility", is relegated to the epistemic realm:

> Both emergentism and reductionism [...] agree in holding that "the behavior of the whole" is determined by – that is, it supervenes on – the properties and structural relationships characterizing its components. Where they differ [...] concerns the in-principle deducibility – presumably, logical/conceptual deducibility – of the properties of the whole from facts at its basal level. [33, p. 552][24]

Kim interprets as "logical/conceptual" the in-principle deducibility as a separate and non-ontological issue. This move makes plausible to distinguish between emergence and supervenience, according to the idea that it is possible to make ontologically irrelevant the emergents. This idea clearly supposes and reveals some

[23] Kim, along his works, was not consistent about this. Earlier, for example in his 1998 work, relations were in the base, but in the 1998 book they are removed from "micro" base. The macro-/micro- distinction in 1998 is stated in different terms and in particular, is based on a different concept of emergence base.

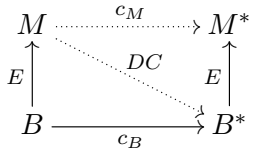
[24] Actually this should contrast the original British Emergentism with "reductionism". Kim's move renders (by semantic stipulation) what might be called 'organizational' emergentism as reductionism. But this is at least a misleading move, and is arguably false when the problems with supervenience are understood. Early Kim took emergentism to be equivalent to British emergentism (e.g., see [31]).

empiricist bias.[25]

So, Kim's intentions are in some way declared. Indeed, the formal model of basal condition(s) depends strongly on Kim's materialist view. A few pages earlier, Kim sketches the intuitive idea of an emergent property as one that appears when "a purely physical system [...] reaches a certain degree of complexity in its structural organization" [33, p. 548]. The understanding of Kim's words depends on the notion of *pure physical system* (PPS) he provides (see [33, p. 548]):

(PPS) A physical system is *pure* if, and only if, it is composed exclusively of bits of matter.[26]

Accordingly, since any collective macro-property is, from the ontological standpoint, *completely determined* by exactly the basal conditions from which it supervenes and that are modelled on PPS, the ontological acceptance of DC is irremediably affected. The following diagram represents Kim's argument:



[25] With respect, at least, to the conceptual import of logic (a priori) and the truth-preserving characterisation of deduction (non-ampliative rules).

[26] Notice that no mention of some relation among bits of matter is essential for the definition of what a physical system is. However, the introduction of relations in the emergence base poses a stronger problem, the so called *regularity argument*. See [8] for a clear exposition.

where E is the supervenience relation, c_M, c_B are causal relations at macro- and at basal-level respectively. The argument against the physical plausibility of DC – as the relation from M to B^* – and, then, of c_M[27] – dotted in the diagram – proceeds from two (additive) assumptions:

(PCC) *Principle of Causal Closure*: a physical system can be physically caused only by a (different) physical system;

(PCE) *Principle of Causal Exclusion*: one and one only is the sufficient cause of any physical event.

As the argument goes, it is the interplay between PCC and PCE only that forbids the physical and ontological plausibility of DC and the point is that B^* cannot have B and M as two distinct causes. But, as R. Campbell's and M. Bickhard's works [16] points out, rather than providing a counter model of the plausibility of DC, Kim's argument simply shows that DC is *a priori* intractable from any position based on the (materialist) assumption of PPS.[28] In fact, the argument is based on a *petitio principiis*: Kim is here [33] assuming from the outset that M is not a physical system, because organizations of whatever complexity

[27] Because any macro-system has its own basal condition(s) by definition and, thus, the passage from M to M^* (c_M) supposes DC but B^* supposes in turns c_B: therefore, c_M supposes necessarily both c_B and DC.

[28] In addition Campbell and Bickhard argue that Kim's argument is unsound for the materialist premise PPS is false; while R. Corry (in [21]) argues for its invalidity.

does not belong to the physical realm, according to PPS. The epistemic interpretation of the irreducibility of emergents is forced from the idea that emergents are not ontologically relevant because the physical realm saturates the ontology. It is (formally) obvious, then, that whatever interaction between M and B^* there may be, it cannot be ontologically relevant. Therefore, instead of providing a counter model of DC, the exclusion argument says only that DC is ontologically and physically implausible for it is not formally defined in physical terms. Contrary to what Kim believes then, as a matter of logic, it is the interplay of both PCC and PCE with PPS that prevents the ontological interpretation of DC and of emergence.[29] So, what makes DC causally ineffective is exactly the materialist assumption (A1) encoded by PPS and that corresponds to the existential commitment to a bottom domain of particulars on which all causality lies (A2) – i.e., Kim's physicalism.

On this basis any treatment of genuine emergence is problematic and prevented from the outset and something analogous holds with respect to Whitehead's process of concrescence. Even concrescence is defined from

[29]In his earlier positions [31, pp. 117-118], things are completely different. There, relations are taken to be 'part of' the emergence-base, but at the cost of having supervenience as a "rather obvious and unintersting notion", that of identity between the mereological configurations of the emergence-base and its own micro-structure. As a consequence, supervenience is now blocked at the micro-level at the emergent base and does not contribute to the emergence of the macro-structure. Thus Kim's 2006 idea that supervenience is always involved in emergence processes does not hold together with the determination thesis.

a basal level of many (disjoint) atoms, whose suitable model is the same of PPS. Atoms (bit of matter) are disjoint in the sense that are immersed in the mechanical vacuum that, by its own nature, prevents any ontological interpretation of relations and interactions amongst the members of the base – being the mechanical vacuum inert and physically neutral. But the process of concrescence correlates the concrescence base with an entitiy, i.e., the concrescent, that is in some non-epistemic sense irreducible to the base. Indeed, the idea that each concrescent entity is immersed, by transition, into the same level of the members of its concrescence base is equivalent to saying that concrescent entities perform causally efficacious powers in the sense of *DC*. This equivalence holds because any concrescent entity enters in the ontological constitution of the successive concrescents as element of their base. But, according to the atomistic premise that commits Whitehead to PPS, the concrescent entities cannot be causally efficacious from the outset.

Certainly PPS, and the dry materialism supposed there, affect Kim's attempt of understanding *DC* and, then, emergence of genuine new causal powers. But the rationale of Kim's failure comes from a stronger issue, namely a specific formal problem depending on the tacit formal dualism typical of the background substance framework.

3.2 The formal limitation of an extensional model of supervenience

Kim's belief on the validity of the exclusion argument seemed to justify the appeal to supervenience according to the belief that this is a safer relation inasmuch as it does not commit the ontology to higher-level entities: "supervenient additions to ontology are pseudo additions" [13]. So, supervenience enters as a common assumption among all varieties of non-dualist ontologies (like empiricism, atomism, trope-nominalism etc.). However, despite that common belief, a theory that appeals to supervenience presents a problem that, not incidentally, originates from the same assumption that makes the exclusion argument a *petitio principiis*, namely the assumption of a bottom level of entities, the emergence or supervenience base.

Supervenience, as involved in emergence, is formally defined as a relation from a bottom level to higher-levels, despite it remains at the basal level, rejecting any ontological commitment to those higher-levels. Nonetheless, the concept of supervenience share the formal distinction among levels that is supposed by the standard approach to emergence. Indeed, when regimented in a formal theory whose language formally preserves that dualism, supervenience inevitably implies a semantics that discharges the higher-level commitment. This poses a particularly relevant problem: how to map the holistic higher-levels ontology to the bottom one starting from a second-order language nominalistically interpreted (see [23] for a dis-

cussion). Indeed, at the level of its syntax, such a theory cannot be regimented as first-order theory, i.e., one regimented in first-order predicate language (L_I). Campbell and Bichkard write:

> Since [emergent configurations among basic entities] are holistic, *configurations are properties of a set of constituents*, as we said above - not of those constituents themselves, nor of any aggregate of them. Ever since Bertrand Russell wrote his famous letter to Gottlob Frege in 1902, the logical perils of regarding a set and its members as being on the same level have been clear. *It follows that configurations and their constituents cannot coherently be described in the same vocabulary.* [...] But it also follows that *the properties of sets which are generated by their configuration cannot be treated as on a par with the properties of their constituents.* [...]. Likewise, a set of physical entities is not a physical entity, and physical properties can neither be affirmed nor denied of a set of physical entities. [16, pp. 47-48; italics added]

Simply, the language in which to regiment a theory of supervenience – that includes the expression "M supervenes on B_i" (i.e., "$S(M, B_i)$") – cannot include expressions of a unique order only, on pain of formal contradiction. The term M and, obviously, the predicate S are to be at least of second-order (or $n + 1$-order, if

B is of order $n \in \mathbb{N}$). But now, once assumed the level distinction, the hard task is to provide a nominalist semantics to discharge the higher-order commitment (see [23]). The analogy between Kim's formal treatment of supervenience relation and the membership relation $\in$ of set theory and the likes (ST) is ultimately justified by the employment of the language of predicate logic that is forced by the materialist or substance metaphysics assumptions (A1) and (A2).

As Seibt sanely stresses, the techniques of formal modelling "supported by 'standard readings' of predicate logic" follows a theoretical bias that "operates a problematic restriction in the solution space of ontological theories, rendering many new questions arising from contemporary science *ab initio* as 'absurd' and thus inaccessible from within mainstream ontology." [43, p. 481]. This holds for a theory of emergence when defined as *emergence from* an emergence base – think, for example, of the exclusion argument – as well as for a theory of *supervenience on* that base. In the specific case of supervenience, this absurdity, actually, corresponds to an insurmountable and widely acknowledged formal problem: the idea that it is possible to consistently define supervenience in a homogeneous language, i.e., within L_I. In essence, Campbell and Bickhard, pointed out (i) that Kim's analysis of emergence and supervenience supposes a naive ST model of the ontology forced by (A2) and, on these set-theoretic basis, (ii) both relations are metaphysically (emergence) and formally (supervenience) problematic or, worse, intractable (*ab initio*).

From the formal standpoint, the assumption (A2) of the existential commitment to a bottom level of objects in isolation induces to maintain a ST model as the model of the theory. But, on this basis, any supervenience argument – any argument for the thesis that supervenient additions do not expand the original (first-order) ontology – fails on its own terms because of the *extensional* character of the formal framework in which supervenience/emergence is formally modelled, i.e., ST and the predicate language – and not by the peculiar metaphysical nature of those relations. By "extensionality" here I mean two issues primarily: (A2a) the existential commitment to basic particulars and (A2b) the fixed or rigid reference to them in the formal definition of systems. Whatever sort of relation between levels, if defined according to extensionality, will always find that formal limitation.

To see this inevitability, consider the idea to add relations amongst basic objects at the basal levels. Augmenting with relations amongst particulars the bottom level of objects (to which we are existentially committed) does not solve the problems outlined so far against the emergence of new causal powers form that augmented base. Rather, it makes the issue to shift to a second and stronger argument: the *causal regularity argument*. In few words, once assumed in addition to particulars at the bottom level, relations at the base are assumed to bring some causal powers in addition to that of those particulars over which they are defined; nonetheless, by stipulation, the causal powers of those relations are confined to that bottom level and do not

emerge at higher-levels of organisations. These latter, now, may show just the causal regularities of the base, as the statistical laws describing the behaviour of the collective basal system.

The solution of the problem of emergence lies, then, on the abandon of the assumption of extensionality (A2a-A2b) that, in turn, will induce to abandon the formal dualism bottom-/higer-levels that is implicit in the language of materialism and substance metaphysics, i.e., the language of predicate logic.[30] But this shall have the effect of calling even for a different formal model, one that diverges essentially from the set-theoretic one.

4 Process-based entities are relational structures

Arguments in favour of emergence "are frequently based on a vague and ambiguous notion of process" [43, p. 482]. So far processes and process-based entities have been presented as dynamic – namely, holistic, emergent, and relational – entities. This is for their constitution is viewed as strongly depending on the relations with their environment. In this section I show that there is a specific formal model that satisfies all these characterizations and that, then, can be employed to solve that ambiguity. In particular, this model makes

[30] Seibt refers to those premises as those that "create a theoretical bias in favor of the ontological primacy of 'thing-like' basic ontological entities, that is, concrete, countable, particular (i.e., uniquely located) individuals, called 'substances' or 'objects"' [43, p. 481].

of the abandon of extensionality the essential issue.

4.1 Organizations and structures

I already mentioned the organisational model proposed by Campbell and Bickhard. Organisations are thought to be a suitable model for processes and process-based entities because they are essentially holistic and emergent entities. I mentioned, also, the structural characterisation of processes proposed by Rescher. Structures are thought to be a suitable model for processes and process-based entities for they are holistic and, some of their variants, relational entities. Here I stress that organizations and structures can be made compatible so to resolve any ambiguity about the model of dynamic entities.

When Campbell and Bickhard pause on the formal difficulty of the extensional and dualist formal model of emergence and supervenience they continue suggesting, as a way out, that the commitment to "a hierarchy of levels of organizations" won't raise that sort of formal difficulty [16, pp. 47]. This may be true to the extent we are able to weaken the formal and sharp distinction into levels that is ultimately due to extensionality. The idea is that once the existential commitment to a bottom level is avoided, we may be freed from speaking of emergence *from* an emergence base and, accordingly, be free to model emergence as realized *in* the organizations themselves [8]. Campbell and Bickhard claim that organizations are the one and the only locus of emergence and, then, the model of process [16, 8], inasmuch they have not to be existentially

committed to a base of particulars.

Despite processes are concretely realized in space-time – as anything natural – they need not to be bound to particulars,[31] and this is the fundamental aspect detected and involved by the employment of process ontology. On closer inspection, even the structural model presented by Rescher takes this point as fundamental. Rescher points out that "By their very nature as such, processes have patterns and periodicities that render them in principle repeatable" [40, p. 10]. The key point is the expression "in principle". Processes are repeatable or multiple realizable *in principle*. To model processes, Rescher continues, it is required to model even the related characteristic of abstractability *in principle* – that is a variant of emergence – of processes. Now, to model abstractability of processes means, then, to model their non-locality *in principle*, for it means to renounce to model process by assuming, *in principle*, that they are rigidly bound to their concrete realization(s) as particular realizers of general characterizations. Accordingly, the structural account seems to be of some help, for a structure "is something

[31] Someone may think the organizational model of processes to be counterintuitive, at least from the naturalist assumptions that processes and process-based entities are to be conceived as concrete entities, namely in some way bound to some factor of particularization. Zemach's account of process is an example of this (mis)understanding [51]. But the misleading source of this reading is to think of process ontology as a form of nominalism, namely one committed to concrete entities (concrete processes) meaning particularized individual, from the outset. Seibt, fortunately, tells us that to speak of processes means to speak of non-particular individuals as confirmation of the goodness of the organizational model.

that a concrete item concretely exhibits" [40, p. 10] independently from the particular occasions of such an exhibition.

Indeed, the power of the structural framework seems to consist in providing a solution for the dualism particular-universal even from the point of view of the formal model and language:

> [A]ctual process is at once concrete and universal. There is, presumably, little or no problem about process types because these can be accounted for in terms of a commonality of structure.[40, p. 11]

Thus, so far, we have seen that, on the one side, organizations are convenient to model process-based entities for they allow for genuine emergence, inasmuch are not committed with a basal level of particulars; while, on the other, structures are convenient to model processes for they allow to account and explain for the compatibility of concreteness and universality of processes without the appeal to the particulars that concretely realize processes. Certainly, both organizations and structures converge towards the solution of the dualism perpetrated by the commitment to basic substances but, then, the key point shift now to that of making organizations and structures compatible *in principle*.

Usually one is naively induced to think of a structure as a collection of objects and relations over them. However, as argued at the end of the previous section, in the case of taking a hierarchy of so defined struc-

tures, the commitment to basic objects will affect genuine emergence as the regularity argument proceeds. In other terms, it is not clear that the suitable ontology of genuine emergence matches with ontological structuralism – *Ontic Structural Realism* (OSR).[32] OSR, especially in that case of structures obtained from objects and relations, seems to be an ontological thesis mostly framing a static view of reality, i.e., one bound to extensions. In order to account for the dynamics, typically, OSR friends advance claims concerning modality, namely, advancing the idea that structures are 'nomological', with this the modal ingredient which they attempt to describe. This is a dualist idea for structures – taken as rigidly bound to extensions – and the laws guiding their evolution are separated components of OSR.[33]

However, OSR is a wide umbrella that covers at least three main variants, depending on the entities assumed to enter as primitive in the definition of structures [1]: OSR1, that assumes *relations* as the only primitive entities; OSR2, that assumes *objects* (individuals) in addition to relations; OSR3, that assumes *properties* and relations on a par. Notice that the view discussed above about the regularity argument corresponds to OSR2. Instead, OSR1 and OSR3 share the idea that structures are holistic and relational entities,

[32]The term "ontic" is prefixed for it is incorrect to identify structural realism with OSR. There is also epistemic structural realism, but in this case emergence may be interpreted as non-genuinely ontological but epistemic emergence.

[33]Thanks to one of the anonymous reviewer for this commentary.

but not necessarily in the same sense organizations are. Indeed, their structures are holistic for they do not mention explicitly particulars, and relational, for both are defined in terms of relations, but this does not make them necessarily – namely, in principle – what is needed to model dynamic entities. The reason is that process-based entities are dynamic in the sense of being non-extensional entities[34] – i.e., not satifying (A2a) and (A2b). Rather, they are:

(H) Holistic (non-localized), because emergent;

(R) Relational, because their constitution and individuation depends on their (internal and/or external) environment(s) and its stability.

And, of course, (H) is equivalent to the negation of (A2a) and (R) is equivalent to the negation of (A2b) and, therefore, to be a dynamic entity is to be a non-extensional entity.[35]

[34]Whitehead, after all, is a non-extensionalist. For example, Whitehead would consider functions f and g over natural numbers n and defined as $f(n) :=$ *add* 5 *to n, then multiply by* 2 and $g(n) :=$ *multiply n by* 2*, then add* 10 as not equal, even if these are extensionally so: given the same input, both functions always produce the same value or output. Indeed, the *definitions* of the functions are not equal, and in that (intensional) sense the functions are not the same. In particular, they are not identical because the difference of symbols reflects different processes that are interpretable, in turn, as their meaning.

[35]An informal proof of this claim. (H) implies the negation of (A2a) because the plausibility of emergence is due to the non-existential commitment to individuals or to a base; (R) implies the negation of (A2b) because in specifying a process or organization we cannot make any reference on a specific and defined set or extension and, thus, that the existential commitment to

Clearly organizations show structural features. This is out of discussion. The issue is now, then, to understand which sort of structures match with organizations *in principle*. Namely, to find a structural model for organizations that is non-extensional. OSR2 is not suitable for this task for it makes an explicit use of (A2) assuming objects as basic ingredients of structures, while OSR1 and OSR3 present a great advantage on this regard explicitly avoiding objects as primitive. Question: "Is that advantage sufficient for modelling dynamic structures?" Answer: "No". Indeed, it is perfectly possible to *implicitly* assume extensionality by the appeal to ST as the formal model of relations, so to make *implicit* the commitment to a fixed base of objects in OSR1 and OSR3. The appeal to the formal model of structures, category theory (CT), can give us the opportunity of revealing the genuine nature of structures, independently from the various metaphysical views about them.

4.2 Organizations and genuine structures

It is possible to give a ST model of structures up to a certain extent, meaning that a ST model shows some limitation when about to model structural entities. Indeed, the commitment to objects is a peculiar char-

the members of the set has to be avoided from the outset. The negation of (A2a) implies (H) for, trivially, if they do not depend on some particulars they are non-localized entities; The negation of (A2b) implies (R) because if processes do not depends on particulars their individuation has to depends on the specific characterization of their behaviour or "functioning" with respect to other entities.

acteristic of set-theoretic ontologies and extensionality mirrors their essential rigidity. The object-based model of emergence is unsatisfactory from the outset with the result that genuine emergence and dynamism are effectively inexplicable notions in ST framework.

The other widely recognised formal framework suitable to accommodate structures is CT. The use of CT in the context of OSR is, of course, not new although, to some extent, it is still "unclear whether category theory offers a better framework than the set-theoretic one" [24, p. 131]. According to S. French, the demanded model, more specifically, shall be able "of representing the shift in focus from objects to structures that is central to OSR" [24, p. 132] – i.e., OSR1 and OSR3 – and one way to challenge this claim would be

> [T]o consider whether category theory offers a better framework for OSR because a category is characterized by its morphisms and not the relevant objects, with the latter regarded as secondary at best, or as definable in terms of, and consequently but more radically perhaps, reducible to, the morphism going in and out. [24, p. 132]

Personally, I find myself inclined to favour such evaluation, namely that CT structures diverge so sensitively from ST one that we may fairly say that CT is the theory of *genuine structures*. Moreover, I claim that genuine structures are inherently dynamic entities in the precise sense of being non-extensional so to, incidentally, satisfy at once even the metaphysi-

cal requirement imposed by genuine emergence; that genuine structures would make possible the match between organisations and processes.

As widely known, a genuine formal analysis of a concept depends on the characteristic mathematical theory that models the entity referred by that concept. According to S. Awodey the evident difference between the specific entities modelled by ST, i.e., sets, and those of CT, i.e, categories makes ST unable to model genuine structures:

> From Dedekind, through Noether, and to the work of Eilenberg and Mac Lane, the fact has clearly emerged that mathematical structure is determined by a system of objects and their mappings, rather than by any specific features of mathematical objects viewed in isolation. To a great degree, the structural approach in modern mathematics is characterized by increased attention to (systems of) mappings, and the idea that mathematical objects are determined by their 'admissible transformations'. [2, pp. 209-210][36]

Let us firstly address the attention to the distinction between sets as systems of objects in isolation and structures as systems of objects with their mappings. Within CT the opposition object-mapping seems to echo the opposition object-relation that characterises

[36]This work generated a heated debate between the Author and G. Hellman. See [29] and [3].

ST[37]. The reality diverges from this reading. The opposition is just apparent for – as Awodey stresses – objects are (formally) *determined* by their mappings and, for this reason, CT is free to focus just on systems of mappings, leaving aside objects. So, mappings intrinsically determines objects exactly in the sense of being mapping *in and out* the objects they characterise.

In a very recent work, [28], M. Heller provides a formal explanation of the most general idea of the "shift from objects to structures" that confirms this 'relational' account of structures. Accordingly, the formal model of structures does not depend on object because basic objects in the definition of a structure can always be seen as *reflexive* mappings. This proves that what is syntactically relevant for structures are mappings.

Let see an example. A category $\mathbf{C}$ is usually defined in terms of objects and mappings satisfying composition and commutation (transitivity) axioms, f.i., objects A, B and a map f. The resulting diagram $A \xrightarrow{f} B$ belongs to[38] $\mathbf{C}$ in the sense of being an *object* of the category. Now, assuming as many identity maps as objects, say I_A, I_B, one may define that diagram as the *formula* asserting that A *is* I_A and B *is* I_B, namely that the identity maps are the domain and codomain of f respectively. Formally,

$$A \xrightarrow{f} B \Longrightarrow (I_A \xrightarrow{f} I_B \Longrightarrow (A \xrightarrow{I_A} A \wedge A \xrightarrow{f} B \wedge$$

[37]Think of the mathematical fact that, within ST, the primitive relation of membership $\in$ cannot be modelled as an object of the theory, i.e., a set.

[38]It is not the set-theoretic membership relation.

$$\wedge B \xrightarrow{I_B} B \wedge I_A f = f = f I_B)).$$

According to F. Lawvere the diagram $A \xrightarrow{f} B$ is at once that universally valid (conditional) formula [36]. And in the consequent of the implication any talk of objects, accordingly, has been avoided: think in particular to the last conjunct $I_A f = f = f I_B$ that says that the maps f commutes with both the composition of I_A with f and that of f with I_B and where the maps f, I_A, I_B are the only entities. Indeed, as Heller calls to attention, it is possible to eliminate all the variables for objects in the formal language of CT. So, objects become here syntactically secondary entities, for they are definable in terms of reversible mappings (relations).

Actually, the example reveals a further and even more fundamental issue that goes over and above the simple formal stipulation (syntax). I am referring to the facts that the above example shows that, although the diagram is a mathematical *object*, i.e., it belongs to **C**, it also plays the role of an *assertion*, i.e., the complex term "$A \xrightarrow{f} B$" flanks propositional connectives "$\Longrightarrow$". The grammatical distinction between a *formula* (a predicate) and a *term* is then left blurred and the formal dualism term-predicate is no longer maintained within CT. I will now expound why this point is a consequence of the abandon of extensionality.

In the formula above we used identity maps, strongly reflexive, in order to substitute objects by definition (formal stipulation). But, actually, the appeal to those identity maps is neither necessary nor desired. What

I mean is that reflexivity may be formally reached by *composition* in many different ways. So, it is perfectly possible to obtain by *construction* objects of various types, through more or less complex reflexive (commutative) morphisms. This is allowed by the peculiar understanding of the identity and individuality that is distinctive of CT.[39]

The objectual approach performed by ST and its background (classical) logic makes a strong use of what Heller calls *absolute objectuality*, reached by means of the logical theory of identity and the principle of identity of indiscernibles – that together give the Leibniz Law.[40] On the contrary, CT makes large use of a weaker notion of objectuality, called sometimes *contextual individuality* and which can be construed in various degrees "of intensity", to say, depending uniquely on the complexity of the reflexive relations built up through suitable reversible transformations – like natural transformations, equivalence relations, etc. At the basis of this understanding of reflexivity it stands the idea that identity and reflexivity are peculiar cases of many non-extensional *equivalence relation*. More precisely, A. Rodin emphasises:

> Equivalence relation E can be interpreted as a reversible transformation, which turns

[39] This diverges from that of ST that make identity and individuality to collapse in the Leibniz Law[25, 24].

[40] A specific thing is a substance if it does not allow anything else to enter in its constitution or definition. This is exactly the view encoded in the theory of identity of classical logic, characterised by the *reflexivity axiom* for identity, $\forall_x(x = x)$, and the *substitution axiom*, $\forall_{x,y}(x = y \rightarrow (\varphi(x) \leftrightarrow \varphi(y)))$. The identity of indiscernibles is the inverse of the substitution axiom.

> x into y and vice versa, and the identity $=$ as identity through this transformation. [...] Given an equivalence xEy there are, generally speaking, many distinguishable transformations turning x into y while xEy only says that one such transformation exists. [41]

The idea is that objectuality or thisness is not an absolute notion and an evidence of this shift to a contextual individuality can be spotted in the divergence between ST and CT with respect to their theory of identity. It is a fact, indeed, that CT rules out the principle of the *indiscernibility of identicals* that is the basis of the classical theory of identity and, as a consequence, reflexivity and identity can now be defined by construction in many weaker and contextual ways, by means of the composition of mappings:

> Instead postulating the existence of objects, one postulates the existence of morphisms which, when composed with other morphisms, change nothing. One cannot speak here about the primitive thisness in the sense [...] [of absolute thisness], but only about the contextual thisness, and the context is now given by those morphisms with which a given identity morphism composes (to change nothing). I propose to call it compositional thisness. This is the closest (but still faraway) from the primitive thisness (as it can be defined in set theory) that

> can be obtained in category theory. Let us notice that the principle of indiscernibility of identities, in its original form, does not hold for this kind of thisness two identities could be discernible through their compositions with different morphisms. We can, therefore, speak of discernibility through compositions. [28, p. 453]

The interpretation of the notion of existence and of existential commitment in this context really diverges from the familiar one of ST. The interpretation of the expression "existence" now depends on the many possible reversible transformations we can obtain by compositions and, then, the interpretation of the existential quantifier is completely 'equivocal'. On this regard, G. Hellman operates a helpful distinction among the two approaches. He sees CT as an *algebraic* theory (of existence); while ST as an *assertive* theory (of existence) [29]. This is exactly because the notion of contextual individuality is weaker and depending on the sort of compositional reflexive mappings employed.[41] ST, instead, is *assertive* for it is rigid with respect to its ontology. Rigid in the sense that is committed, by axioms, to the existence of sets and, in particular, to the existence of a bottom domain of objects (individuals), sometimes called *ur-elements*. One may claim that this is not true in general, for most ST variants

[41] This feature provides a formal account of the following intuition. It is possible to formally build up a category of very different things, different but of the same category. For example, different humans, i.e., me and you, all equivalently humans.

do not allow for ur-elements. But another shall respond that, although it is true that such theories do not assume *explicitly* the existence of ur-elements, they do so in a formal or *implicit* way: by means of the *well-foundation axiom*. This axiom has the precise purpose of postulating the existence of *bottom domain* with the consequence of preventing the reflexivity of the membership relation, namely granting the absolute distinction between any set and its own element(s) and thus between the properties of the elements and the properties of the sets.[42] As a consequence of the fact that a set cannot be element of itself (reflexivity), we have that the property characterizing the elements of that set are not properties of the set itself (formal dualism). Such a dualist distinction is, then, part of the ground of extensionality and the core of the term-predicate dualism encoded by predicate logic. The change in the formal concept of individuality, the shift from objects to structures, is at the bottom of the "new perspective":

> In the "set theoretical ontology", the individuality of a set element is given by its very "thisness", independently of its relationship to the environment. In the "on-

[42]That we found to be critical for a coherent account of emergence from and supervenience on a base. That postulation and the assumption of well-foundation are provably equivalent. Notice that non-well-founded set-theories (NST) (those that reject well-foundation) allow for sets that are members of themselves ($\Omega = \{\Omega\}$) allowing for the collapse of the relative properties in specific cases. But, still, in this latter case extensionality holds, at least in terms of (A2b) so that NST cannot be considered a suitable model for processes. Furthermore, since the collection of all sets is not a set, it is a further entity in the sense that it belongs to a second and different domain.

> tology" determined by the strategy of arrows, one can also speak of thisness of some structures, but they always are contextual from the very beginning. As we have seen, they strongly depend on their environment. [28, p. 456]

This strong dependence on the environment makes the notion of genuine structure essentially holistic and relational in the sense of (H) and (R). The reason is that CT ontology is not bound to the assumption of an ultimate and rigid domain of objects – nor explicitly as it is in OSR2, neither implicitly as it may be by an ST model of OSR1 and OSR3.[43]

In spite of the peculiar metaphysical differences among OSR variants, CT tells us that genuine structures are the suitable setting for modelling emergence and organizations. OSR1 *plus* CT seem the suitable candidates to set and model process ontology in adequate formal fashion. Processes-based entities are relational and emergent genuine structures.

[43]In addition it is worth to notice that, according to CT as the background formal model, OSR1 is even stronger than OSR3. Indeed, within CT framework the formal properties of structures relies on the specific behaviour or operations certain specific structures performs, i.e., universal properties, independently from the specific category those structures belongs to. This is specific characteristic of CT properties mirrors the idea of a "individuation" of structures independently from their extensional determination as elements of a category, being a certain specific (universal) behaviour or operation shared by different structures each possibly belonging to different categories. Thus properties need not to be assumed as primitive entities of CT ontology exactly because they can be always mapped into the specific category in terms of the specific commutative diagram characterising the behaviour of the structure of that category.

5 Conclusion

An interesting issue of process ontology is its intrinsic naturalism, namely that ontology is not an armchair and speculative activity but should have some grounding in the empirical sciences. When metaphysical assumptions origin from experimental results, rather than from formal stipulations and metaphysical speculations, we have naturalism.[44] The belief in the materialist assumptions (A1) and (A2) finds a naturalist motivation in particle physics, while the unsoundness of the exclusion argument finds it in their empirical falsification. The progressive weakening of the classical notion of particle as isolated system is a constant in the evolution of quantum theories, from QM to Quantum Field Theory (QFT). In particular, QFT cannot be interpreted as a particle ontology inasmuch as it requires an ontology of fields which, as it is very well-known, are not able to be treated as objects. According to this picture, physical reality is *not* made of fields (floating) *on* a fixed and external space-time on the background[45]

[44] One of the Reviewer suggested to discuss a little be more the the naturalism employed here. The Reviewer, rightly, pointed out that "if naturalism is related to the absence of a first philosophy judging science, then it is hard to see how the proposal of this paper is naturalistic, given that it commands abandoning set-theory, which is employed (informally) by most mathematicians and physicists today." I can simply reply to such an interesting point that it is still a widespread view to informally deal with set-theory but that, otherwise, in fundamental physics as well as in non-foundationalist approaches to mathematics, the formal framework currently employed the one that is explicitly formalized in CT. The main example in the field of fundamental physics is Landsman's work [35].

[45] That would have the effect to make fields particulars of some sort.

but, rather, of "fields on fields" [42, p. 152] or fields *in interaction*:

> A process is the passage from one interaction to another. The properties of 'things' manifest themselves in a granular manner only in the moment of interaction, that is to say, at the edges of the processes, and are such only in relation to other things. [42, pp. 105-106]

Contrary to QM – which still preserve some atomist bias [46, p. 2] – QFT is a dynamic theory for it addresses the efforts in explaining and representing the *transition* from one field to another(s) and the emergence of particles as their stable interactions. In this framework a special role is given to the mechanism of the *spontaneous symmetry breaking* (SSB)[46] as the physical correlate of the notion of emergence at quantum scale [35], so no longer relegated to have a major role for pattern formation just at the macroscopic scale of thermodynamic and chemical systems. For this reason QFT is able to provide a theoretical basis of a unified picture of the universe in terms of a consistent explication of the passage *Micro* $\longrightarrow$ *Macro* [46] that finds a major evidence in the phenomenon of superconduction.

[46]Symmetries are physical (or mathematical) features of the system (observed or intrinsic) that are preserved under some transformation. SSB is the mechanism that underlies phase transitions or transformation of a system from one state of aggregation (order-heat) to another.

The peculiar and distinctive aspect of QFT lies ultimately in the *active agency* of Quantum Vacuum (QV) [46, 22].[47] While the dualist interpretation of substance metaphysics still induces to think of QV as the Democritean mechanical or absolutely empty and inert vacuum in which bits of matter are immersed as isolated particles,[48] according to QFT "Bodies were no longer able to be isolated", since they could well have been disconnected from the other bodies – as closed systems are – "but could not be disconnected from the vacuum" and, then, "the dynamics of particles is necessarily connected to their environment" [22, p. 1876], i.e., the vacuum. As a direct consequence, "the fundamental physical actor is no longer the atom, but the field"[49] [22, p. 1876].

A further empirical evidence of the relational character of physical systems comes from the phenomena of *neutrino oscillation* [39].[50] This physical phenomenon

[47]Such an idea origins from an experimental evidence, the *Casimir Effect*, according to which QV possesses an energy quantity. This quantity is determined by *virtual* particles, namely particles that are continuously created and annihilated by the effect of quantum fluctuations – according to the *uncertainty principle*. This quantum phenomenon has shown that is possible to transfer *heat* in vacuum [26].

[48]A false idea due to some *misled* intuition about the manifest world. According to [38] there are no reasons to project our intuitions about the macroscopic world to the quantum one as they are neither more intuitive of the latter.

[49]The field is the atom space distributions variable with time.

[50]Two are the categories of elementary particles according to the Standard Model: fermions (quarks and leptons), whose matter is made of, and bosons, the force carries that act on fermions. Neutrinos are leptons and, then, fermions. The Standard Model is the collection of theories that describe the smallest experimentally observed particles of matter and the interaction between matter and energy. It is currently incomplete and does

forces us to revise the very criteria of individuation and thus to revise our understanding of the notion of particle in terms of process-based entity or relational structure. Indeed, these oscillations correspond to *changes* in the *identities* of the neutrino particle: oscillations are identity changes. This phenomenon clearly does not satisfy the classical concept of particle as material substance or particular individual (see [25]), for a simple point: according to the classical interpretation, a particle is that physical system that is subject of univocal and fixed individuation.[51] The changes of identity falsifies such an univocal individuation, while are consistent with Seibt's criteria of individuation for processes in virtue of their specific functioning. A formal account of this criteria is formally captured by CT with the concept of relational or contextual identity ultimately grounded on the *compositional individuality* of structural entities: two identities could be discernible through their compositions.[52]. The dependence from the environment is so strong that C. Rovelli has no doubt when he stresses that "The world of existent things is reduced to a realm of possible interactions"[53] namely relations.

not explain many features of known universe, such as gravity and mass.

[51]The formal concept of individuation is formally coded by a component of the Leibniz law: the principle of the *identity of indiscernibles*.

[52]A formal theory of compositional identities (with different operators, morphisms) is provided by CT as mentioned in the previous section.

[53]In this view, particles are just the asymptotic limits of the *correlation* between two fields and the emergent 'result' of the dynamic interaction among fields.

Some conclusive considerations are now needed. So far I presented empirical evidences according to which our best contemporary physics, QFT, tells us that there are no particles, at least in the sense that the classical or substantialist particle physics cannot model our world. That a process metaphysics can model our world depends on the characterization and on the model of process we take. Certainly, if a substance or particle framework constrains possible models of emergence and dynamism in detrimental ways, a process framework was motivated by reversing those constraints since its beginning with Whitehead (Sect. 2). Although some substance metaphysics residual due to an implicit particularism (Sect. 2.3), Whitehead has the merit of focusing on the intrinsic dynamism of entities as grounded on their relational and emergent nature.

The discussion about the exclusion argument (Sect. 3.1) and the formal analysis supervenience (3.2) gave us the opportunity to spot what constraints possible models of genuine emergence, i.e., *extensionality*: (A2a) the existential commitment to basic particulars and (A2b) the fixed or rigid reference to them in the definition of systems. In Sect. 4 I argued that a different and positive result depends on the compatibility of the organizational and structural models. In particular, fundamental support toward this convergence came from the formal theory of genuine structures, CT, (Sect. 4.2) that helped us to pick up the specific structural model that explicitly captures the dynamic notions of organization and of emergence. Indeed, here

I presented reasons according to which process metaphysics can model our world just if process-based entities are interpreted as relational structures.

A further and last consideration on the kind of naturalism supported and implied by process ontology. Empirical evidences (Sect. 5) forbid us to intepret our world in terms of particle-like entities, namely substances or things or absolute individuals. On the contrary, fields and process-based entities are dynamic entities and can be modelled in terms of relational structures. This ontological account makes our naturalism a non-reductive naturalism, namely a new form of physicalism, one essentially based on the interaction system-environment and on emergence as notions deeply interwoven and in constant interplay. This new form of physicalism is non-reductive *ab initio*.

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