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Ontological Tools for the Process Turn in Biology

Some Basic Notions of General Process Theory

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1. Introduction

Recently philosophers of biology have presented arguments calling for a reconceptualization of the biological domain that is focused on processes, or even exclusively formulated in terms of processes (Dupré 2012; Falkner and Falkner 2013; Koutroufinis 2014b). Such arguments for a 'process turn' in biology could be strengthened if one could show that recasting biological phenomena in the classificatory terms of a sufficiently precisely formulated process-ontological framework can increase explanatory depth in biology and serve as a heuristic for empirical research. But is there an ontological theory out there that those interested in the process turn in biology could turn to?

From Aristotle onwards, ontology has been under the spell of what I have called the 'myth of substance'—a set of unreflected presuppositions for ontological theory construction that prescribe a focus on static entities, mainly a dualism of particulars and universals, as the most 'natural' way to describe the structure of the world.[1] One good antidote to the myth of substance might appear to be Whitehead's 'philosophy of organism', a metaphysics that presents reality as patterns of events. A small but growing number of philosophers of science are currently exploring Whiteheadian reconceptualizations of the domains of empirical science.[2] The purpose of this chapter is to introduce in outline another candidate process ontology, general process theory (GPT), as an auxiliary conceptual framework for the process turn in biology.

[1] On the notion, definition, and detailed studies of the counterproductive effects of the myth of substance or substance paradigm, see e.g. Seibt 1990, 1994, 1995, 1996, 1997, 2005, 2008, 2010, 2014, 2015. I am indebted to discussions with L. B. Puntel and W. Sellars for identifying some of the elements (about twenty) of the substance paradigm; see also Puntel 2002, 2010 and Sellars 1960.

[2] For Whiteheadian process chemistry, see e.g. Earley 2013; for Whiteheadian neurophysiology, see e.g. Brown 2005; for Whiteheadian quantum physics, see e.g. Hättich 2004; Eastman, Epperson, and Griffin 2016. Koutroufinis 2014b collects several proposals for Whiteheadian approaches to biology.

According to GPT, the world is 'the ongoing tissue of goings-on', as Sellars (1981: 57) put it—or, somewhat more precisely, the interacting of more or less generic interaction dynamics.

I will proceed as follows. In section 2 I introduce the new category of the monocategorial framework GPT, called 'general processes' or 'dynamics', and argue that the features of this category actually should be quite familiar to us, since they dovetail with our reasoning about subjectless activities. In section 3 I set out some elements of a non-standard mereology in terms of which relationships between general processes can be formally defined. In section 4 I sketch the dimensions of the classification system of GPT by means of which general processes can be diversified into many types of processes. In particular, I show how the classificatory parameters of GPT can be used to distinguish between processes that have the temporal and logical structure of a 'goal-driven' development, while others have the temporal and logical structure of 'non-developmental' or 'dynamically stable' temporally unbounded activities that persist in time by literal recurrence. In section 5 I offer some ideas on where in the current ontological debate in philosophy of biology the special constructional features of GPT could provide conceptual support for arguments in favour of a process-geared description of the living world. In passing I supply two reasons why Whitehead's philosophy of organism, albeit the most fully worked out process metaphysics to date, may prove an obstacle rather than an aid for the good cause of inviting a revisualization of the biological domain in terms of processes.

Before setting out let me insert two cautionary remarks. First, GPT is a process ontology but not a metaphysics—neither a speculative metaphysics like Whitehead's nor a 'realist' metaphysics, at least not in any of the problematic senses of 'realism' that are currently connected with the recent return to pre-Kantian meta-philosophies in analytical philosophy. Even though GPT lends itself to combinations with a naturalist or scientific realist position in metaphysics, it is itself an ontological domain theory in the Carnapian vein, specifying truth makers for true statements of common sense or science; it merely aspires, as part of an enterprise of philosophy as rational explication, to describe which entities we could rationally take to make true the accepted-as-true sentences S_i of a natural language or scientific theory L.[3] Second, given that I am not a philosopher of biology, the applications of GPT I offer in the last part of this chapter are presumably of heuristic value only. But, since GPT aims to reconstruct the entitative commitments of our everyday common-sense reasoning, and since it is this kind of reasoning that we employ to understand the non-mathematical content of scientific claims, the following outline and some illustrations of possible application paths will make, I hope, for a useful preface to a process ontology of biology.[4]

[3] For more details on methodology, see Seibt 1995, 1997, 2000a, 2000c, 2005. On the specific issue of the relation between ontological and scientific theories, see also chapter 4.

[4] The sketch I will present here contains many shortcuts and omissions. For this reason I supply throughout the chapter references to more detailed expositions of single aspects of GPT.

2. General Processes or Dynamics: A New Category

GPT is a mono-categorial ontology that postulates only one type of entity, called 'general process' or, to allow for occasional transnumeral references, 'dynamics'. According to GPT, all there is—that is, all the different sorts of entities we speak about in common sense and in science (including in the humanities)—is one variety or other of a general process or dynamics. The main task of GPT is to *differentiate* this basic entity type into subtypes that can form the ontological correlates for true sentences of (part of) some theory T (in common sense or in science).

Like all ontological category terms, the label 'general process' (or 'dynamics') is a theoretical term that receives its meaning and explanatory force from two sources: (i) axiomatically, that is, from the differentiating definitions and principles of GPT; and (ii) from its 'model' or analogical illustration. Since the category of 'general process' is characterized by a feature combination that has not been explored in ontology so far, it will be best to begin by setting out the model of general processes.[5] As we will see, the sort of existence articulated in the category features of general processes may be new in ontology owing to constraints on theory construction introduced by the myth of substance, but it is a familiar element of our common sense and scientific reasoning about the world we live in.

General processes are modeled on 'subjectless' (C. D. Broad) or 'pure' (W. Sellars) activities, as these are denoted by sentences that merely affirm the presence of a dynamic feature, such as 'it is snowing', 'it is itching', 'the fire is spreading', 'photosynthesis occurs everywhere in your garden'. The concept of a subjectless activity consists in its inferential role (in a given language), that is, in the set of inferences that are licensed (and not licensed) by statements about subjectless activities. Subjectless activities qualify as a model for the postulated ontological category of 'general processes' or 'dynamics' to the extent that the inferential role of statements about subjectless activities illustrates the seven category features in terms of which general processes are defined. These seven categorial features are as follows:

(i) Statements about subjectless activities do not license the inference that there is one unique and discrete spatial location or temporal period where the denoted activities occur. A subjectless activity is an entity occurring *somewhere* in space and time; in other words, an entity that is concrete, yet general or non-particular, as these category features are commonly defined. While a particular entity necessarily occurs 'uniquely', that is, in one spatial location at any time of its existence, a general entity may occur 'multiply', that is, in several spatial locations at the same time.

(ii) Non-particular entities cannot be individuated in terms of their space–time location, as particular entities typically are. Instead, as subjectless activities illustrate, they are *individuated in terms of their typical functioning within a*

[5] Ontological categories are commonly characterized and coarsely differentiated from each other in terms of theoretical predicates for category features such as *particular, universal, concrete, abstract, discrete, countable, persistent*, etc.; many of these predicates are related to the way in which a type of entity exists in space and time. Note that the term 'space–time' location is used as an abbreviation for 'spatial location at a time", not in the sense of relativity theory.

dynamic context. When we say, for example, that 'it is snowing, not raining', 'the fire has stopped, but not the radiation', 'on the West coast there is more wind erosion than water erosion', 'there's water in the fridge but no milk', or 'you can't see the gin in your gin and tonic', we individuate items in terms of what they commonly 'do', engender, or are involved in.

(iii) Subjectless activities are occurrences in their own right rather than modifications of persons or thing-like things. Unlike properties and relations, they are *independent* in the sense that sentences such as 'it is snowing', 'today's rush hour was particularly bad', 'an immune reaction occurred in the sample', or 'high energy radiation was hitting the atmosphere during period T' do not entail either statements about determinate single snowflakes, cars, enzyme molecules, or protons, respectively, or statements about any sort of medium or carrier for these activities.

(iv) Subjectless activities are temporally extended and, like things, they are good illustrations of the category feature of being an *enduring* entity, that is, an entity that persists through time by being 'identical' in time.

(v) Quite unlike things and much like stuffs (water, wood, etc.), subjectless activities are not *countable* in the sense that they do not necessarily occur in space and time pre-packaged into discrete spatio-temporally extended units that afford our common practices of counting. Since subjectless activities are individuated or differentiated in terms of their functional features, we can also count them in this way. For instance, metabolism and photosynthesis are two activities, and so are C3 photosynthesis and C4 photosynthesis.

(vi) In our reasoning about (subjectless) activities we 'zoom in and out'. We accept that there are highly generic and also highly specific activities. For example, we may say that in a tobacco plant the following activities occur: photosynthesis, C3 photosynthesis, C3 photosynthesis in a tobacco plant, C3 photosynthesis in a tobacco plant on a window sill directed eastward, C3 photosysthesis in a tobacco plant on a window sill with spatial coordinates <x, y, z> at time t′, and so on. In other words, (subjectless) activities are a good model for entities that are said to be concrete, yet more or less *indeterminate.* Since activities are more or less indeterminate, any activity is possibly multiply recurrent in space and time. This holds even when a space–time location is among its 'determinations' (that is, when it is expressly specified). The activity denoted by the phrase 'photosynthesis extending over the space–time region <x, y, z, t>' might de facto not recur in space or time, but this is merely a contingent fact. In other words, the location serves merely to ensure reference to a highly specific and contingently unrepeated yet in principle repeatable activity.

(vii) Subjectless activities are not changes. Constitutive 'phases' of a subjectless activity—for example, the change of place of every single flake that constitutes the dynamicity of the snowing—contribute to the activity's occurring, but not *as* temporal stages or phases. So our reasoning about subjectless activities provides us also with a model for the category feature of being a *dynamic* entity—a category feature rarely used in ontology so far—in a sense where such dynamicity is not immediately associated with the 'telic' or directed dynamicity of developments and with internal temporal differentiation into phases of different kinds.

In sum, then, guided by familiar patterns of common-sense reasoning, we can claim that subjectless activities can serve as a model for an entity that is concrete, non-particular, enduring, more or less indeterminate, dynamic, and individual in the sense of being functionally distinct from others.

3. Relationships among General Processes: GPT's 'Levelled Mereology'

GPT is a domain theory that postulates one basic category or entity type and one basic relationship that holds among such entities, namely the relationship of 'being part of' in its most basic sense of 'belonging with', which in everyday speech is used with any entity type.[6] In order to capture the sense of this notion of 'being part of', one cannot, however, resort to any of the standard mereological systems of so-called classical extensional mereology or to their intensional modifications, for these systems axiomatize part–whole relations that are informationally richer (e.g. 'is a spatial part of', 'is a material part of', 'is a functional part of', etc.).[7] Thus the inferential meaning of 'is part of', in its most basic and generic sense of asymmetric 'belonging with', must be captured within a non-standard mereology called 'levelled mereology' (LEM), which operates with an irreflexive, antisymmetric, and non-transitive part relation. In other words, according to the axioms of LEM, when we claim that dynamic D1 is part of dynamic D2, and D2 is part of D3, we speak of parts at different 'levels' of conceptual partition of a phenomenon, and we cannot in all cases conclude that it makes sense to say that D3 is part of D1. Parthood on dynamics does not hold automatically indirectly, that is, across levels, or, technically speaking, parthood on dynamics is not transitive.[8] For this sense of direct parthood—which is, again, our most basic sense of parthood—it holds that no dynamics is part of itself (irreflexivity) and that, if two dynamics seem to be part of each other, they are in fact identical (antisymmetry).

Assume that P is the partition of an entity D, specifying a tree-structure of direct parthood relations with D as the head node. In connection with such a partition of D we can then introduce relationships of indirect parthood relating to the n-th level of D's partition.

[6] Consider the following everyday examples, taken straight from the Worldwide Web: 'Blogging is part of life'; 'Russia is part of the West'; 'Music is part of God's Universe'; *All I see is part of me* (book title); 'Learning to negotiate is part of the advocacy process'; 'My heritage is part of who I am'; 'Looking immaculate is part of what I do'; 'Pain is part of running a marathon'; 'Hopping too is part of running'; 'Fab Face is part of Screaming Talent'; 'The concert is part of the 11th Ludwig van Beethoven Easter festival'.

[7] I argue that 'x is part of y' is transitive only if x and y denote spatio-temporal regions. More on this claim and on the details of LEM can be found in Seibt 1990, 2004, 2005, 2008, 2009, 2014.

[8] For example, ionization is part of hydrolysis, which is part of proteolysis, which is part of the adaptive immune reaction by B-cells, which is part of the human immune system. Unless we read 'is part of' in a narrow sense, as 'is a spatio-temporal part of', it is false to say that ionization is part of the human immune system—the functional organization that the latter term identifies normally does not 'reach that far', i.e. it leaves indeterminate how proteolysis occurs.

(Definition of 'n-part'): If P is a (possibly infinite) partition of entity D, let us call the direct parts of D at partition level 1 the 1-parts of D, the direct parts of these at partition level 2 the 2-parts, and so on. In general, the 'n-part' of D in partition P of length m, counting from the top, is any entity at partition level n, where $1 < n \leq m$.

This has a number of advantages. First, one can quantify over the parts in the partition of an entity in a much more differentiated fashion. One can refer to any part above a certain partition level n: 'x is <n-part of y'; at a partition level n: 'x is n-part of y', and below a partition level n: 'x is >n-part of y', as shown in Figure 6.1.

Second, using the basic, not very informative part relation of 'is part of', which supports only weak axioms, it is possible to introduce other, more informative varieties of parthood (spatial parts, material parts, functional parts, morphological parts, etc.) by stipulating additional conditions. In fact, in GPT, each dynamics is defined in terms of a collection of partitions, each created by a parthood relation that either is or is defined in terms of 'is part of'. More concretely, a dynamic D is represented by its base partition (BP) and three or more additional partitions. BP lists all the dynamics that are direct or indirect parts of D, in other words, all the $\leq n$-parts of D, where n is the lowest level of BP (counting levels downwards). In addition to BP, it is useful to specify the spatio-temporal partition SP of D, the material partition MP of D, and the functional partition FP of D (and possibly others); these additional partitions either are included in BP or else include BP. In this way one can refer to the 'parts' of an entity not only with greater precision but also in a less ambiguous and systematically more enlightening way. For example, the question 'How does natural selection work for organisms with hierarchical organization—which parts of the organism are involved?' could be answered by suggesting that only certain first-level and second-level material parts, multicellular subunits and apical meristems, are involved, but not third-level material parts. Moreover, if dynamics are represented in terms of a collection of partitions, one can compare kinds of mereological relationships as they hold on kinds of dynamics. For example, one can compare whether 'is a material part' has the same transitive scope on different kinds of biological dynamics (e.g. on photosynthesis vs mitosis), or whether it has the same transitive scope for biological, chemical, and physical kinds of dynamics.

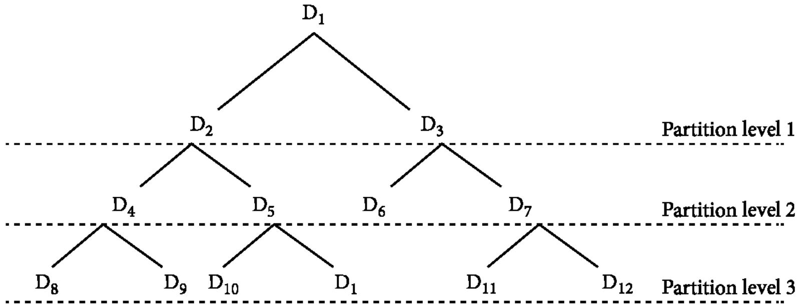

Figure 6.1 The n-parts of D_1 are the dynamics at partition level n. Note that dynamics can appear in several places in a partition—D_1 is its own 3-part

A third advantage of operating with a non-transitive parthood relation is that one can interpret the requirement of having 'the same parts' in a more precise and differentiated fashion than usual. In general, it is true that the 'identities' of dynamics are determined on the basis of the so-called 'proper parts principle': names for dynamics D_1 and D_2 co-refer iff D_1 and D_2 have the same parts. But in LEM the co-referentiality for dynamics D_1 and D_2 is defined in terms of 'x is $\leq n$-part of y'. That is, identity is always defined with reference to a given level n of mereological depth in the base partitions of D_1 and D_2; in order to determine whether D_1 and D_2, one compares each of the parts that lie on partition levels $1 \leq k \leq n$. By specifying which partition levels are to be taken into account, one can operate with more coarse-grained or more fine-grained requirements for co-referentiality in different contexts. For example, consider the partitions in Figure 6.2.

In some contexts we might want to claim that turf grass and crab grass both grow by making use of 'the same process', namely photosynthesis. Such a statement is made true by the parts of the base partitions of 'photosynthesis in turf grass' and 'photosynthesis in crab grass', if we restrict the level of analysis to partition levels 1 and 2 of these two dynamics, that is, to the 1-parts and 2-parts of photosynthesis in turf grass and photosynthesis in crab grass. In other contexts we want to stress the difference between these two processes, and such a statement is made true by extending the level of analysis to partition level 3, that is, we compare their 1-parts, 2-parts, and 3-parts.

A fourth advantage of LEM is that, unlike standard mereologies with transitive parthood, in this system we can formally represent emergent parts of processes and feedback structures (parthood loops). In particular, as I shall sketch below, it is possible to represent the difference between emergent products of an interaction dynamics without causal role—simple emergence—and emergent products of an interaction dynamics that causally influence the conditions under which the interaction dynamics occurs and is further propagated—generative emergence, as it occurs in self-maintaining systems such as organisms (Seibt 2014; see also sections 5.2 and 5.3 below).

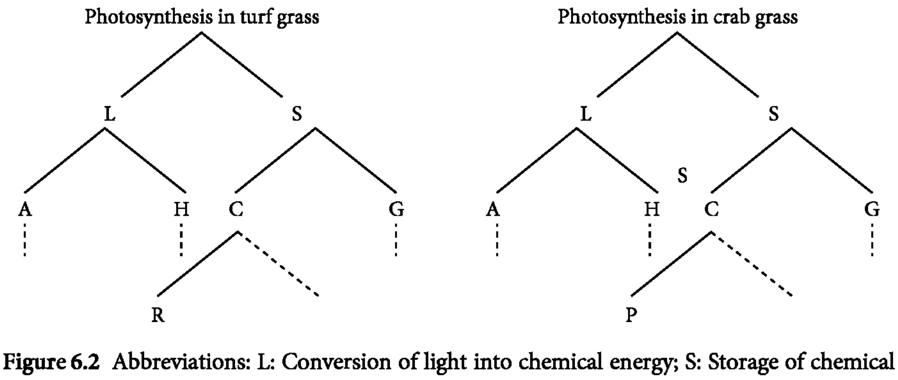

Figure 6.2 Abbreviations: L: Conversion of light into chemical energy; S: Storage of chemical energy; A: absorption of energy by proteins; H: Formation of hydrogen ions; C: Calvin cycle; G: formation of glucose; R: Carbon fixation with RuBP; P: carbon fixation with PEP. Dashed lines indicate omitted branch regions of the partition

4. A Typology of Processes

Since everything there is—that is, everything we refer to, in natural or scientific language, as being in the world—is a general process or dynamics according to GPT, the explanatory power of this framework hinges on the classificatory statements it can deliver in order to describe more precisely what varieties of dynamics there are and how they relate to each other. The classificatory scheme or typology of GPT uses five evaluative 'dimensions': (1) spatio-temporal signature, (2) participant structure, (3) dynamic constitution, (4) dynamic shape, and (5) dynamic context. The classificatory parameters of each dimension are here stated informally, but formal analogues can be defined with the resources of LEM.

4.1. Spatio-temporal signature

The most basic concepts of common sense and scientific reasoning, 'thing', 'stuff', 'event', 'state', 'activity', 'field', 'organism', and so on, are associated with characteristic inferential patterns pertaining to how the item in question occurs in space and time. The entity type that an ontological domain theory postulates as ontological correlate or relevant part of a truth maker for a sentence about a thing, some stuff, an event, and so on must be defined in such a way that these inferential patterns are entailed. In GPT this is achieved through a systematic extension of the predicate of *homeomereity*—that is, like-partedness. Aristotle observed that our reasoning about stuffs can be accounted for if we assume that stuffs are 'like-parted (i.e. homeomerous) bodies... composed of [spatial] parts uniform with themselves',[9] and it was noted early on in the debate about the ontological interpretation of 'action types' and verbal aspects that an analogous homeomereity with respect to temporal parts dovetails with our reasoning about activities (Vendler 1957; Kenny 1963; Mourelatos 1978). Just as any spoonful of a puddle of water is like the whole, namely an expanse of water, so any minute of an hour of snowing is like the whole, namely a period of snowing. Thus we can formulate a generalized notion of homeomereity:

> *Like-partedness or homeomereity*: An entity of (proximate) kind K is homeomerous with respect to its spatial extent (temporal extent) iff all of its spatial parts (temporal parts) are of kind K.

Upon closer look, however, our reasoning about stuffs and activities suggests an even more remarkable mereological feature than like-partedness. Since stuffs and activities are purely 'functionally' individuated, it does not make sense to distinguish between a stuff or an activity and its 'nature'—stuffs and activities *are* 'natures', even though they occur concretely. For the ontological correlates of our sentences about stuffs or activities, the following condition holds (where 'all of E occurs in spatio-temporal region R' is to be read as 'all parts of E occur in region R'):

> *(Spatio-temporal) Self-containment or automereity*: An entity E is automerous iff for any spatio-temporal region r (r > 0): if r is a subregion of a spatio-temporal region R in which all of E occurs, then r is a region in which all of E occurs.

[9] Aristotle, *History of Animals* 487^a2. See Seibt 2017.

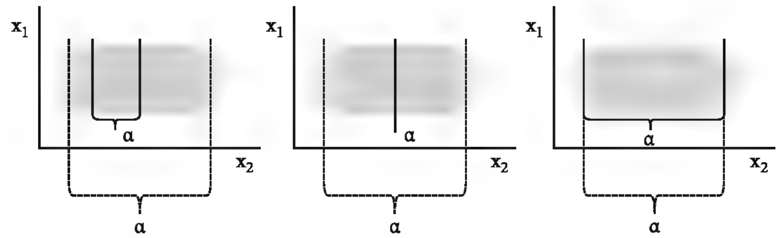

Figure 6.3 Graphical illustration of degrees of self-partedness (automerity) in space or time, depending on the interpretation of coordinates x1 and x2 (as spatial coordinates or with x1 as spatial and x2 as temporal coordinate, respectively; in the first case one spatial dimension is surpressed, in the latter case two, as usual)

In other words, the entities denoted by sentences about stuffs and activities are not only like-parted in space and time, respectively. They are also literally the same individual; that is, they are *recurrent* in space and time, respectively.

Our reasoning about mixtures (e.g. (a) fruit salad, (a) forest) and about repetitive sequences (e.g. hammering) suggests that on these occasions we refer to entities that are uniformly structured only for a certain 'grain size' of parts. Similarly, since no spatial part of a frog is a frog and no temporal part of a symphony or of a translation process (in gene expression) is a symphony or a translation, our reasoning about things or developmental events requires that we postulate entities for which it holds that there are *no* parts like them or containing them. Thus the predicates of like-partedness and self-containment can be generalized in two respects: first, with respect to dimensionality and, second, with respect to degree (see Figure 6.3 for a graphical illustration):

Maximal, normal, minimal homeomereity: An entity D of (proximate) kind K is maximally/normally/minimally like-parted$_K$ in space(/time) iff *all/some but not all/none* of the spatial(/temporal) parts of the spatio-temporal extent of D are of kind K.

Maximal, normal, minimal automereity: An entity D is maximally/normally/minimally self-contained in space(/time) iff a spatio-temporal region in which D exists has *only/some but not all/no* spatial(/temporal) parts in which all of D exists.[10]

[10] Generalized homeomerity and automereity in this sense were first introduced in Seibt 1997. In a different terminology, the properties of homeomereity and automereity have also been called 'dissectivity' (a cut in any region occupied by C will yield C) and have been supplemented with the property of 'additivity' (adding C to C will yield more C). Zemach's (1979) little noticed fourfold classification of entity types in terms of 'bound' and 'continuous' occurrence in spatial and temporal dimensions is kindred in spirit. Whether minimal homeomereity always implies minimal automereity depends on whether proximate kinds are restricted to *natural* kinds—if an entity D is defined as sortally amorph, that is, as changing continuously its proximate natural kind in ways that are sometimes connected with the idea of 'flux', then we might say that D is temporally and spatially automerous (kindless occurrence occurs in every temporal or spatial subregion of the spatio-temporal region R in which kindless occurrence occurs), but we might nevertheless allow that an occurrence of D in R* is of the proximate non-natural kind K *occurring in R**, and thus minimally homeomerous with respect to K. Similarly, maximal automereity mostly, but not always,

The individual entities of the ontological tradition, for example, material objects but also Whiteheadian 'actual occasions', cannot be self-contained or recurrent in a region, since they are conceived of as particular entities; they are individuated in terms of their location, and thus are by definition (i.e. necessarily) non-recurrent. Spatio-temporal self-containment is a coherent concept only for functionally individuated entities and can be coherently defined only in terms of the 'is part of' relation, in the wide sense of asymmetric 'belonging with' described in section 3. For example, breathing is part of walking, and so is moving your legs, lifting and placing your feet, swinging your arms, keeping balance, moving forward; assuming that these five activities are all of what is part of walking, we can coherently say that any hour in which walking exists has temporal parts in which all of (what is part of) walking exists. As I will elaborate briefly below, spatio-temporal self-containment provides a straightforward account of persistence as identity (recurrence across time) as well as a consistent account of generality (recurrence of features in space).

The predicates for different varieties of homeomerity and automereity can be combined to define the 'spatio-temporal signature' of a dynamic.[11] Together with other conditions, these spatio-temporal signatures can be used to define ontological correlates or parts of truth makers of the statements of natural or scientific languages. As I have shown elsewhere, to demonstrate the wide scope of GPT for the interpretation of ontological commitments expressed in natural language, we can define spatio-temporal signatures of entities that reflect the inferential patterns that carry the ten basic types of inferential information in natural languages. In other words, GPT can be used to define ontological correlates that dovetail with the way natural languages guide our reasoning about things, events as developments, events as results, stuffs, activities, states, collectives, sets, sorts, and features.[12] Here I will briefly illustrate six spatio-temporal signatures.[13]

Type-1 dynamics: Dynamics D is the ontological correlate of an *activity* statement iff
(i) D is temporally maximally automerous and
(ii) D is spatially maximally, normally, or minimally automerous.

Condition (ii) highlights that the concept of activity implies spatial occurrence without further specification. The ontological correlates of sentences about activities may be spatially maximally automerous (e.g. 'the water is boiling', 'it is itching', or 'the light is shining') or spatially normally automerous (e.g. 'the vortex is turning', 'all

implies maximal homeomerity: the entity that is first a caterpillar and then a butterfly is maximally automerous (along the temporal dimension) but not maximally homeomerous (along the temporal dimension).

[11] More precisely, the 'mereological signature of the spatio-temporal distribution' of a dynamic.

[12] In Seibt (2015a) I argue, on the basis of research in linguistic typology on the verb and noun systems of the world's languages, that GPT is currently the only (western) analytical ontology that can aspire to formulate truth-makers for sentences of a wide range of the languages of the world; otherwise in analytical ontology the peculiar inferential patterns of the noun system of Indo-European languages are simply read into the structure of the ontological domain to create the long-standing fixation on concrete individuals that are particular and countable per se.

[13] I shall retain here the GPT terminology and label these dynamics type-1, type-2, and type-5 through to type-8, instead of using continuous enumeration.

three beehives are swarming'), or spatially minimally automerous (e.g. 'the soccer team is singing', 'the immune system is working normally again').

This is quite similar in the case of type-2 dynamics, that is, the ontological correlates of sentences about developments such as 'the plant grew from 10 cm to 2 m', 'the stickleback moved into the nest', 'the ribosomes disassembled'; the dynamics referred to by sentences like these must be temporally minimally automerous—the 'grain size' of their temporal occurrence is the entire temporal extent of any temporal region in which they occur. But, as the last example of a collectively performed 'accomplishment' shows, a type-2 dynamic may be normally homeomerous and automerous in space.

Type-2 dynamics: Dynamics D is an ontological correlate for a *development* (accomplishment) statement iff

(i) D is temporally minimally homeomerous and temporally minimally automerous, and
(ii) D is spatially minimally automerous (and spatially minimally homeomerous), or spatially normally automerous (and spatially normally homeomerous).

Omitting spatio-temporal signatures for the ontological correlates of sentences about 'results' and 'states', of particular interest for the interpretation of biological claims may be the fact that GPT postulates processes or dynamics also as ontological counterparts of our talk about things or singular objects, collectives, sets, sorts, masses, and features. (To simplify, I will speak about the ontological counterpart of a noun N, in order to abbreviate the more cumbersome formulation 'ontological counterpart of a truth maker for a statement containing a referential use of noun N'.) Process philosophers occasionally say that objects are abstracted from processes. From the point of view of GPT, such a statement is somewhat misleading, since objects *are* a type of process or, more precisely, our talk about objects can be ontologically interpreted as being about a certain type of process.

Type-5 dynamics: Dynamics D is an ontological counterpart for a *singular object noun* iff

(i) D is spatially minimally automerous (and minimally homeomerous) and
(ii) D is spatially normally homeomerous[14] and
(iii) D is temporally maximally automerous.

The dynamic denoted by 'a cat', for instance, is spatially minimally homeomerous and automerous: no spatial part of the extent occupied by a cat is a region where a cat exists. Minimal automereity warrants unique bounded spatial existence as well as the failure of additivity and dissectivity, as required by our common-sense reasoning about cats. Condition (ii) is added here to establish that D might be either an integrated whole (e.g. a living organism) or a locally homogenous material expanse (e.g. the ontological counterpart of *a/this stone* or *a/this lake*), but not an entirely arbitrary collection of things without any sortal identity or family resemblance

[14] An entity D of kind K is (spatially vs temporally) maximally/normally/minimally homoeomerous or 'similar-parted' iff all/some/none of the (spatial vs temporal) parts of the extent of D are of a kind K* that is a necessary condition for being of kind K.

among its members (see Seibt 2000b). Condition (iii) states that type-5 dynamics persist by *literally recurring*—type-5 dynamics are wholly present at any moment of their existence.

The ontological counterparts of sentences about collectives, on the other hand, should fulfil inferential requirements of the following spatio-temporal signature:

Type-6 dynamics: Dynamics D is an ontological counterpart for a *collective* iff
(i) D is spatially minimally automerous and
(ii) D is spatially minimally or normally homeomerous
(iii) D is temporally maximally or normally automerous.

A dynamics D that fulfils the application conditions of, for example, the English expression '(this) herd' should not be spatially recurrent, since collective nouns are said to denote several entities conceived of as a unit. Dynamics D does not recur as a unit in any of its spatial parts. This does not exclude, however, that the region occupied by D has spatial parts that also fulfil the application conditions of the English expression 'a herd'. This is captured in condition (ii)—some collectives are weakly structured groups, and the same structure may recur within the group (e.g. a large herd may contain smaller herds), while strongly structured groups (e.g. a soccer team, the processes that make up an organism) do not. Condition (iii) accounts for the fact that some collectives (such as herds) persist through recurrence, while others (e.g. the metabolic processes that co-occur in an organism) take time.

Some languages (e.g. Oromo), but not English, have 'set nouns' that refer to entities as 'one or several' of a kind. The spatio-temporal signature for the relevant ontological counterpart is as follows:

Type-7 dynamics: Dynamics D is an ontological counterpart for a classification with a *set noun* iff
(i) D is spatially minimally automerous and minimally homeomerous, or
(ii) D is spatially normally automerous and normally homeomerous, and
(iii) D is temporally maximally automerous.

While the English noun 'sheep' is not a proper set noun, it might do to adumbrate the idea: the disjunction of clauses (i) and (ii) allows for the ontological counterpart of 'sheep' to be *one or several* entities. I mention type-7 dynamics here only to contrast this type with the following one, type 8, these being two possible candidates for an ontological interpretation of biological species as individuals (see section 5.1). Nouns referring to concrete items can, but do not need to, imply that the items denoted occur in a bounded region or have determinate shapes. While Indo-European languages predominantly use nouns that carry these implications, the so-called 'sort nouns' of classifier languages do not. Consider the mereological counterpart of a dynamic that is indeterminate with respect to shape and boundedness:

Type-8 dynamics: Dynamics D is an ontological counterpart for a *sort noun* iff
(i) D is spatially normally automerous and spatially normally homeomerous, and
(ii) D is temporally maximally, normally, or minimally automerous.

English counterparts of the sort nouns of classifier languages are noun phrases in generic sentences such as 'the African elephant is on the brink of extinction' or terms for natural kinds such as 'humankind'. The ontological counterpart of 'the African elephant' or 'humankind' is normally automerous—some of the parts of regions in which the African elephant or humankind exists are regions in which the African elephant or humankind exists. This entails indeterminate spatial location and accounts for the inhomogeneity of sorts, that is, for the fact that there are minimal portions satisfying the noun 'the African elephant' or 'humankind'. Condition (ii) again acknowledges that sort nouns can imply all varieties of temporal existence.[15]

The spatio-temporal signature specifies the 'mode of spatio-temporal occurrence' of a dynamics. While the relevant inferential patterns of natural languages suggest that there might be ten such modes of occurrence (here selectively illustrated), scientific languages may require additional ones. But there are many scientific kinds that can be characterized in terms of one of the ten modes of occurrence. For example, let the gene for protein P be the statistical relationship between sequences of DNA and coded proteins; the UBE3A gene for the protein ubiquitin ligase may be interpreted as a type-6 process (collection) of type-6 processes (collections) of type-5 processes (DNA sequences and amino acid sequences). Describing dynamics in terms of their spatio-temporal signatures emphasizes that many of them are quite unlike the bounded developmental processes or events (the growth of the oak tree) that the ontological tradition so far saw fit to acknowledge. Dynamics may be gappy, relational, unbounded, and non-countable—they can occur distributed into disconnected spatio-temporal regions and have themselves such distributed processes as their parts. Let me now turn to a brief sketch of the remaining four dimensions of the classificatory system of GPT.

4.2. *Participant structure*

The participant structure of a general process or dynamic states what types of processes are involved in a complex dynamics, and in what role. There are three basic roles, labelled 'agent', 'patient', and 'interagent', but additional ones can be defined recursively. For example, for the ontology of biology, it would be of particular interest to introduce the role of an emergent constituting constrainer (ECC), as a special variety of interagent. Self-maintaining far-from-equilibrium systems like a candle flame, a hurricane, or a biological organism *are* complex dynamics that emerge from, and constrain, certain interactions and thereby constitute the dynamic system (Christensen and Bickhard 2002; Bickhard 2009; Bickhard and Campbell 2002; see also chapters 1, 7 and 10 here).

Differences in the participant structure, that is, in the types and roles of participants in occurrences, are often encoded linguistically. In general, however, since neither the syntax nor the verb semantics can be used as reliable indicators of the

[15] To operate again with English counterparts for illustration, the ontological counterparts of 'the African elephant', 'humankind', and 'the completion of the zygote' are temporally maximally, normally, and minimally automerous, respectively.

participant structure of a dynamic, it is useful to articulate the causal composition of a complex dynamic in terms of these simple role concepts.[16]

4.3. Dynamic composition

The third dimension of the classificatory system of GPT analyses the partition of a dynamic in terms of various predicates for linear and non-linear composition. In LEM, the sum D_1 of two items D_2 and D_3 may have *n*-parts at (graphically) lower levels that are neither parts of D_2 nor parts of D_3. How these additional parts of a dynamics emerge and what role they have is reflected in the partition structure. For example, one may contrast the partition structures representing 'weak emergence' (i.e. the emergence of a part without subsequent dynamic role) with those representing 'generative or strong emergence', where emergent parts both facilitate and constrain the dynamics they are emerging from (Seibt 2014).

To illustrate, consider the differences in dynamic composition among (i) a linear mechanism, (ii) a feedback loop, and (iii) a self-maintaining dynamic. To simplify the exposition, let me here switch to the idiom of 'episode' and 'type'. Even though in GPT, where all individuals are non-particular entities, there are no 'tokens' in the traditional sense, given that tokens are particular entities, the occurrence of a dynamic D_1 in a determinate location can be treated, in Leibnizian style, as the occurrence of more a specific dynamics D_2, which we may call an 'episode of process type' D_1. From here on 'the dynamics of [*linguistic expression*]' will be used as shorthand for 'the dynamics denoted by [*linguistic expression*]'.

A mechanism is a linear sequence of process types $D_1 \ldots D_n$ such that it holds for any concrete 'run' of the mechanism that any member in the sequence of episodes of processes from D_2 to D_n directly dynamically presupposes its predecessor D_{n-1}.[17] Importantly, if a mechanism M is run repeatedly, the episode that occurs at stage S_i of M is each time an episode of the same process type D_i (e.g. an episode of 'this gear's making half a turn'). In contrast, in a simple loop of positive or negative feedback, it is also the case that, after initialization, each episode directly and dynamically presupposes the previous one, but what happens at stage S_i is not with absolute regularity always an episode of the same specific process type; rather, at different times, we find at S_i episodes of process types that are merely *similar*—at each time a different intrinsic efficacious character may be actualized, in dependence of (i.e. dynamically presupposing) a regulatory change to the 'causal signal' upstream.

Finally, consider a system of processes that maintains itself far from the thermodynamic equilibrium, for example a burning candle or a living organism. The component processes of the burning candle or of the organism (e.g. the melting of the wax, the percolation of the wax in the wick, the combustion in the flame, the air convection that adduces oxygen and carries away residues; or respectively

[16] Many sentences with intransitive verbs do not express a one-subject process. Some involve implicit references to locations, times, or observers—consider 'he disappeared', 'the wedding took place', 'the game was disappointing'—others express qualifications of dynamic shape or dynamic context of a process—for example 'the feeding frenzy increased', 'the rate of change remained constant', 'this development could not be stopped'.

[17] The notion of direct dynamic presupposition I must leave here undefined; see Seibt 2016.

the processes constituting catabolism, energy transformation, anabolism, immune reaction, and reproduction) not only feed into each other in the way in which this could also be said to hold for a mechanism or feedback loop; they each depend on, or dynamically presuppose, not only each other but also the occurrence of the entire process system (Bickhard 2004; Seibt 2009). Taken in isolation, the process types 'melting of wax' or 'percolating of wax' can have episodes that occur without any candle burning; and the same holds of the process types 'electron flow' or 'carbon fixation'. However, once the process system D of a burning candle or prokaryotic organism is up and running, any episode *in D* of 'melting of wax' or 'carbon fixation' directly and dynamically presupposes not only an episode in D of 'heating' or 'electron flow', respectively, but also an episode of D—for the process system D as a whole and for each of its constituents to occur, nothing but the occurrence of D is required.[18]

As these examples may convey, the predicates used in the formulation of the classificatory parameters in the dimension of dynamic composition (here, 'dynamically presupposes') involve modalities of the possible and necessary, not merely the modality of what occurs normally or for the most part, which is captured in partitions set up with the 'is part of' relation of LEM. Precisely how these strong modalities can be integrated into the formal framework of GPT—which is conceived of as a naturalist and so to speak 'actualist' ontology eschewing possible worlds realism—is currently an open question.

4.4. Dynamic shape

The fourth dimension of evaluative parameters of the classificatory system of GPT relates to differences in behaviour that can be geometrically described in terms of predicates of phase space trajectories—for example, whether a process stays in the same regions of its phase space, periodically switches between different attractors, or behaves chaotically. Some of these differences in trajectory can be related to intuitive characterizations of the 'flow' of a process—for example, whether it is slow or fast, or whether it is, metaphorically speaking, a sparse, normal, or rich realization of a process type. Such adverbial modifications of process types have so far received very little attention in ontology, traditional and contemporary.

The relevant classificatory predicates for such modes of performance can be defined in terms of deviations from typical partitions, that is, the partitions of generic dynamics. For example, while the partition of the dynamics D 'reproduction in *Hemidactylus garnotii* (Indo-Pacific house gecko)' will contain the dynamics 'copulating with a member of the species of different sex' and 'sexual reproduction', there are episodes of D whose partitions contain the dynamics 'copulating among female members of the species' and 'parthenogenesis', which could be classified as a sparse realization of dynamic D. Instead of, or in addition to, characterizing modes of performance on the basis of structural features of the partitions of 'types' and

[18] In contrast, an episode in a mechanism does not directly dynamically presuppose a previous run of the entire process system; and the same holds for or an episode in simple regulatory feedback system. In both of these types of system, episodes depend on the one hand on the preceding episode (direct dynamic presupposition) and, on the other, on an episode outside the system that initializes the episode at the first stage of the system (indirect dynamic presupposition).

'episodes' (i.e. dynamics and their specifications), one can also resort to dynamical systems theory and correlate the different modes of performance with deviations from the 'normal' shapes of trajectories in the phase space.

For the ontology of biology, it would seem all important to introduce suitable predicates for the modes of performance for processes, since the latter are often mentioned as playing a decisive role in natural selection.

4.5. *Dynamic context*

Finally, processes are differentiated with respect to how they relate to their *dynamic context*. In natural language we often characterize a dynamics D in relation to the dynamics that occurs or occur before or after D, or of which D is a temporal part. This is done, for example, by means of so-called verbal aspects (e.g. perfective, progressive, repetitive, ingressive, egressive). The technical predicates of the fifth classificatory dimension shall capture the relationships expressed by verbal aspects of this kind, as well as corresponding scientific predicates specifying contextual conditions. Other classificatory parameters in this dimension specify how a dynamics affects its dynamic context and is affected by it. Of particular importance for the ontology of biology may be the distinction between dynamics that have *linear causal impact* on their immediate environment (such as disturbances in the air flow around a kite) and dynamics with *non-linear causal impact* (such as changes in ecosystems that alter selection pressures).[19]

In sum, then, in GPT a dynamics D is classified by way of determining parameters associated with five evaluation perspectives, specifying:

(1) how D occurs in space and time, that is, D's mode of spatio-temporal existence or spatio-temporal signature;
(2) what causal (also agentive) roles are performed by which of D's parts, that is, D's participant structure;
(3) how the part processes of D compose (i.e. how they feed into each other, where dynamics 'emerge', and in which sense), that is, D's dynamic composition;
(4) how D is performed in relation to the 'norm' reflected in the partitions of the relevant process type or generic dynamics, that is, D's dynamic shape; and
(5) how D relates to its environment, that is, D's dynamic context.

5. Applying GPT in the Philosophy of Biology

GPT was developed in 1990 as a project of paradigm revision in ontology, in order to show that the three big problems of the ontological tradition—the problem of individuation, the problem of universals, and the problem of persistence—are artifacts of a certain tradition of ontological theory construction, namely the substance paradigm or the myth of substance (Seibt 1990, 1994, 1995, 1997, 2004). Accordingly, the applications of GPT have been mainly focused on topics in general ontology, in particular on the problem of persistence (Seibt 1997; 2008). Elsewhere

[19] These two examples are due to Bickhard and Campbell (2002).

I have shown that the current main alternatives in the theory of persistence, the perdurance approach—both the 'stage version' and the 'hunk' version—and the endurance approach, incur their familiar problems precisely because they are based on the presupposition that all concrete individuals must be fully determinate particular entities. Once we relinquish this assumption and allow for individuals that are concrete but general (that is, indeterminate with respect to their location and other aspects), we can consider persistence as the *recurrence* (in time) of an individual. In GPT, assertions about persistence, such as 'this is the same cat that we saw in the fall', are made true by a dynamics D—here, say, *catting-F-ly*,[20] where *F-ly* is a way of physical appearance—which recurs identically through time, yet happens not to recur in space. On the other hand, an assertion about change, such as 'but it (the cat we are seeing now) is much thinner now than it (the cat we saw then) was', is made true by a pair of different dynamics D_2 and D_3—here *(catting-F-ly)-thin-ly* and *(catting F-ly)-fat-ly*—that are specifications of D_1. In other words, once we give up on two elements of the myth of substance, namely the presumption that all individuals are particulars and the presumption that persistence statements and statements about change have the same subject, the puzzle of persistence has a straightforward solution. When we assert change, we are not literally making an assertion about that which we claim to have persisted. We are making an assertion about how that which persists is turning out now in comparison to how it used to turn out, and we say that how it is turning out now or occurring now is a specification of, but is not identical to, how it is occurring all the time.

This analysis of statements about persistence and change has three specific advantages. First, it allows for straightforward temporal and causal continuity (unlike the perdurance view). Second, it can be coherently formulated for either eternalist or presentist conceptions of time. Third, it makes do with concrete individuals only, in other words without having to postulate an additional category (e.g. a universal or a Whiteheadian eternal object) that relates to concrete individuals through an additional relationship (e.g. instantiation or Whiteheadian ingression, respectively).

In short, since GPT relinquishes the traditional fixation on discrete, particular, determinate individuals, it can offer a straightforward approach to an ontological interpretation of statements about general features in space ('x and y are both F') and time ('x-now is the same F as y-then'). In addition, the new category of non-particular, indeterminate concrete individuals might have applications in the ontology of quantum field theory and can be used to devise ontological interpretations of claims of interactions, from the interactivist interpretation of cognition to claims about social interactions (ch. 5 in Seibt 2005; also Seibt 2009 and 2014).

While it may be clear already from the sketch in the preceding sections *that* this framework might be employed in support of a 'process turn' in the philosophy of biology, let me highlight here three aspects of *how* or *where* the constructional ideas of GPT would seem particularly useful.

[20] Compare Quine's (1985: 169) playful rendition of 'a white cat faces a dog and bristles' as 'it's catting whitely, bristlingly, and dogwardly'. Ontology is never in the business of linguistic revision, but occasionally some tongue-in-cheek transpositions are useful.

5.1. Biological individuality

An ontology like GPT, which is based on a rejection of the classical variety of concrete individuals, can offer a new perspective in the recent debate about individuality in biology.[21] As several authors have argued, given our current state of knowledge about multispecies consortia (e.g. biofilms such as dental plaque) and plants, the standard criteria of individuation used in biology (germ/soma separation, developmental bottleneck, sexual reproduction, genome from one species, genome forming reproductive lineages, physical boundaries, or immune response) are no longer unproblematic tools for an unambiguous demarcation of those bits of organic matter that should be classified as an individual (Clarke 2010, 2011, 2012; Dupré 2012; Ereshefsky and Pedroso 2013, 2015). This situation has been understood as an opportunity to discuss critically the set of criteria and to streamline one of the four main perspectives (evolutionary, topological, physiological, and organizational) that commonly have been guiding definitions of biological individuality or individuation. Thus it has been argued that some of the more generic criteria (e.g. the 'interactor' approach instead of the more specific 'bottleneck' criterion) should be adopted for the notion of evolutionary individuality (Ereshefsky and Pedroso 2015).

To assist this discussion, one could reformulate the candidate criteria in the terminology of GPT so as to make the relevant proposals more precise. Hull's notion of an interactor, for example, has the drawback that is operates with a vague notion of a 'cohesive whole': an interactor is 'an entity that directly interacts as a cohesive whole with its environment in such a way that replication is differential' (Hull 1980: 318). A cohesive whole in Hull's sense has 'reasonably sharp beginnings and endings in time' (ibid., 313) and must 'exist continuously through time and maintain its internal organization' (ibid.). A cohesive whole in this sense is a type-5 dynamic—it is temporally maximally automerous, spatially minimally automerous, and spatially minimally homeomerous. Thus a dynamics D that is an interactor must be a type-5 dynamics; and the fact that an interactor interacts with its environment only as a cohesive whole can be captured by the requirement that the participant structure of D only has D as agent in all interactions with processes outside of the spatial region occupied by the spatial parts of D. Such a translation into the more abstract idiom of GPT would support the general strategy of the interactor approach of defining individuality in terms of an entity's function in the process type of selection: 'in order to be selected... an entity must be an individual. Anything that can be selected the way an organism can, must be the same sort of thing an organism is' (ibid. 326).

An alternative suggestion in the debate has been to determine a joint underlying rationale that can explain the previous success of the standard individuation criteria and to develop more generic rephrasings of individuation criteria in terms of 'mechanisms... whose effect is to constrain the extent to which populations at different compositional scales exhibit heritable variance in fitness' (Clarke 2012: 356). The relevant mechanisms (i.e. the constraining sources of heritable variance or fitness differences) pertain to 'interactions amongst parts' (ibid.) of a collection of

[21] Chapters 9 and 10 in this volume also address this debate.

cells, where the notion of 'part' at issue is non-transitive (though not explicitly identified as such) and the interactions referred to are at different partition 'levels'. GPT could be used to represent in more formal terms the central claim of this proposal, namely that individuality is relative to a partition level, that is, relative to mechanisms that 'fix the degree to which units at any particular hierarchical level are individuals' (ibid., 351).

GPT could also be used in the debate about biological individuality to advance a much bolder claim. Our current focus in ontology on classical (i.e. discrete, particular, unified, persistent) individuals stems from Aristotle's attention to biology and from his ontological intuition that 'living things'—typically, animals and non-clonal plants—exemplify what it means *to be*. To Aristotle, such beings seemed to enjoy a distinctive developmental independence and organizational unification that illustrated a 'primary' sense of Being or *ousia* ('being', 'essence'), which he characterized as powerful self-realization. At a time when biological research has uncovered a rather different picture, characterized by macrobe–microbe dependencies, 'genetic commons', and a profusion of dependencies in cycles and networks, it seems puzzling that philosophers of biology still would want to hang on to a notion of the individual that is motivated by obsolete biology. While philosophers of biology have observed that individuality is always relative to (the principle of individuation associated with) kind K (Ereshefsky and Pedroso 2013) and that different individuals must be treated as numerically different, for example as two (Clarke 2012), it has not been questioned, as far as I can see, whether one should continue to endorse the traditional tenet that the principle of individuation must also double as a principle of counting. For some kinds of entities—oak trees, cats, chairs, and tables, which ontologists throughout the centuries have not tired of discussing—the principle of individuating what is of kind K automatically supplies a principle of counting that which exists or occurs of kind K, since what is of kind K exists or occurs in 'pre-packed' units. But, for other kinds of entities (e.g. activities and stuffs), the principle of individuation for K leaves open how we bundle into units and count what is of kind K. Briefly put, we have been duped by tradition and the grammar of Indo-European languages when we think that whatever is countable as a kind also must be a kind of countables. For example, we differentiate water and milk, or walking and waltzing, in terms of chemical composition or types of bodily movements, respectively, but this criterion or principle of individuation for stuffs and activities, which surely gives us two stuffs and two activities in each case, leaves open how we should count what exists or occurs of them. So, if the standard criteria of biological individuality are not suitable for receiving a unique and unambiguous count of plants, one might address this problem by specifying new criteria for counting (to use on purpose this contorted expression) 'that which exists of plant individuals'.

On the other hand, one might challenge the assumption that how we individuate a plant of kind K determines how we count that which is of kind K.[22] The plant demographer's dilemma (i.e. should one count gamets or ramets?) can be solved by treating gamets, ramets, and any other unit one might count by analogy with litres

[22] This assumption drives especially Clarke's treatment of biological individuality; see Clarke 2012.

and grams: as units one may count by, not as units that individuate the entity of kind K that is being counted. Alternatively (or additionally), one may point out that once we liberate—within a process ontology like GPT—the ontological notion of 'concrete individual' from its clandestine traditional restriction to things and living *things* (i.e., animals or non-clonal plants) understood as determinate, discrete particulars, we may take each of the standard criteria for biological individuality to yield an individual—the dynamics of immune response, the dynamics of sexual reproduction, the dynamics of germ/soma separation, and so on. Instead of discussing whether entities of kind K qualify as proper individuals, we would then be discussing which individuals (dynamics) overlap or co-occur in dynamics of kind K.

5.2. Biological composition

In GPT a dynamics is represented by several partitions—the partition of the basic part relation 'is part of' and the partitions of derivative part relations, such as 'is spatio-temporal part', 'is material part', 'is functional part', and so on. How many levels of these partitions identify the dynamics in question may change with a change in communicative context—the biophysicist may countenance more material parts of a frog than the morphologist—and their maximal depth is relative to the current state of inquiry. That a dynamics is represented by several partitions in GPT is in line with Winther's recent analysis of biological part–whole explanations, which emphasizes that 'there are multiple cross-cutting manners of abstracting a system into kinds of parts—i.e., there are multiple partitioning frames' (Winther 2011: 397). Winther's suggestion that 'parts are abstracted through partitioning frames closely linked to explanatory projects' (ibid., 400) nicely fits with the constructive strategies of GPT, namely (i) to begin with the most generic part-relation terms from which specific part relations (functional, structural, or even more specific: morphological, physiological etc.) can be defined; (ii) to operate with a part relation that—unlike the transitive 'part of'—does not impose any implicit domain restrictions and allows, for instance, genes in the role of 'structure parts' and 'activity parts' (see ibid., 412); and (iii) to associate terms with default partitions. That the constructional strategies of GPT in this way match the use of classificatory partitions in biology becomes particularly important when the latter shift focus onto process-based classification:

> The more general point is that classifying a thing as a cheetah identifies a set of processes in which it can be involved. Classifying it in other ways might identify different processes. Such possibilities of multiple, perhaps cross-cutting, classification become more salient as classification becomes less determinate. This will be most clearly the case among the microbes.
>
> (Dupré 2012: 78)

The fact that in GPT the identity of a dynamics can be defined at different depths, according to context, by taking more or fewer levels of the representing partition into account, dovetails with another recurrent argument for the process turn, namely that developments and dynamically stable units can be realized along different paths. To explain, in the GPT formalism, the identity of a dynamic can be unfolded by adding levels to the base partition that represents D, then compressed again, accordion style. In other words, we can move between more coarse-grained and more fine-grained identity conditions. Consider now the statement 'the *same* development or homeostatic unit H can been realized along path A as well as path B'. The truth maker for this statement is a dynamic D that is defined for example by the upper five levels of the base partition BP that represents D, while the truth maker of the sentence 'H can be realized via path A' is D as defined for example by ten levels of the base partition BP representing D (where partition levels 6 through to 10 state the dynamics required for a realization along path A).

5.3. *Emergence*

Do biological process systems exhibit cases of generative strong emergence, that is, of emergent processes with a causal role both in the sense of constraining and in the sense of generating the processes from which they emerge? For reasons of space I must leave matters in the hypothetical mode here: if there were cases of generative emergence, they would surely make for the most compelling argument for a process turn in biology (as well as in cognitive science; see Bickhard 2009b; Boogerd et al. 2005; Seibt 2015). It is important to note, however, that, at this potentially most strategic point, the categories and the basic setup of Whitehead's philosophy of organism do not provide immediate conceptual support. Whitehead's ontology contains the means to describe weak emergence and even emergence with 'downward' influences of emergent parts onto other parts of a process. But in Whitehead's setup the interactions between the processual parts of an entity-constituting process ('concrescing occasion') can never affect the process of 'concrescence' itself. All concrescences point forward, as it were, and cannot affect themselves or any part that constitutes them. In GPT, on the other hand, such forms of generative feedback or literal self-modification can be defined in terms of self-similar partitions. A self-modifying or self-regulating dynamics D—that is, a dynamics with negative or positive feedback such as a self-maintaining dynamics—has a base partition BP with some (graphically speaking, upper) section S consisting of all $\leq$n-parts of D in BP and S is repeated further below in BP at a partition level $n + m$, $2 < m$.[23]

6. Conclusions

The purpose of this chapter was to offer a sketch of a process ontology that may contain relevant conceptual resources for philosophers of biology who are promoting a revisualization of the domain of biology in terms of processes. I have introduced the basic concepts and constructional ideas of GPT, an ontology or domain structure theory that operates with only one category, the category of concrete, non-particular, dynamic individuals called general process or dynamics, and a five-dimensional parameter matrix that is used to classify the many different types and subtypes of general processes. By way of three selective illustrations, I have adumbrated how the framework of GPT can be used to define processes as ontological counterparts for the basic kinds of entities that we commit ourselves to in our reasoning practice, both in common-sense judgements and in science (entities such as things, stuffs,

[23] For further details, see Seibt 2014. See also Koutroufinis 2014a, where non-Whiteheadian and Whiteheadian explanations of embryogenesis are discussed.

developments, results, activities, states, collectives, sorts, features). Since GPT is constructed on the basis of a systematic rejection of the unreflected presuppositions of traditional substance metaphysics, and in particular of the traditional axiom that concrete individuals must be particulars (i.e. necessarily uniquely located), determinate in all their features, and countable (existing or occuring in discrete units), I have suggested that the process individuals of GPT might be used to reconfigure the debate about biological individuality. GPT uses a special mereological system based on a non-transitive part relation called levelled mereology. This sort of mereology and, more specifically, the fact that dynamics are represented by collections of partitions seem to fit with biological part–whole explanations better than extant mereological systems. Finally, GPT represents differences in process architectures in terms of structures of partitions, and it therefore holds out the prospect of defining types of biological mechanisms, various forms of feedback, and 'emergence' relations—including 'self-referential' processes—in formal terms.

GPT is a reconstructive framework intended to provide what Carnap called a 'rational explication'. Unlike Whitehead's philosophy of organism, GPT is not a speculative metaphysics. For this reason, the conceptual tools of GPT are bound to appear as shallow reformulations of what we know anyway. In contrast, if we reconstruct biological concepts with the tools of Whiteheadian metaphysics, all terms acquire additional semantic content deriving from speculative principles. But precisely the interpretational austerity of GPT is, in my view, an advantage rather than a drawback, especially in a situation where philosophers of science wish to encourage a new way of visualizing a scientific domain. In a communicative situation where the force of habitual categorizations in a science must be broken, it is strategically preferable to refrain from recasting the new view in the—initially rather impenetrable—theoretical terms of Whitehead's speculative metaphysics. To speak of 'dynamics' and their parts and to be able to express differences in process flow and feedback more precisely, in terms of partition structures, may be a useful stage along the way.

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