AKR *Advances on Knowledge Representation Journal*

Categories in Top-Level Ontologies: Revisiting the Aristotelian Background

Ludger Jansen[1], Barry Smith[2]

Abstract. *In the field of applied ontology, it is now commonplace to refer to a top-level ontology, and the Basic Formal Ontology (BFO) has even been recognized as an ISO standard. Like other contemporary top-level ontologies, BFO makes use of distinctions that have been developed in philosophy, many of which are already to be found in Aristotele. In this essay, we revisit Aristotele's metaphysics and discuss the similarities and differences with BFO.*

Traditionally, the task of ontology has been to represent reality, for example in terms of a division between different modes of being. More recently, ontologies are being used to support not only philosophers but also scientists and others in their representation of reality. Indeed, with the advent of computers there has arisen a new discipline of applied ontology, whose task is to support the integration and discoverability of data deriving from different sources, nowadays including financial, industrial, governmental and other organizations, by providing logically supported classification systems (Munn 2008).[3]

An important instrument for all these purposes is the technique of classification. But, in any classification we have to select what will be the classes or kinds we place at the very top. What should the top level of an ontology, or indeed of any classification, look like? What are the most general classes of all classifications? It is upon questions such as this that we shall focus in what follows.

[1] Cusanus Professor for Philosophy at the PTH College Brixen in Bressanone, Italy. Supernumery Professor at the University of Rostock. Email: ludger.jansen@pthsta.it. Affiliation: PTH Brixen College; University of Rostock. ORCID: https://orcid.org/0000-0002-0097-6359.
[2] Distinguished Professor of Philosophy, Professor of Biomedical Informatics. Professor of Computer Science and Engineering. Director of the National Center for Ontological Research. Email: phismith@buffalo.edu. Affiliation: University at Buffalo, NY, USA.ORCID: https://orcid.org/0000-0003-1384-116X.
[3] This essay is an updated and extended version of Jansen, Ludger. "Categories: The top-level ontology". Applied Ontology. An Introduction, eds. K Munn, B. Smith, Frankfurt: Ontos 2008. The text has been heavily revised, and several old sections have been deleted. Introduction and Sect. 7 are totally new. To a fair extend, references originate from this first version, though they have been supplemented by pointers to the more recent literature.

AKR Advances on Knowledge Representation Journal

Authors in the fields of informatics and knowledge representation have suggested various anwsers to these questions. An early candidate for the role was SUMO, short for 'Suggested Upper Merged Ontology',[4] which was developed from an open-source project bringing together freely available, non-commercial ontologies into a common system. Nowadays *Basic Formal Ontology* (BFO) is a popular candidate top-level ontology, with over 600 domain ontologies defined in its terms (Otte 2022).[5] BFO has been recognized by the International Standards Organization (ISO) and the International Electrotechnical Commission (IEC) as an ISO standard (ISO/IEC: 21838-2), confirming that it satisfies the requirements for being a top-level ontology set forth in standard ISO/IEC:21838-1 (2021). In addition, use of BFO as top-level ontology has been mandated by the Joint Enterprise Standards Committee of the US Department of Defense and Intelligence Community. BFO also provides the architecture for the agency wide data repository of the US Department of Homeland Security.

The first thinkers to address the idea of a standard ontology were, in fact, philosophers, most notably Aristotle in his short treatise on the *Categories*. This classical text can be read as addressing exactly those questions that matter to applied ontologists today when they think about top-level ontologies (Jansen 2007). From the point of view of traditional philosophy, the question of a top-level ontology is tantamount to the question of the most basic categories of being, and our strategy for addressing this question is to examine Aristotle's theory of categories and describing some of the ways in which this theory has influenced current work in the discipline of *applied* ontology.

There were three principal influences which helped to shape the earliest versions of BFO: Aristotle's *Categories*; the literature of geographic information science (cf. Smith & Mark 2001); and the realist phenomenological approach to ontology pioneered by Edmund Husserl, Adolf Reinach, Roman Ingarden and other members of the so-called Munich-Göttingen school (cf. Smith 1996). We will here address only the first of these influences by presenting the ontology laid out by Aristotle in his *Categories* and showing how it maps to the philosophical foundations underlying BFO. We first clarify what a category is (section 1). From there, we continue to introduce three ontological dichotomies that are at the root of both Aristotle's ontology in the *Categories* and of BFO: the distinction between universals and particulars (section 2), the distinction between dependent and independent entities (section 3), and the distinction between continuants and occurents (section 4). We then present two diagrams that synthesize various ontological views that can be generated along the lines of these three distinctions: the

[4] See Jansen 2008 for a discussion of other early suggestions, such as OpenCyc and the Sowa Diamond.
[5] For a regularly updated list, cf. http://basic-formal-ontology.org/users.html.

AKR Advances on Knowledge Representation Journal

ontological square, inspired by Aristotle's *Categories*, and the ontological sextet, which is, as we claim, a more adequate representation of the ontological structure of reality, and represents the basic structure of BFO (section 5). We conclude by pointing out some points where we need to go beyond the simple picture of Aristotle's *Categories* in order to represent adequately our world as described, for example, by biology and medicine (section 6).

1. What are Categories?

1.1 The word "category"

As far as we know, Aristotle was the first to use the Greek word *kategoria* as a technical term in the context of philosophy. Originally, the noun *kategoria* and its corresponding verb, *katêgorein*, belonged to legal discourse. There, *kategoria* means the accusation in front of the judge, and *katêgorein* means t*o accuse someone*. Probably because an accusation asserts something of someone, the verb can also mean *to make known* or *to assert*, and it was used in this way by Plato.[6]

Aristotle uses the active verb phrase *katêgorein ti tinos* in the sense of: to assert something about something, but even more often he uses the passive *katêgoreisthai ti tinos* or *katêgoreisthai ti kata tinos* in the sense of: is said of something. The noun *kategoria* is used by him in a variety of ways, including using the plural of the noun in the sortal sense to mean 'kinds of predicates' or 'kinds of predication'. Such kinds of predicates are for example quantitative or qualitative predicates such as '3 foot long' or 'wet'. It is in this sense that the Greek word *kategoria* can be translated into English as *category* (Jansen, 2006).

We have evidence that Aristotle's conception of the categories developed in three phases. First, as in *Topics* I 9, the distinction of different categories was meant exclusively as a classification of predicates. In this first phase, the categories served as aids for finding arguments and for avoiding or discovering false inferences, and it was in this way that talk of categories found a place in the theory of argumentation, which is what the *Topics* are about.

The second phase is represented in Aristotle's *Categories*. Here the division of categories encompasses, not only predicate terms such as 'is tall' or 'is hungry', but also subject terms, including proper names such as 'Socrates' or 'Plato', which function in sentences only as the subject of predication but never as predicates in their own right

[6] See for example *Theaetetus* 208b; *Phaedrus* 73b. *Theaetetus* 167a links the two meanings.

AKR Advances on Knowledge Representation Journal

(*Categories* 5, 3a 36-37). This represents a step in the direction of ontology and away from concerns with the theory of argumentation.

The third phase finds its expression in the *Metaphysics*. There we find Aristotle's famous observation that 'to be' and 'a being' are used in as many different ways as there are categories (*Metaphysics* V 7, 1017a 22-23). Here, the division into separate categories becomes a full-fledged part of one of the most important of Aristotle's ontological works.

1.2 The Interpretation of Aristotle's Categories

Aristotle's theory of categories was the subject of much dispute in antiquity, and it has been interpreted in a variety of ways in the history of philosophy ever since. Partly, this has to do with the fact that category theory had many different facets even in the works of Aristotle himself. This came about because Aristotle repeatedly subjected his ideas to further development and highlighted different aspects when presenting his theory. But we can distinguish four prototypical conceptions of what categories are (which often appear in combination), according to whether they classify:

(1) subject and predicate *terms* and their associated *meanings*,

(2) mental or extra-mental *concepts*,

(3) *meanings of the copula* 'is', or

(4) *beings* or *entities*.[7]

Here, we draw on the last of these, which was certainly the main conception of the late Aristotle, namely that categories are the highest species of beings.

One reason why the question of the highest species of beings is important turns on the way in which definitions are conceived by Aristotle and his successors. Aristotle himself was interested in *real definitions*, that is, in definitions of things. A definition is then a phrase indicating a thing's essence (*ti esti*, what it is). Only substances have essences, and so only substances are definable – an outcome that is confusingly bolstered by the fact that the same word *ousia* is used to mean both 'substance' and 'essence' (Jansen 2017). The essence of a thing is what is expressed in its definition.

One standard technique for creating definitions has its roots in Aristotle's thinking on this topic, and thus in some circles of contemporary applied ontology its results are referred as 'Aristotelian definitions' (Rosse, Mejino & Jose 2003). Such Aristotelian definitions are constructed by joining a genus term with a specific difference, following the template:

[7] For these four options cf. Bonitz 1853, Ebert 1985, Kahn 1978, Oehler 1986.

AKR Advances on Knowledge Representation Journal

An *S* is a *G* which *D*s

Here, '*S*' stands for the species to be defined, '*G*' for the genus term, and '*D*' for the *differentia*, or in other words for the specific difference which picks out all and only those instances of *G* that are also instances of *S*, as for example, in the classical definition of human beings as rational animals, where "animal" is the genus term and rationality the specific difference.

A problem arises for such an approach to definitions, however, since it works only where the term to be defined has some more general term which can be used as starting point in creating its definition. Hence the need for a top-level ontology comprising 'top-level general terms',[8] which are *primitive* in the sense that they cannot be defined, though they can in various ways be *elucidated*, for example by specification of necessary conditions for instantiation, and by provision of examples. Aristotle's ideas on categories represent the first attempt to create a top-level ontology so conceived.

1.3 Aristotle's Ten Categories

There are many lists of categories in the extant works of Aristotle, of different length and content.[9] In *Topics* I 9, Aristotle says explicitly that there are ten categories, which he then proceeds to delineate. A list of ten categories can also be found in the *Categories* (see Table 1). The ontology thereby envisaged is nicely summarized in the following passage:

> Expressions which are in no way composite signify substance, quantity, quality, relation, place, time, position, state, action, or affection. To sketch my meaning roughly, examples of substance are 'man' or 'the horse', of quantity, such terms as 'two cubits long' or 'three cubits long', of quality, such attributes as 'white', 'grammatical'. 'Double', 'half', 'greater', fall under the category of relation; 'in the market place', 'in the Lyceum', under that of place; 'yesterday', 'last year', under that of time. 'Lying', 'sitting', are terms indicating position, 'shod', 'armed', state; 'to lance', 'to cauterize', action; 'to be lanced', 'to be cauterized', affection. (Aristotle, *Categories* 4, 1b25–2a4, transl. Edgehill)

[8] As Bonaventure describes the problem in his *Itinerarium mentis in Deum* c. 3, 3: "The function of the intellective faculty consists in understanding the meaning of terms […]. Now, the intellect grasps the meanings of terms when it comprehends in a definition what a thing is. But definitions are constructed by using more universal terms; and these are defined by more universal terms until we come to the highest and most universal. Consequently, unless these latter are known, the less universal cannot be grasped in a definition."

[9] A synopsis of these lists can be found in the appendix of Oehler 1986.

AKR Advances on Knowledge Representation Journal

Table 1 lists the Greek terms Aristotle uses for his ten categories, together with their verbal translations, Latin equivalents, and some modern terms now in use. Aristotle presents this system of categories by adverting to how each category is represented in ordinary language. More particularly, Aristotle would sometimes name categories not directly, but rather by using questions whose answers would make reference to entities in the respective categories. Many of the names we currently use for these categories then have their origins in the corresponding Latin interrogative expressions (see Figure 3).

Table 1: Different Terms for Aristotle's Categories

Aristotle's Term	English Translation	Latin Term	Modern Terms
ti esti *ousia*	What is it? Essence	*quod est, quiditas, essentia*	Essence, Substance
poson	How much?	*quantum, quantitas*	Quantum, Quantity
poion	How is it?	*quale, qualitas*	Quality
pros ti	Related to what?	*relativum*	Relative, Relation
pou	Where?	*ubi*	Place
pote	When?	*quando*	Time
keisthein	Lying, Being situated	*situs*	Position, Posture
echein	Having	*habitus*	
poiein	Doing	*agere*	Action
paschein	Suffering	*pati*	Passion

Kant accused Aristotle of choosing his categories in a 'rhapsodic manner', without any guiding principles. It is for this reason, or so Kant argues, that Aristotle could never be certain that his list of categories was complete (*Critique of Pure Reason*, A 81 = B 106-

AKR Advances on Knowledge Representation Journal

107). Later Aristotelians, such as Thomas Aquinas[10] or Franz Brentano (1862)[11], undertook the task of reconstructing a system that yields the Aristotelian categories in the precise order in which they are named and discussed in the *Categories*.[12]

To do justice to Aristotle, however, we should note that the works by him that survived are mainly lecture notes and not polished works ready for publication. This helps to explain the disparities between Aristotle's various lists, disparities which draw attention also to the fact that the elements in his lists are not all of the same standing.

There are three important dichotomies in terms of which we can understand how Aristotle's categories are organized:

- they make room for both *universals* (kinds, types) and the *particulars* which are the instances of these universals (section 2 below);
- they encompass *dependent* as well as *independent* entities (section 3);
- they divide reality into *continuants* and *occurrents* (section 4).

Taken together, these dichotomies help to systematise Aristotle's list of categories, as can be seen in Figure 1.

[10] See Aquinas, *In Physicorum Aristotelis expositio* III, lectio 5, Nr. 322 [15] and *In Metaphysicorum Aristotelis expositio* V, lectio 9, Nr. 891-892.
[11] On Brentano's idea see Smith 1987.
See also Simons 1992 and Jansen 2007 for new proposals for the hierarchical organization along the lines suggested in this communication.
[12] See Jansen 2007 for a new suggestion of a hierarchy of Aristotle's categories along the lines suggested here.

AKR Advances on Knowledge Representation Journal

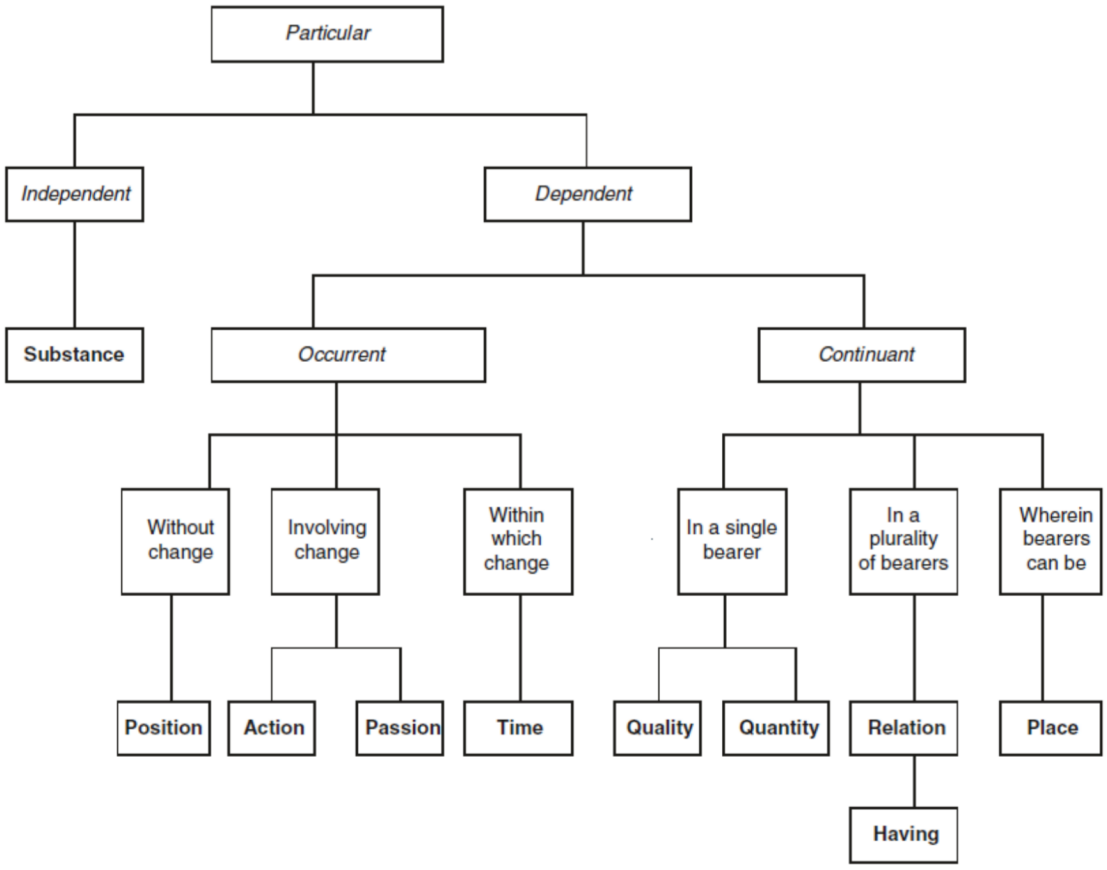

Figure 1: A schematic representation of Aristotle's categories. Source: Smith 2022, modified after Jansen 2007.

2. Universals and Particulars

Concerning the first of these dichotomies, we note that *universal* and *particular* are not themselves categories in Aristotle's sense, and nor do they divide the categories into distinct groups. Rather, both universals and particulars can be classified according to the categories; hence the distinction between universals and particulars is orthogonal to Aristotle's categorial distinctions. We can call it 'transcategorical' (Lowe, 2006, 21).

This dichotomy is given systematic treatment in the second chapter of the *Categories*, where Aristotle distinguishes between what can and what cannot be predicated of another entity. Predication requires an aspect of generality. Particulars, such as Socrates or my height, cannot be predicated of other entities. Sentences that contain as predicates expressions such as 'is Cicero' or 'is my height' are not predications in the technical sense at work here. Rather, they are identity claims comparable with 'Tully is Cicero' or 'My

AKR Advances on Knowledge Representation Journal

height is 5 feet'. A general expression such as 'human' can, in contrast, appear both as the subject and as the predicate of predicating assertions, as in 'A human is a vertebrate', and 'Cicero is a human'.

3. Dependent and Independent Entities

3.1 The Priority of Particular Substances

Aristotle is quite clear that his ten categories are not to be viewed as equals. Pride of place is given to the so-called substances, most notably material objects like organisms. They are called 'substances' because their existence is in a sense basic – substances allow entities of all other categories to exist: qualities are always qualities *of* substances, relations are ultimately relations *between* substances, and so on. Qualities and relations are, thus, *ontologically dependent* on substances. From Aristotle's perspective, this dependence on substances is even that which guarantees the unity of ontology (*Metaphysics* IV 2).

Customarily, the dependent categories are called *accidents* and are placed in opposition to substances. Examples of accidents are *being hot*, *being hungry*, *being seated*, or *being asleep*. A traditional criterion for the opposition of substances and accidents can be found in the second chapter of the *Categories*: qualities and quantities are *in a substance*, while substances are *not in* but are, rather, *identical with* a substance. But it is not entirely clear how this 'being in something else' is to be understood (Smith & Mulligan 1982). A heart is in a body and a tapeworm is in its host, but these are not cases of the 'being in something else' relation that Aristotle had in mind. Thus he explicitly excludes 'being-in' in the sense in which a part is in a whole (as the heart is in the body). And a parasite such as a tapeworm is not even a part of its host, any more than a foetus is a part of its mother, or a tub of yogurt is a part of a refrigerator.

The criterion of ontological dependence helps to solve this problem. The tapeworm could leave its host and move into another host. Both tapeworm and host are independent entities. A headache or an instance of colour, in contrast, cannot leave its bearer in this way and continue to exist. It is not possible for the Cheshire Cat to disappear and leave its grin behind.[13] The headache and the colour are dependent for their existence upon a specific bearer, a substance which has this headache, or this colour, among its properties. These properties cannot migrate from one substance to another.

In addition, Aristotle also sees a similar dependence between universals and particulars. For him, universals are ontologically dependent on particulars that instantiate

[13] We discuss this topic further under the heading of 'tropism in subsection 5.1 below.

AKR Advances on Knowledge Representation Journal

them. In the *Categories*, Aristotle distinguishes between primary substance (*protê ousia*), that is, a particular substance, such as an organism, and secondary substance (*deutera ousia*), that is, a kind of substance, like the kind *Man* or the kind *Bed*. Of these two, Aristotle accords special ontological status to the particular substances. Every universal is then predicated either of some particular substance, or of some particular accident that is *in* some particular substance in the sense explained.[14]

3.2 The Relation of Dependence

Substances do not require entities of the other categories further down the list in order to exist. But entities of these other categories do require some entity in the category of substance to serve as ground or fundament for their existence. It is in this sense that substances are said to be *ontologically independent* entities, where accidents are *ontologically dependent*. More precisely: substances are ontologically independent of accidents, while accidents are ontologically dependent upon substances. The notion of ontological dependence can be formally captured through a counterfactual criterion. The rough idea is that an entity *x* is ontologically dependent upon an entity *y* if *x* could not exist if *y* did not exist.

To elaborate further on this relation, we examine how it applies within the categorial framework laid down by Aristotle. First, we note that substances are independent entities. That is to say, they do not rely upon anything else in order to exist. This relation is an ontological one – it is a constraint which operates only in the plane of existence (Ingarden 1965, II/1; Koslicki 2012). Thus our usage of 'dependence' and 'independence' here is distinct from what we find in other domains, for example when we talk of dependent children or of someone's being drug dependent.

Such dependence relations hold, now, for all instances of accident categories. More precisely, it holds that. if *s* is a substance and *a* is one of *s*'s accidents, then *a* cannot exist unless *s* exists. This means that *a* is ontologically dependent on *s*, or, in a more traditional formulation used already by Aristotle, that *a* is ontological 'prior' to *s*. In the case of substances and their accidents it is also often said that accidents 'inhere' in their substance. This specific form of dependence is a matter of the ways *a* and *s* exist – they are different sorts of beings in reality, or, as ontologists express the matter, they belong to different ontological categories.[15]

[14] *Categories* 5. 2a 34-35; 2b 3-5; 2b 15-17. In later texts, Aristotle affirms the centrality of particular substances and their special importance with respect to the other categories, which he then also calls 'affections of the substances'. *Metaphysics* IV 2, 1003b6: *ousiai – pathê ousias*; see also *Metaphysics* XIV 2, 1089 b 23: *ousiai – pathê – pros ti.*

[15] Aquinas refers in this connection to different degrees of being, with God at the highest degree.

AKR Advances on Knowledge Representation Journal

Quantities and qualities specifically depend on the one substance they inhere in; they cannot switch their bearers. This many–one pattern (many accidents in one substance) can be modified in various ways, as we will see in the next subsection.

Second, there are relational entities, which are ontologically dependent on two or more bearers, possibly at the same time (see Smith *et al.*, 2006). Relational accidents – such as *being owner of* or *being in the marketplace* – also show that not all things that are ontologically dependent on a certain entity do in fact inhere in that entity. Relational processes, such as kisses or hits involving two persons, are ontologically dependent upon each of their relata taken singly, but they inhere not in their relata taken singly, but in the totality which these relata form. It is also possible for two or more entities to be mutually ontologically dependent. There can only be a timbre of a musical tone, for example, if there is also a pitch and a loudness (Smith 1997). This also applies for reciprocal relational accidents. There can only be a husband if there is a wife, there can only be an employer if there are employees, and in each case *vice versa*.

3.3 Generic Dependence

Accidents are in every case dependent on the specific substance or substances in which they inhere. This variety of dependence is often called ‘specific dependence’. Not all dependence relations are of this kind. Remember that, according to Aristotle, universals depend on their instances. They do not, however, depend on any one specific instance. It suffices for the universal *human* to exist that any instance of *human* exists, and in fact there is no instance of this species that exists now and already existed in Aristotle’s time.

Similarly, being a doctor is not dependent upon the existence of any particular individual patient; any patient at all would be sufficient. By the same token, the existence of a patient does not end when there is no longer any doctor treating him. Only if there are no more doctors at all would there be no more patients. And while being an employer requires having at least one employee, the employees can vary over time. This variety of dependence is normally called ‘generic dependence’. Universals are thus *generically* dependent on their instances. Doctors are generically dependent on their patients, employers on their employees, and so on. This relation can be viewed also at the level of universals, so that, for two universals F and G, being F is generically dependent upon being G if and only if nothing can be F unless something is G.

Taken together with Aristotle’s idea that the existence of a universal depends on the existence of at least one instance thereof, we can then carry this idea over to the instances of universals, and define:

AKR Advances on Knowledge Representation Journal

> An instance of the universal *F* is generally dependent on the universal *G* =def. an instance of *F* cannot exist unless there exists *some* instance of *G*.

This kind of dependence is important for a wide range of phenomena. Organisms are generically (but not specifically) dependent on their constituent cells and molecules. Literary texts cannot exist without their exemplars. A poem can be written or printed on paper, stored on a computer, learned by heart, or stored as the recording of a recitation. The poem exists as soon and as long as one of these 'concretizations' of it exists, but it does not need to be the same concretization for the entire duration of its existence (Arp, Smith & Spear 2015, 105–107, following Ingarden 1974).

4. Continuants and Occurrents

4.1 Time and Existence

There is another way in which Aristotle's list of categories can be divided into two sub-groups. Note, first, that, where a substance such as a bacterium, a quantity such as a length of 20 meters, or a quality such as an instance of redness, exists *in toto* at every point in time at which it exists at all, actions and passions are as it were spread out over the course of some time interval. Whenever we encounter a bacterium, we encounter the *whole* bacterium – and this is so at each point in time over the course of the bacterium's life. The process (action) by which a bacterium reproduces, by contrast, or by which it moves through a medium, takes place in time and is manifested over a time span. The process of bacterial reproduction has a beginning and an end; it is composed of various phases that follow one another in time. Instances of process universals like *reproduction* and *movement* have temporal parts. By contrast, the bacterium itself has spatial parts – for example, a nucleus, a membrane, a cytoplasm – each of which exists as one and the same entity through time, even while potentially gaining and losing qualities, and even while gaining and losing parts.

Hence, we see that there are two kinds of entities. First, there are for example organisms, which *continue* to exist through time, and for this reason they are called *continuants.* Next to an organism, however, there is its *life* or *history*. It and its successive phases *occur in time*, and for this reason they are called *occurrents*. The organism itself is present as a whole at every time at which it exists. For the organism's life, in contrast, there is no time it is wholly present. Rather, it unfolds itself in successive phases.

The words 'continuant' and 'occurrent' can be traced back to the Cambridge logician William Johnson. Johnson defines 'continuant' as 'that which continues to exist while its states or relations may be changing' (1921, 199). More recently, David Lewis (1986, 202) drew a similar distinction between *endurers* and *perdurers*:

AKR Advances on Knowledge Representation Journal

> Something *perdures* iff it persists by having different temporal parts, or stages, at different times, though no one part of it is wholly present at more than one time; whereas it *endures* iff it persists by being wholly present at more than one time.

Distinguishing between these two modes of existence is often seen as marking a distinction between two competing theories of the ontology of reality, referred to as endurantism and perdurantism, respectively (Donnelly 2011). Lewis, for example, is a perdurantist. He held that *all* entities are four-dimensional occurrents,[16] a view which is accordingly often referred to as four-dimensionalism, reflecting the fact that occurrents are seen as occupying four-dimensional chunks of spacetime. There is no David Lewis, on the perdurantist view, but rather a process of *davidlewising* filling out a certain spacetime region.

Other philosophers, in contrast, follow Aristotle – and common sense – in embracing a view according to which there are two very different modes of existence exemplified by the bacterium on the one hand and its movement on the other (McCall & Lowe 2009). We, too, hold a view of this sort – namely that we need to acknowledge both continuants and occurrents in order to achieve an accurate representation of reality.

However, the opposition between entities which continue to exist over time and entities whose existence is spread across successive regions of time does not present an exhaustive classification. This is because it captures only those entities whose existence is, in fact, extended in one or other way over multiple points in time. But there are in addition also what we can think of as temporal boundary entities, including instants of time, on the one hand, and also instantaneously existing qualities and quantities (see Johansson, 2005). If, for example, the temperature of a body is increasing continuously from 2° to 3°C across a certain stretch of time, then it has at just one time point somewhere in the middle the instantaneous quality of exactly 2.5°C. If a tumour grows continuously during its growth process and maintains constant density, then there are no two points at which the tumour has the same weight. If a surface changes its colour continuously from, say, blue to red, then there are no two points in time at which this surface has the same colour.

Temporal instants and the temporal boundaries of processes are limit cases of occurrent and are therefore included in the occurrent class. And we must similarly define ‘continuant’ in such a way as to comprehend also instantaneous existents in the realm of specifically dependent continuants, for example the instantaneous quality of 2.5°C in the body temperature example above.

[16] For an overview of this discussion, see for example Lowe, 2002, 49–58.

AKR Advances on Knowledge Representation Journal

4.2 SNAP and SPAN

If we picture the world at any single point in time, we will discover in our picture planets, people, animals, artifacts, colours, sizes, and relations. But changes, processes, events and happenings that are taking place at that point in time will not be visible in the picture. In order to represent the latter, we need a sequence of pictures; we need something like a film. In order to obtain an all-inclusive picture of our ever-changing world, we thus need two kinds of representation. On the one hand, in order to capture the continuants, we need snapshots of the world at particular points in time. We might call such snapshots *SNAP ontologies* (following Grenon and Smith, 2004). Included among SNAP entities are substances, quantities, qualities, relations and positions. It will include also the boundaries of substances, collections of substances, spatial regions such as points, lines, surfaces, and spatial volumes, as well as places such as niches and holes, and also the environments in which substances are to be found (Smith 2001). Over and above the traditional category of continuants, SNAP ontologies comprise also the merely instantaneously existing instances of qualities and quantities which would otherwise be ontologically homeless.

On the other hand, we need a representation of change, something like a film which represents entire time spans. Grenon and Smith (2004) called these representations *SPAN ontologies*. Included among SPAN entities are processes and temporal regions, as well as time instants and instantaneous process boundaries which serve as their boundaries. Spatiotemporal regions and the boundaries of such regions are also included, since they too exist along the temporal dimension. Boundaries of processes include for example the beginning and ending of a race, the beginning and ending of a millennium, or the beginning and ending of your life as a 2-year old.

5. Putting It All Together

5.1 The Ontological Square

Joining together the universal–particular dichotomy and the dichotomy between inhering and non-inhering entities yields a fourfold distinction of entities represented by the so-called *ontological square* (Figure 4), which captures the core structure of Aristotle's early ontology.[17] We can think of both Aristotle's list of categories and the ontological square as transparent partitions of reality (Bittner & Smith 2001). That is, if we look through (as it were) the respective cells in these partitions, then it is as if we can see the corresponding entities in each cell.

[17] See Smith, 2003a. On the history of such diagrams see Angelelli, 1967, 12; see also Wachter 2000, 149. An alternative interpretation, drawing on *Categories* 2 is given in Jansen 2014/15, where the ontological square is seen as combining the universal–particular dichotomy with the concrete–abstract dichotomy.

AKR Advances on Knowledge Representation Journal

	substantial **(not in a subject)**	***accidental, non-substantial*** **(in a subject)**
universal **(predicated of a subject)**	III. *substance universals* human being horse	IV. *accident universals* being white knowing
particular **(not predicated of a subject)**	I. *individual substances* this human being this horse	II. *individual accidents* this individual whiteness this individual knowing

Figure 4: Aristotle's Ontological Square

One of the most important contemporary exponents of the idea of a four-category ontology is E. J. Lowe (2006), whose account in his *The Four-Category Ontology* provides an overhaul of the ontological square designed to match the needs of contemporary philosophers but still very much in Aristotle's spirit. On the other hand, many contemporary philosophers reject some of the fields recognized by proponents of the ontological square. These rejections take a number of different forms, including:

- Nominalist philosophers accept only particulars, i.e., only entities from the two lower fields, I and II. Some nominalist philosophers even try to make do with only one of these two categories. For example, the so-called tropists accept only the existence of particular accidents in field II, which they call 'tropes'. This would be a view close to one in which the world consists exclusively of accident instances, a view under which individual substances such as you and me are viewed as more or less loosely connected bundles of such tropes. This view has been defended, for example, by Donald C. Williams (1953, 2018) and Keith Campbell (1990).
- Plato, in contrast, ascribed real being only to universals, i.e., to the entities in the two upper fields, III. And IV. A modern defender of such a position was Bertrand Russell,

AKR Advances on Knowledge Representation Journal

who wanted to eliminate the level of individuals,[18] most likely under the influence of Leibniz's theory of individual concepts.[19]

- Very many twentieth-century philosophers embraced a view amounting to the acceptance of only cells I. and IV. This is because they see the language of First-Order Logic as their tool for understanding reality, as though they regard its syntax as providing a mirror of reality. The particulars in cell I. correspond, on this account, to the individual constants (*'a', 'b', 'c'* …), and the property universals in cell IV. to the predicate variables (*'F', 'G', 'R'* …). The idea that the formula '*F*(*a*)' is the key to ontology has been dubbed *fantology* by Smith (2005a). Representatives of fantology include the Wittgenstein of the *Tractatus* (Wittgenstein 1960) and an elaborated version of this view, traces of which can be found in the works of almost all of the principal figures of 20th-century analytic philosophy, in the work of David Armstrong, who accepts only particular substances and what he calls property universals (Armstrong, 1978 and 1997).
- As concerns the ways in which analytic philosophers treat entities in what we are calling cell IV., different accounts exist as to whether terms such as 'horse' or 'human being' refer (i) to genuineentities (e.g., Bigelow and Leckey 2022), or (2) to one or other logical or set-theoretic constructions or to concepts in people's minds (e.g., Goodman and Leonhard 1940), or (3) such terms are merely *façons de parler* and so lacking in referents of any sort (e.g., Quine 1964).

Ontologists who want to eliminate one or more of the fields of the ontological square represent one or other kind of reductionist position. They are required to produce an alternative explanation for why we suppose in our everyday understanding that these things – people, their lives, the species *mus musculus*, the colour red, the number 2, the redness of this apple – exist. They do this mainly through explaining our reference to entities in these fields as merely a roundabout way of talking about entities in other, philosophically more highly favoured, fields.

5.2 Adding Processes: The Ontological Sextet

But can Aristotle truly fit all his categories into the ontological square? In particular, does he deal adequately with the role of processes in his category system? He does list 'doing'

[18] See for example Russell, 1940, ch. 6; and 1948, Part II, ch. 3 und Part IV ch. 8; 1959, ch. 9. For a similar position see Hochberg 1965, 1966, and 1969.

[19] Russell (1948) attributes this conception explicitly to Leibniz. See also Armstrong, 1978, I 89: "while the influence of Leibniz on Russell is clear, it is less clear that Leibniz held this theory of the nature of particulars."

AKR Advances on Knowledge Representation Journal

(action) and 'suffering' (passion) among his ten categories, and seems to understand them as the active and passive sides of a change (*kinesis*, *De anima* III 2, 426a2, cf. *Physics* III 3, 202a13 –21). Moreover, he refers elsewhere to processes that are not associated with change, as for example in *Metaphysics* IX 6, where he calls these non-change processes *energeiai*. It is difficult to say where processes such as seeing or living are to be put in the list of ten categories It seems, indeed, that Aristotle resists the idea that processes should be treated as fundamental entities .

On the side of mainstream analytic philosophy, Donald Davidson appears against this background as something of a hero, thanks to his argument in favour of the need for what he called an 'ontology of events' (Davidson 1970, 1980). He starts with a problem we face in understanding the semantics of a sentence such as 'John buttered the toast slowly'. Here the 'slowly' requires an entity with which the corresponding adverbial characteristic could be associated. This is why Davidson analyses the sentence as predicating something of a certain event, namely, a *buttering event* that is slow. Davidson hereby breaks out from the radically simplifying fantologically reduced ontological square by admitting a cell devoted to events as particulars.

A picture of the world which did not provide a special place for occurrents would indeed be incomplete. We need to account for the dynamic, processual character of the world, and for this reason we need to add occurrents, including not only processes but also temporal intervals in our ontology. There are also of course important relations that obtain between occurrents and continuants, for example individual substances *participate in* individual processes. There are also important kinds of processes, for example nuclear decay or apoptosis, which have all of the features of universals in the continuant sphere. All of which suggests that we expand the ontological square to an *ontological sextet*, as illustrated in Figure 5 (Smith, 2005a).

AKR Advances on Knowledge Representation Journal

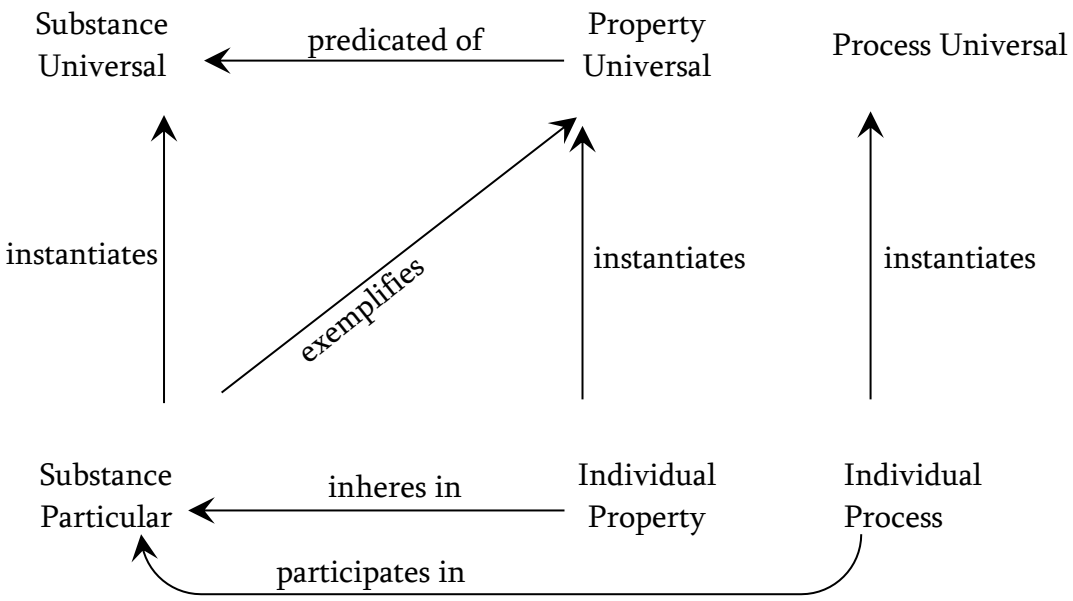

Figure 5: The Ontological Sextet and Associated Formal-ontological Relations

5.3 Ontological relations

The discussion of ontological dependence, the ontological square and the ontological sextet already revealed that there is a number of *relations* that are of utmost relevance for ontology. First and foremost, these are the basic relations that obtain among entities in the six fields of Figure 5, namely:

- individual accidents *inhere in* individual substances.
- accident universals are *predicated of* substance universals.
- individual substances *instantiate* substance universals.
- individual accidents *instantiate* accident universals.
- individual substances *exemplify* accident universals.

The relations of inherence, exemplification, instantiation, and participation govern the relations among the entities in the four fields of the ontological square. If we look at the ontological sextet, we can add relations to deal with processes ('events' in Davidson's terminology) drawing on the *participates_in* relation, as follows:

- individual substances *participate in* processes.

AKR Advances on Knowledge Representation Journal

- individual processes *instantiate* process universals.

One important feature of ontological relations is their generality. Regardless of which area of reality we want to represent, we must take relations like inherence and instantiation into account. In all domains that display changes over time, the relation of participation will be needed.

A second feature of ontological relations is their 'formal' nature. This means that these relations hold in a way that does not involve any additional 'matter' in the world. Rather, they hold simply because of the very ontological nature of their relata. For more familiar 'material' relations something different holds. If Mary is in love with Peter, this is not simply because there are Mary and Peter, but because there is this third thing, namely, Mary's love for Peter. Similarly, if Peter and Mary are married, this is because there was this processual entity, their marriage, that made them a married couple. It is because of their generality that ontological relations are so important for applied ontology. Because they apply in virtually all domains of reality, much work has been done in recent decades to formalize and standardize the representation of such relations, which are being re-used in myriad ontology applications.

6. Complex Entities

In addition to the categories we have discussed thus far, contemporary ontologists have considered other candidate categories, such as states of affairs, sets and classes, and mereological sums. As they are regularly referred to in writings on applied ontology, we introduce them briefly here.

6.1 States of Affairs

The idea of states of affairs (in Latin *status rerum,* German *Sachverhalte*) has a long history, starting out from its usage in clinical trials (Smith 1992), but it reached the apogee of its influence in the era of Lotze (Milkov 2023), and then of Lotze's student Carl Stumpf (Chrudzimski 2015), who, in turn, inspired Husserl and through him Adolf Reinach. Husserl's and Reinach's work on states of affairs then runs in (partial) parallel with Wittgenstein's thinking on this topic as laid down in his *Tractatus* (Smith 1978). Since then, interest in the idea has waned, having been pushed aside, by set-theoretic approaches to semantics on the one hand, and by truthmaker approaches on the other (see for example Faroldi & Van De Putte 2023).

States of affairs are complex entities that can be represented in normal language by means of 'that' clauses such as *that the ball is green* or *that the cat is on the mat.* The state of affairs *that John is sick* is a complex entity composed of a substance (this person), and a certain quality or disposition (the sickness). The state of affairs *that a certain molecule is*

AKR Advances on Knowledge Representation Journal

attached to a receptor is composed of a substance (the molecule), a part of a substance (the receptor), and the two-place relation of being attached.

One problem with attempts to specify the ontology of states of affairs turns on an apparent redundancy which arises from the fact that, if we are representing (for example) the aforementioned ball, then we are already representing something that is green. If we now represent the state of affairs *that the ball is green*, and if we assume that this state of affairs includes all that exists on the side of reality that is salient to (part of the truthmaker for) our representation, then the ball's greenness quality – in contrast to its other qualities of being round, weighing 4 ounces, being made of plastic – would seem to figure twice in the state of affairs that we are representing. It figures once as it were *coiled up inside the object* alongside all its other qualities, and then again as somehow uncoiled, or made in some sense explicit, by our representation (Ingarden 1965, II/1 §§ 39–42; Smith 1978). This seems, however, to add an unfortunate epistemological or cognitive or language-dependent dimension[20] to the idea of a state of affairs, which makes such entities not strictly ontological. Part of the background behind the idea of 'truthmakers' (Mulligan, Simons & Smith 1984) was the aim of providing the means to solve this problem.

On the other hand there are states of affairs where an epistemological dimension is ontologically in order – where the epistemological dimension is part of the objective reality which makes the corresponding assertion true. Consider the state of affairs *that the doctor believes that her patient has the flu*. This is composed of the doctor and the intentional relation of believing, and (if the doctor has a true belief) of the further state of affairs *that the patient has the flu*.

From the perspective of applied ontology we can now identify at least part of the reason for the contemporary disregard of states of affairs as lying in the difficulty we face if we attempt to construct logically coherent taxonomies of states of affairs in the face of the sorts of combinatorial explosions we encounter in taking account of intentional relations such as this.

6.2 Sets

Sets are well known from mathematics, where the term (in German '*Menge*') was introduced by Cantor in 1883 to refer to 'a collection *M* of definite, well-differentiated

[20] Compare Strawson (1950): "If you prise the statements off the world you prise the facts off it too; but the world would be none the poorer."

AKR Advances on Knowledge Representation Journal

objects *m* […] into a whole'.[21] Mathematical views of sets proceed axiomatically, and a number of different axiomatic set theories have been devised. We are interested here, however, in how set theory in general might help us in understanding the sorts of classification or categorization of real-world entities in which ontologists are interested. Does it make sense, for example, to try to understand Aristotle's list of categories, or the ontological square, in set-theoretic terms? Does it make sense to understand real-world phenomena such as a horse race or a ride on the L Train in terms of set theory? Can even a stamp collection be correctly described as a *set* of stamps?

To answer this question, we note that sets can be represented either by simply listing their elements or by pointing to a common feature of these elements. As examples of the first, we can write '{2, 3, 5, 7}' or '{Aristotle, 2, my stethoscope}', reflecting the fact that sets can be built out of unrelated elements. As an example of the second, we can write 'set of prime numbers less than 10'. Here we represent a set by specifying certain necessary and sufficient conditions for membership. Further examples would be 'the set of all patients in Leipzig at noon on November 1, 2008', or 'the set of all such patients with a fever'.

Sets are identical if and only if they contain the same elements. From this it follows that sets are in a certain sense timeless; hence: sets can include elements which exist at different times and at no times. They are also outside space (if the elements of a set move about in space the set is not affected in any way). Sets are in all of these respects distinguished from other collections – for example, my stamp collection or your collection of cancer tissue samples – in that its members are fixed, though this feature that is not clearly captured in Cantor's definition). This means that sets are something abstract; they live outside the world of what happens and is the case.

In his "Against Set Theory", Peter Simons quotes a number of authorities in set theory who have, as he says, pulled the wool over the eyes of philosophers and others by presenting sets as something wholly natural and uncontroversial:

> The technique, usually applied on or about page 1 of a textbook of set theory, is to claim that we are already familiar with sets under some other names or guises, and then trade on this supposed familiarity to sell us a bill of fare which is ontologically far from neutral and far from benign.

Simons quotes several authorities from mathematics and logics:

[21] Translation taken from Oliver & Smiley 2018. The German original (Cantor 1895, 481 and 1932, 282) reads: "Unter einer 'Menge' verstehen wir jede Zusammenfassung *M* von bestimmten wohlunterscheidbaren Objecten *m* […] zu einem Ganzen."

AKR Advances on Knowledge Representation Journal

> Consider a collection of concrete objects, for instance of the apples, oranges etc. in a fruit shop. We may call it a set of fruit, the individual apples etc. being the members (or elements) of the set. Conceiving the collection as a new single concept is an elementary intellectual act. (Fraenkel 1953, 4)

Or:

> In our examples, sets consisted of concrete and familiar objects, but once we have sets, we can form sets of sets, for example the set of all football teams. (Van Dalen, Doets and de Swart 1978, 1)

So, as Simons goes on, "one can buy a set from a fruiterer, or we can buy a set called 'Manchester United' or 'Juventus'" (Simons 2005). Because they exist outside space and time, however, sets are peculiar entities, in ways which would forestall their use for the sorts of ontological purposes pursued by Aristotle or Lowe or by contemporary applied ontologists.

6.3 Mereology: Wholes and Their Parts

The mentioned problems have induced some logicians and philosophers to develop an alternative to the set-theoretic approach under the heading of 'mereology'[22], and like set theory, mereology has been subjected to a number of different axiomatizations (Simons 1992; Varzi & Cotnoir 2021).

In the world of sets, every element is just what it is, and has the granularity that it has – whether this be of molecules, of cells, of whole organisms or of entire populations. Mereological sums, in contrast, are concrete entities that can be partitioned on various levels of granularity. Each human being is an organism, and a mereological sum of cells, and a mereological sum of molecules – and all of these are at any given time identical. Moreover, in mereology – as contrasted with set theory – there is no requirement that an ultimate bottom layer of mereological simples needs to be specified or accepted (Smith & Brogaard 2002).

My stomach, my sandwich, and the Midwestern US states can each comprise such a mereological sum. Just as with sets, there is, on some formalizations, virtually no limitation to the building of mereological sums. And just as with sets, many mereological sums (such as the sum of Napoleon and the pebbles in this bowl) have an artificial character, though some have sought axiomatic ways of restricting mereology in such a

[22] Simons, 1987; Ridder, 2002; see also Husserl's third *Logical Investigation*, "On the theory of wholes and parts" (Husserl 1970).

AKR Advances on Knowledge Representation Journal

way as to allow credence only to what we can think of as 'natural wholes' (see Simons 2006).

While sets are abstract entities even when composed of concrete elements, mereological sums composed of concrete elements are themselves concrete. Mereological sums exist in space and time, but only – on most formalizations – for so long as all of their parts exist. Like membership in set theory, parthood is temporally rigid in classical mereology: A mereological sum does not survive the loss or destruction of even one of its parts. Gaining or losing a part will result in *another* mereological sum.

In many ontologies, part-whole relations are used as formal-ontological relations. The theory of granular partitions (Bittner & Smith 2001, 2003) introduces an approach which attempts to blaze a third trail between set theory and mereology by linking the concreteness of mereological sums with the hierarchical nature of the element-of relation.

6.4 Classes

Although the words 'set' and 'class' are often used as synonyms, we will here use them to signify different things. In many standard mathematical treatments, sets can be composed arbitrarily by placing singular terms between curly brackets as in: {Aristotle, the year 1969, New York}. But there are also sets that are defined by means of a uniform property, or a conjunction of such properties, as in: like the class of all things that are red, or the class of all humans, or the class of all electric charges. We will reserve the term 'class' for collectives of the latter sort..

This is the approach followed by Smith and Ceusters (2006, 60) for whom 'class' signifies 'a collection of all and only the particulars to which a given general term applies'. When the general term connected to a class represents a universal, we can speak of a *natural class*, which is the totality of instances of a universal. Where sets may be constructed by enumeration of their members, natural classes require that there be universals of which they are the extension. Two natural classes are identical if their defining general term represents the same universal. Because not all general expressions correspond to universals, not all classes are natural classes. The non-natural classes are called 'defined classes', as for example: the class of diabetics in Paris on a certain day, or the class of Italian restaurants in San Diego.

Where sets can have members of arbitrarily different sorts, 'class' on this reading refers to collections of members which are in some sense constrained, as for example in:

AKR Advances on Knowledge Representation Journal

the class of mammals, the class of red things, the class of electrons. The account of classes suggested here thus attempts to mitigate the arbitrary features of set construction.[23]

Unlike what is the case in set theory, class theory does not require us to know what things there are in the world in order to say, for example, that the class of red things and the class of round things are different from one another.

In addition, natural classes, but not sets, can survive the destruction or coming into existence of new instances; for sets are individuated by their elements, where natural classes are individuated by a (possible) universal which stays the same even as it has different instances at different times.[24]

The result of dividing entities into classes is called a *classification*. Instead of speaking of a class we sometimes speak of a *taxon*, which is derived from the Greek *tattein* meaning: to place in order, which form in turn the nodes of a *taxonomy*. A taxonomy must be distinguished from a *partonomy*. While a classification or a taxonomy divides a universal into species or kinds, a partonomy divides a whole into its parts.

7. Top-Level Ontologies Today

What should an ontology look like at the highest level? In this essay, we used Aristotle's *Categories* as a guideline for our understanding the development of crucial ontological distinctions that underlie many modern top-level ontologies, including BFO. We already pointed out that Aristotle focusses mainly on continuants and does not really develop the analysis of occurrents. BFO addresses this problem by enriching the ontological square to form the ontological sextet.

There is another respect in which Aristotle's analysis should be supplemented. As presented in the foregoing, Aristotle's theory of categories conforms to a high degree with our common-sense understanding of reality. It shares with common sense above all a view of the world as of a single granularity – the granularity of organisms and their qualities – where our contemporary scientific understanding requires a multi-granular approach, incorporating cells and cell components, molecules, atoms, electrons, and so forth, as well as planets, stars, galaxies, black holes, and other entities dealt with by cosmology.

[23] There are earlier attempts to link intensional elements with set theory; for example, in Feibleman, 1974. The remarks presented here draw on Johannson 2006. See also Smith 2005b and Smith *et al*. 2005.
[24] We here leave open the question as to how one might deal with the natural class corresponding to the universal *dodo.*

AKR Advances on Knowledge Representation Journal

Reality, on this approach, appears as a complex hierarchy of levels that are nested within each other. Molecules are embedded in the interior of cells, cells in leaves, leaves in trees, trees in forests and so on (Smith 2001). As our everyday perceptions and actions are tuned to the entities appearing on the level of the common-sense world, so various sciences are tuned to entities on other levels within this complex hierarchy. For example, there is not only macroscopic anatomy, with offshoots such as clinical, surgical and radiological anatomy, but also microscopic anatomy, with sub-disciplines such as histology, cytology and secondary branches such as anatomical embryology, anatomical genomics, neuroanatomy, and so on. Astronomy, similarly, incorporates multiple disciplines such as planetary science, stellar astronomy, galactic astronomy, radio astronomy, and infrared astronomy, which focus on different aspects of the cosmos at different levels of granularity.

Basic Formal Ontology shares many of the features of the Aristotelian ontology set forth above, but as is made clear throughout the BFO handbook (Arp, Smith and Spear 2015), BFO embraces the principle of perspectivalism, whereby the BFO ontology can be implemented in association with domain ontologies at many different levels of granularity. For example, the BFO class *object* might comprehend cells and cell components in one implementation, and planets and their satellites in another. In this way BFO can serve as an ontology that simultaneously supports both common-sense and scientific realism, doctrines which are otherwise seen as being incompatible.

BFO and its many users thereby provide support for the case that the progress of science is not a step away from Aristotle towards something better, any more than quantum physics is a step away from classical Newtonian physics. Rather, just as quantum physics incorporates the physics of Newton as a limit case, so contemporary science as a whole incorporates many features of Aristotle's ontological approach.

References

Angelelli, Ignazio. Studies on Gottlob Frege and Traditional Philosophy. Dordrecht: Reidel, 1967.

Aquinas. In octo libros Physicorum Aristotelis exposition, ed. Maggiòlo, Turin-Rom: 1965.

Aristotle. Categoriae, transl. by E.M. Edghill, in: The Works of Aristotle, ed. W. D. Ross, vol. 1, Oxford: Oxford University Press, 1928, repr. 1994.

Aristotle. The Complete Works of Aristotle (Revised Oxford translation). ed. Jonathan Barnes. Princeton,1984.

AKR Advances on Knowledge Representation Journal

Austin, John L. “Truth”, Proceedings of the Aristotelian Society, Supplementary Volumes 24 (1950), 111–128.

Chrudzimski, Arkadiusz. “Carl Stumpf über Sachverhalte”. In: Denis Fisette & Riccardo Martinelli (eds.), Philosophy from an Empirical Standpoint: Essays on Carl Stumpf. Rodopi 2015.

Armstrong, David M. Nominalism and Realism: Universals and Scientific Realism, Volume I. Cambridge 1978.

Armstrong, David M. A World of States of Affairs. Cambridge: Cambridge University Press, 1997.

Arp, Robert; Smith, Barry; Spear, Andrew D. Building Ontologies with Basic Formal Ontology, Cambridge, MA: MIT Press, 2015.

BFO, Basic Formal Ontology, http://basic-formal-ontology.org/.

Bigelow, John; Leckey, Martin, “Two Kinds of Platonism and Categorial Semantics”. In: Helen Beebee, A. R. J. Fisher (eds), Perspectives on the Philosophy of David K. Lewis, Oxford: Oxford University Press, 2022, 154–173.

Bittner, Thomas, and Barry Smith. "A taxonomy of granular partitions." International Conference on Spatial Information Theory, Berlin, Heidelberg: Springer Berlin Heidelberg, 2001. 28–43.

Bittner, Thomas and Barry Smith, A Theory of Granular Partitions, Foundations of Geographic Information Science, M. Duckham, M. F. Goodchild and M. F. Worboys, eds., London: Taylor & Francis Books, 2003, 117–151

Brentano, Franz. Von der mannigfachen Bedeutung des Seienden nach Aristoteles. Freiburg/Brsg: 1862.

Bucher, Thomas. Einführung in die angewandte Logik, 2nd edition, Berlin 1998

Campbell, Keith. Abstract Particulars. Oxford: Basil Blackwell, 1990.

Cantor, Georg. “Beiträge zur Begründung der transfiniten Mengenlehre.” Mathematische Annalen 46 (1895) 481–512.

Cantor, Georg, Gesammelte Abhandlungen mathematischen und philosophischen Inhalts, ed. Richard Dedeking, Berlin: Springer 1932.

Davidson, Donald. “Events and Particulars”, Noûs, 4 (1), 1970, 25–32

Davidson, Donald. “The Logical Form of Action Sentences.” Essays on Actions and Events. ed. Donald Davidson. Oxford: Clarendon Press, 1980.

Donald Davidson, “Events and Particulars”, Noûs 4:1 (1970): 25–32.

AKR Advances on Knowledge Representation Journal

Donnelly, M. Endurantist and perdurantist accounts of persistence. Philosophical Studies 154, 27–51 (2011). https://doi.org/10.1007/s11098-010-9526-z.

Faroldi, Federico LG, and Frederik Van De Putte. Kit Fine on Truthmakers, Relevance, and Non-classical Logic. Springer, 2023.

Feibleman, James K. "Professor Quine and Real Classes." Notre Dame Journal of Formal Logic 15 (1974): 207–224.

Fraenkel, Abraham A. 1953 Abstract Set Theory, Amsterdam: North-Holland.

Frege, Gottlob. "Begriff und Gegenstand." Breslau: Koebner 1884, in: Vierteljahrschrift fur wissenschaftliche Philosophie 16 (1892): 192–205.

Frege, Gottlob. The Foundations of Arithmetic: A Logico-Mathematical Enquiry into the Concept of Number. Trans. J. L. Austin. Oxford: Basil Blackwell, 1980.

Goodman, Nelson; Leonard, Henry S., "The Calculus of Individuals and Its Uses", Journal of Symbolic Logic 5 (1940): 45–55.

Grenon, Pierre. "Spatio-temporality in Basic Formal Ontology, SNAP and SPAN, Upper Level Ontology, and Framework for Formalization, PART I." IFOMIS Reports, ISSN 1611-4019, November, 2003.

Grenon, Pierre and Barry Smith. "SNAP and SPAN: Towards Dynamic Spatial Ontology." Spatial Cognition and Computation 4 (2001): 69–103.

Grenon, Pierre, Smith, Barry, Goldberg, Louis. "Biodynamic Ontology: Applying BFO in the Biomedical Domain." Ontologies in Medicine: Proceedings of the Workshop on Medical Ontologies, Rome, October 2003. ed. Pisanelli, Domenico M. Amsterdam: IOS Press, 2004, 20–38

Guarino, Nicola. "Review of Sowa's Knowledge Representation." AI Magazine, 2/3 (2001). 123–124.

Hochberg, Herbert. "Moore and Russell on Particulars, Relations and Identity." Studies in the Philosophy of G. E. Moore. ed. E. D. Klemke. Quadrangle books, 1969.

Hochberg, Herbert. "Things and Descriptions." American Philosophical Quarterly 3 (1966): 1–9.

Hochberg, Herbert. "Universals, Particulars and Predication." Review of Metaphysics 19 (1965): 87–102.

Husserl, Edmund, Logical investigations. Vol. 2, transl. by J. N. Findlay from the second German edition, London : Routledge & Kegan Paul, 1970.

Ingarden, Roman. Der Streit um die Existenz der Welt. Vol. II/1, Niemeyer, Tübingen 1965. English translation: Controversy over the Existence of the World. Vol. II, translated by Arthur Szylewicz, Bern: Peter Lang, 2016.

AKR Advances on Knowledge Representation Journal

Ingarden, Roman. The Literary Work of Art, Evanston IL: Northwestern University Press 1974.

Jansen, Ludger. "Aristoteles' Kategorie des Relativen zwischen Dialektik und Ontologie." Philosophiegeschichte und logische Analyse 9 (2006): 79–104.

Jansen L, "Aristotle's Categories", in: Topoi 26 (2007) 151–158.

Jansen, Ludger. "Categories: The top-level ontology". Applied Ontology. An Introduction, eds. K Munn, B. Smith, Frankfurt: Ontos 2008.

Jansen L, "The Fullness of Being. Why Property Nominalism and Physicalism Are Falling Short of the Demands of Philosophy of Religion." International Journal for Philosophy and Public Affairs 2-3 (2014/15) 17–30. https://www.interjournalphilpubaffairs.com/Contents_Contribu.aspx?cId=1007.

Jansen L, Art. "Substance", in: Hans Burkhardt, Johanna Seibt, Guido Imaguire (eds.), Handbook of Mereology, München: Philosophia 2017.

Johansson, Ingvar. "Four Kinds of 'Is_A; Relations: Genus-subsumption, Determinable-subsumption, Specification, and Specialization." Contributions to the Third International Workshop on Philosophy and Informatics, Saarbrücken 2006 (IFOMIS Reports 14). eds. Ingvar Johansson, Bertin Klein, Thomas Roth-Berghofer. WSPI (2006: 47–62.

Johansson, Ingvar. "Qualities, Quantities, and the Endurant-Perdurant Distinction in Top-Level Ontologies." WSPI '05. Proceedings of the Second International Workshop on Philosophy and Informatics. CEUR-WS 130 (2005), eds. G. Büchel, B. Klein, Th. Roth-Berghofer, <http://CEUR-WS.org/Vol-130/>.

Johnson, William E. Logic, Part I. Cambridge: The University Press at Cambridge, 1921.

Kahn, C. H. "Questions and Categories." Questions. ed. Henry Hiz. Dordrecht/Boston: Reidel, 1978. 227–278.

Kant, Immanuel. Critique of Pure Reason, trans. Norman Kemp Smith. London: MacMillan, 1950.

Koslicki, K. Varieties of Ontological Dependence. In F. Correia and B. Schnieder (eds.), Metaphysical Grounding: Understanding the Structure of Reality. Cambridge: Cambridge University Press 2012, 186–213.

Lewis, David. On the Plurality of Worlds. Oxford: Oxford University Press, 1986.

Lowe, E. J. The Four-Category Ontology: A Metaphysical Foundation for Natural Science. Oxford: Oxford University Press, 2006.

Lowe, E. J. A Survey of Metaphysics. Oxford/New York: Oxford University Press, 2002.

AKR Advances on Knowledge Representation Journal

Macdonald, Cynthia. “Tropes and Other Things.” Contemporary Readings in the Foundations of Metaphysics. eds. Stephen Laurence and Cynthia Macdonald. Oxford: Basil Blackwell, 1998. 329–350.

McCall, Storrs and E.J. Lowe. “The Definition of Endurance, Analysis 69 (2009): 277–280.

Milkov, Nikolay, Hermann Lotze's Influence on Twentieth Century Philosophy, Berlin: de Gruyter 2023

Mulligan, Kevin, Peter Simons & Barry Smith, “Truth-Makers”, Philosophy and Phenomenological Research 44 (3):287–321 (1984)

Munn, Katherine, “Introduction: What is Ontology for”, in K. Munn and B. Smith (eds.), Applied Ontology: An Introduction, Berlin: de Gruyter, 2008, 7–19.

Oliver, Alex and Timothy Smiley, “Cantorian set theory”, Bulletin of Symbolic Logic 24 (4):393–451 (2018).

Ontology portal, as of August 8, 2006, http://www.ontologyportal.org/ (as of August 8, 2006).

Plato. “Phaedrus.” Plato: The Collected Dialogues Including the Letters. ed. Edith Hamilton and Huntington Cairns. Princeton: Bollingen Series LXXI, Princeton University Press, 1961.

Plato. “Theaetetus.” Plato: The Collected Dialogues Including the Letters. ed. Edith Hamilton and Huntington Cairns. Princeton: Bollingen Series LXXI, Princeton University Press, 1961.

Quine, Willard Van Orman, “On What There Is”, in: From a Logical Point of View, 2nd edition, revised, Cambridge, Massachusetts: Harvard University Press, 1964, 1–19.

Rosse, Cornelius and Mejino, Jose L V. “A Reference Ontology for Bioinformatics: The Foundational Model of Anatomy.” Journal of Biomedical Informatics 36 (2003), 478–500.

Russell, Bertrand. Human Knowledge: Its Scope and Limits. London: Allen & Unwin, 1948.

Russell, Bertrand. An Inquiry into Meaning and Truth. New York: Norton 1940.

Simons, Peter. Parts. A Study in Ontology. Oxford: Clarendon Press, 1987.

Simons, Peter. “Categories and Ways of Being.” Philosophy and Logic in Central Europe from Bolzano to Tarski. Selected Essays. ed. Peter Simons. Dordrecht/Boston/London: 1992. 377–394.

Simons, Peter. “Against Set Theory.” Erfahrung und Analyse. eds. M. E. Reicher and J. C. Marek. Vienna: HPT&ÖBV, 2005, 143–152, 145.

Simons, Peter. “Real wholes, real parts: Mereology without algebra.” The Journal of Philosophy 103.12 (2006): 597–613.

Smith, Barry. “An Essay in Formal Ontology”, Grazer Philosophische Studien 6 (1):39–62 (1978).

Smith, Barry. “The substance of Brentano’s ontology”, Topoi 6:1 (1987) 39–49.

Smith, Barry. “Sachverhalt”, Historisches Wörterbuch der Philosophie, Volume 8. Basel: Schwabe, (1992), 1102–1113.

Smith, Barry. “Realistic Phenomenology”, in: Lester Embree (ed.), Encyclopedia of Phenomenology. Kluwer Academic Publishers 1996, pp. 586–590.

Smith, Barry & David M. Mark. “Geographical categories: an ontological investigation”, International Journal of Geographical Information Science 15.7 (2001): 591-612.

Smith, Barry. “On Substances, Accidents and Universals. In Defence of a Constituent Ontology”, Philosophical Papers, 27 (1997), 105–127.

Smith, Barry. “Objects and their environments: From Aristotle to ecological ontology”. In: Andrew U. Frank, et al. (eds.), The Life and Motion of Socio-Economic Units. London: Taylor & Francis, 2001. 79–97.

Smith, Barry. “Aristoteles 2002.” In: Kann man heute noch etwas anfangen mit Aristoteles? eds.Thomas Buchheim, Hellmut Flashar and Richard A.H. King. Darmstadt: Meiner Felix Verlag, 2003.

Smith, Barry. “Against Fantology.” Experience and Analysis. eds. M. E. Reicher and J. C. Marek. Vienna: HPT&ÖBV, 2005 (cited as Smith 2005a).

Smith, Barry. “The Logic of Biological Classification and the Foundations of Biomedical Ontology.” Logic, Methodology and Philosophy of Science. Proceedings of the 12th International Conference. eds. Peter Hájek et al. London: King’s College Publications, 2005. 505–520 (cited as Smith 2005b).

Smith, Barry. “Biomedical Ontologies.” In: P. L. Elkin (ed.), Terminology, Ontology and their Implementations, Springer 2022, 125–169.

Smith, Barry & Berit O. Brogaard, “Quantum mereotopology”, Annals of Mathematics and Artificial Intelligence 2002, 36 (1):153–175)

Smith, Barry & Werner Ceusters. “Ontology as the Core Discipline of Biomedical Informatics. Legacies of the Past and Recommendations for the Future Direction of Research.” Computing, Philosophy, and Cognitive Science, eds. G. D. Crnkovic and S. Stuart. Cambridge: Cambridge Scholars Press, 2006.

AKR Advances on Knowledge Representation Journal

Smith, Barry, et al. “Relations in Biomedical Ontologies.” Genome Biology 6 (2005): R46.

Smith, Barry, et al. (2006). Towards a Reference Terminology for Ontology Research and Development in the Biomedical Domain. In Proceedings of KR-MED, CEUR, vol. 222. pp. 57–65.

Smith B, et al. (2007). “The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration.” Nature Biotechnology 25 (11): 1251–5.

Van Dalen, Dirk, Doets, H. C., and de Swart, H. 1978 Sets: Naïve, Axiomatic and Applied, Oxford: Pergamon.

Varzi, Achille C; Cotnoir, A. J. Mereology. Oxford: Oxford University Press 2021.

Wachter, Daniel von. Dinge und Eigenschaften, Dettelbach: Verlag J. H. Röll 2000.

Williams, D.C. “The Elements of Being.” Review of Metaphysics 7 (1953): 3–18 and 171–192.

Williams, Donald C. The Elements and Patterns of Being: Essays in Metaphysics. Oxford University Press 2018.

Wittgenstein, L. Tractatus logico-philosophicus. Tagebücher 1914–1916. Philosophische Untersuchungen. Schriften, vol. 1. Frankfurt am Main: Suhrkamp 1960.