Towards an Ontological Analysis of Powertypes

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Abstract

In several subject domains, the categorization scheme itself is part of the subject matter. In this case, experts make use of categories of categories in their accounts. This has led to a number of approaches in conceptual modeling and knowledge representation that are called *multi-level modeling approaches*. An early approach for multi-level modeling is the powertype pattern which introduces "power types" and "base types". More recently, other proposals for multi-level modeling include "clabjects", "m-objects", which admit the existence of entities being somehow, simultaneously, types (classes) and instances (usually associated to objects). Regardless of the choice of approach to perform multi-level modelling, a question remains concerning the ontological status of "base types", "power types" and "clabjects". This paper aims to address this question through an ontological analysis. We use here the general term *powertype* to generally refer to types whose instances exhibit it somehow both type-like and instance-like characteristics. We examine alternative accounts for powertype instances: (i) powertype instances as universals (abstract repeatable entities), (ii) powertype instances as mereological sums of instances of an associated type and (iii) powertype instances as variable embodiments. We conclude that the latter is the most promising account for an ontological interpretation of this phenomenon that meets the modelling desiderata for powertypes present in the literature.

Introduction

In several subject domains, the categorization scheme itself is part of the subject matter. In this case, experts make use of categories of categories in their accounts. For instance, in the domain of human resource management, organizations are often staffed according to *employee types* (e.g. "Engineer", "Pilot", "Secretary"). Managers may need to distinguish between different kinds of *employee types* giving rise to *types of employee types*. For instance, "Engineer" and "Pilot" could be considered as examples of "Technical Employee Type", as opposed to "Secretary" which is an example of "Administrative Employee Type". At the same time, managers may need to track the allocation of personnel to specific departments (e.g. John is an engineer in the Maintenance Department). So, within the same conceptualization they need to represent entities belonging to different (but nonetheless related) classification levels, such as *individual persons* ("John"), *employee types* ("Engineer", "Pilot", "Secretary"), and *types of employee types* ("Technical Employee Type", "Administrative Employee Type"). Other examples of multiple classification levels come from domains such as software engineering [1], biological taxonomy [2] and product manufacturing [3].

The need to support the representation of subject domains dealing with multiple classification levels has given rise to what has been referred to as multi-level modeling [3] [4]. Techniques for multi-level conceptual modeling must provide modeling concepts to deal with types in various classification levels and the relations that may occur between those types. The interest in multi-level modeling has led to a number of research initiatives in this subject (e.g. [1], [3], [4], [5], [6]). The relevance of multi-level modeling for knowledge representation and reasoning has also been explored in the literature (e.g., [7]).

An example of an early approach for multi-level modeling in software engineering is the *powertype* pattern [5] [6]. This approach is used to model situations in which the instances of a type (the *power type)* are specializations of a lower-level type (the *base type)*, and both power types and base types appear as regular classes in the model. This approach is adopted in the current version of the Unified Modeling Language (UML) [8], which allows modelers to specify a powertype in the context of a "generalization set". Other prominent approaches for multi-level modelling (such as [9]) propose to address multiple levels of classification independently of the specification construct. They treat the instantiation between arbitrary adjacent levels uniformly [10], i.e., they defend that the nature of the relation linking specific individuals to their types is the same as the nature of the relation occurring between types of adjacent classification levels (i.e., between types and their metatypes). This view creates a terminological issue, since an instance of a type is commonly called an *object*, so the presence of multiple levels creates entities that are, simultaneously, types (classes) and instances (objects). The authors have coined the term "clabject" to emphasize this dual "facet" of classes in a generalized multi-level scheme.

Regardless of the choice of approach to perform multi-level modelling, a question remains concerning the ontological status of "base types", "power types" and "clabjects". We henceforth use here the general term *powertype* to generally refer to types of a subject domain whose instances exhibit somehow both type-like and instance-like characteristics. This paper aims at clarifying the ontological nature of powertypes by analyzing the nature of their instances. We examine alternative accounts for powertype instances including interpreting them as: *universals* (abstract repeatable entities) [11]; as *mereological sums* of instances of an associated type; and, finally, as *variable embodiments* [12]. We conclude that the notion of variable embodiments is the most promising account for providing an ontological interpretation for powertype instances. In particular, we outline how a theory based on this interpretation can be developed to address a number of requirements for a comprehensive multi-level approach, including the representation of properties of types at multiple levels of classification, and modal properties of powertype instances.

A Running Example

In this section, we make use of a running example to illustrate a number of notions that appear in the literature of conceptual modeling associated to powertypes. In this running example, depicted in Figure 1, we use a case of biological species. The modeling of biological species (and animal breeds alike) is known for exhibiting this type of phenomenon, and is often evoked as a typical example in the literature (see, e.g., "tree species" in [8] and "dog breed" in [10]). In fact, one prominent interpretation of biological species is to take them not as abstract universals (roughly types) but as individuals scattered in space and time [13]. As discussed there, without the interpretation of species as concrete entities existing in time and space, it is challenging to explain biological evolution and to talk about a species changing in time or moving to another typical habitat. It is important to highlight, nonetheless, that we do not intend with this paper to address the problem of what biological species are from an ontological point of view. This is a problem that has occupied philosophers of biology for many years. We use the example here merely to convey some intuitions regarding recurrent modeling requirements that are manifested with the presence of powertypes. In any case, the phenomenon referred to here is also manifested in the cases of product models and social roles, among other cases.

Figure 1 uses a UML class diagram to represent our running example. In this figure, we have the type *Bird* that is specialized in two subtypes, namely, *Emperor Penguin* and *Golden Eagle*. According to this model, particular birds have a particular age and a particular height. Two instances of *Bird* in this model are Pat (a particular *Emperor Penguin*) and Joe (a particular *Golden Eagle*). This model uses the so-called *powertype pattern*, which is incorporated in the UML [8]. The two subtyping relations between the latter types and *Bird* are part of a *generalization set* related to the powertype[1] *Bird Species*. If a powertype *P* is connected to a particular type *T* then the instances of *P* are the *explicit* subtypes of *T* present in the model. The relation that connects *T* and *P* is a regular UML association, labeled here "*is classified by"*, saying that the instances of *T* are *classified by* instances of *P*. In the model of Fig. 1, the powertype *Bird Species* is connected to the type *Bird* by being referred to in the generalization set specializing *Bird* and containing the subtypes *Golden Eagle* and *Emperor Penguin*. Hence, *Golden Eagle* and *Emperor Penguin* are instances of *Bird Species*. Moreover, each instance of these types (e.g., Pat and Joe) is *classified by* some instance of *Bird Species*. For instance, Pat (which instantiates the *type Emperor Penguin*) *is classified by* an instance of *Bird Species* also named *Emperor Penguin*, which is supposed to be the reification of the *Emperor Penguin* type.

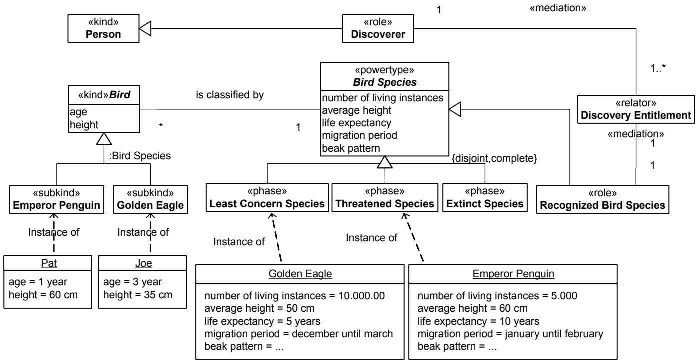

Figure 1 - Representing Powertypes UML ("Types of Types").

Note that instances of *Bird Species* have specific properties (i.e. provide specific values) for all the general properties that characterize the type *Bird Species*. For instance, *Golden Eagle*, the type, may have a *number of living instances = 10.000.000*, an *average height = 50 centimeters*, a *life expectancy = 5 years*, etc. Given that UML does not provide us with a means to represent these properties graphically in class diagrams, we have used the instance specification notation in Figure 1 (which is actually part of the object diagram) to make these properties explicit for *Golden Eagle* and *Emperor Penguin* as instances of *Bird Species*. Notice that these are not properties of particular *Bird*s (e.g., Joe does not have an average height, or a number of living instances), but properties of each species of *Bird*s as a whole.

Indeed, properties such as *number of living instances* or *average height* are properties of instances of *Bird Species* that result from properties of the instances of *Bird* (e.g., the average height of a particular species – *Golden Eagle* – is derived from individual heights of particular instances of *Golden Eagle*). We provisionally term these properties ***resultant properties*** of the species.

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[1] The actual stereotype «powertype» has been deprecated in the UML 2.0 version. The notion of a "type whose instances are types" itself remains in the language. We use the stereotype here in Fig. 1 merely to call attention to the type in the model that is representing this notion. It is also important to highlight that the name "powertype" is a misnomer, given that it does not have the expected properties that one would associate with a powerset. We maintain the name here, however, for the sake of reference to the original UML terminology.

In contrast, properties such as *beak pattern* for *Bird Species* or *maximum speed* for a car model capture regularities over the instances of a particular type. For instances, when representing that the Volvo XC90 type has a *maximum speed* of 300 Km/h, we are capturing that all instances of such type have the particular capacity (disposition, power) of driving at most 300 km/h. To be precise, the Volvo XC90 type does not have a maximum speed at all; it has the *property of having instances that have that property*. In other words, it has the property of bestowing to all its instances the capacity of driving at that speed. We term here these properties ***regularity properties***.

Finally, a property such as being an *Officially Recognized Bird Species* or being *Elected the fastest Car in Europe in 2015* are properties of yet a third kind. For instance, being *Officially Recognized Bird Species* is a property of the type *Golden Eagle* and not a property that any individual instance of *Golden Eagle* has. We provisionally term these properties ***direct properties***. Direct, Resultant and Regularity properties are frequently used in the literature of conceptual modeling and knowledge representation as stereotypical properties inhering in instances of powertypes [3,7].

Now, we would like to call attention to modal issues involving instances of powertypes which should be reflected in an ontologically well-founded conceptual modeling and knowledge representation approach, particularly: (i) the existence of contingent types that classify instances of powertypes (specializations of *Bird Species* in the example) and (ii) the possibility of qualitative change happening to instances of powertypes. These issues are representative of problems in Conceptual Modeling, Knowledge Representation and Ontology Engineering for modeling powertypes. In fact, they should be taken as part of a modeling desiderata that should be addressed if we want to faithfully represent those domain elements that in the literature are typically modeled by using powertypes (or powertype-like notions such as clabjects [4] or m-objects [3]). These include *biological species*, *product types* (e.g., the iPhone 5S type, which is instantiated by individuals like my iPhone, but which also has the property of being created by Jon Ive) and *social roles* and positions (e.g., the role of American President, which is instantiated by Barack Obama, but which has the property of being defined in the American Constitution).

Note in our running example that the type *Bird Species* is instantiated by its instances *necessarily* (in the modal sense), i.e., an instance of *Bird Species* (e.g., *Golden Eagle*) is necessarily a *Bird Species*. These are termed in the literature *Rigid* types [14, 15]. In contrast, we have that the types *Least Concern Species* or *Recognized Bird Species* are instantiated by their instances only *contingently* (again, in the modal sense). In other words, for every instance x of a Recognized *Bird Species*, there is a counterfactual world in which x is not an instance of this type. Types such as *Least Concern Species* (also *Extinct Species*, *Threatened Species*) and *Recognized Bird Species* are termed *Anti-Rigid* types [14, 15].

In contrast with rigid types, instances of anti-rigid types can move in an out of the extension of that type without ceasing to exist. Moreover, there are anti-rigid types termed *phases*, whose instances move in all of their extension due to a change in one or more of its intrinsic properties. For instance, analogous to the manner in which *Adolescent* is defined as phase of *Person* characterized by the intrinsic property *age* (i.e., an *Adolescent* is a *Person* that falls within a certain age range), *Threatened Species* is a phase of a *Bird Species* characterized by the intrinsic property *number of living instances*. Furthermore, there are anti-rigid types termed *roles*, whose instances move in all of their extension due to a change in one or more of its relational properties. For instance, analogous to the manner in which *Employee* is defined as role of *Person* characterized by an *Employment* context (i.e., an *Employee* is a person that participates in an *Employment* relationship with an *Employer*), *Recognized Species* is a role of a *Bird Species* characterized by an official *Discovery Entitlement*. Finally, we have that a *Discovery Entitlement* is an entity that is *multiply existentially dependent* on both the discovered species and on the person playing the role of the discoverer of that species. Entities such as *Discovery Entitlement* are termed *relators* in the literature [15].

Languages such as UML and OWL are oblivious to these modal notions, which are fundamental for conceptual modeling and ontology engineering [14, 15, 16]. In contrast, in an ontology-driven language such as OntoUML [15], ontological notions such as *kinds* (i.e., rigid types that capture essential properties of their instances that provide a uniform principle of identity for these instances), *phases*, *roles* and *relators* are directly represented by the modeling primitives of the language.

What's in a Powertype?

Understanding the relation between *Emperor Penguin* or *Golden Eagle* as subtypes of *Bird* (henceforth, for simplicity, *Penguin-T* and *Eagle-T*) and *Emperor Penguin* or *Golden Eagle* as instances of *Bird Species* (henceforth, for simplicity, *Eagle-I* and *Penguin-I*) amounts to a large extent to understanding the ontological nature of powertypes and their instances. *Mutatis mutandis*, the same can be said for the relation between the *instantiation* relation between, say, Joe and *Eagle-T* and the "*is classified by"* relation between Joe and *Eagle-I*. Exploring the ontological nature of these notions is the goal of following sections.

Are instances of Powertypes Universals?

For instance, suppose that *Eagle-I* and *Penguin-I* are *universals*. By universals here we mean, the so-called *realist view on universals*, i.e., that universals are abstract predicative terms that are repeatable across multiple instances. This view includes the conception of universals as *"patterns of features that are not related to time and space"* [17], the view that complex universals are fully determined by *an axiomatic specification involving a number of other universals representing its essential features* [18], as well as the view that universals are fully determined by the higher-order types they instantiate [11]. In any case, universals cannot change in any respect maintaining their identity. Notice that these characteristics of abstract universals are generally considered appropriate to characterize *types* such as *Bird*, *Person*, *Bird Species*, as well as the *types Golden Eagle* (*Eagle-T*) and *Emperor Penguin* (*Penguin-T*).

Now, if the relation between *Eagle-T* and *Eagle-I* is one of identity, we have that: (i) *Eagle-I* is an abstract universal (a type); (ii) the relation of instantiation is identical to the relation "*is classified by"*; (iii) *Bird Species* is a higher-order universal, i.e., an abstract universal whose instances are abstract universals. This interpretation seems to be the one favored by authors such as Odell [5]. Under this interpretation, we have that the relation between Pat and the universal *Penguin-T* is one of *instantiation* but so is the relation between *Penguin-I* and the universal *Bird Species*, as well as the relation between Pat and *Penguin-I*. In other words, we have that *Penguin-I* and *Eagle-I* are universals and *Bird Species* is a higher-order universal.

Higher-Order universals are controversial in philosophy. Philosophers of the so-called *Elementarist* guise reject them [19], and even those that accept their existence seem to accept only the existence of *formal higher-order universals* (as opposed to material ones). For instance, in his classical book on the subject [11], D.M. Armstrong defends the view that universals should bestow causal powers to their instances and, although one can accept formal higher-order properties such *as being a complex universal*, (or *being self-identical, being directly instantiable, or being rigid*) there seem to be no causal powers that are bestowed over universals by virtue of instantiating a higher-order universal.

Now, even if one accepts the existence of higher-order universals, there are other reasons for rejecting that entities such as *Eagle-I* and *Penguin-I* are abstract universals at all. The reason is that we would like to represent possible changes that these entities can undergo, i.e., these entities can suffer qualitative changes and still remain the same. For instance, biological species can move to an endangered species phase (e.g., being extinct is a contingent property of dinosaurs), they can change migration periods and life expectancies. Moreover, we would like to represent that these entities can bear both *essential* and *accidental* properties and, hence, that these entities could have been different from what they are, i.e., that there can be cross-world identity for entities such as *Eagle-I* and *Penguin-I*. Finally, we would like to represent that an entity such as the species *Penguin-I* exists only contingently, begins to exist in a given point in time and can cease to exist. *Mutatis Mutandis*, we can say the same for social roles or any nominal kind for that matter.

In summary, the problem that we have with this first interpretation is that, in the standard ontological interpretation of universals (as repeatable abstract entities) [11], they are abstract and fully determined entities. As such, they cannot change and cannot be different from what they are. Things become even more complicated if universals are conceived as *"not related to time and space"*. As such, they are also not contingently created or destroyed.

Are instances of Powertypes Mereological Sums?

In the previous section we have attempted at an interpretation instances of powertypes as abstract universals. We have concluded that it is an undesirable interpretation and that under that interpretation *Eagle-I* and *Penguin-I* cannot be identical to entities such as *Eagle-T* and *Penguin-T*, respectively. This is because, ontologically speaking, they bear incompatible ontological meta-properties. Entities of the latter kind are abstract fully determined entities and, as such, have no spatiotemporal properties, are incapable of change and, hence, incapable of being different from what they are. In contrast, entities of the former kind seem to have contingent properties. This motivates us to look for an alternative interpretation for them.

In this second interpretation, entities such as *Eagle-I* and *Penguin-I* are considered *mereological sums*, and entities such as *Eagle-T* and *Penguin-T* (again) as universals. The relation between *Eagle-I* and *Eagle-T* is the following: *Eagle-I* is a collective defined by the mereological sum of the instances of *Eagle-T*, i.e., entities such as *Eagle-I* are the population of the extension of types such as *Eagle-T*.

This second interpretation seems at first to be rather intuitive. Under this view, an instance of *Bird Species* such as *Eagle-I* is an *Eagle* collective that has as members exactly the instances of the type *Eagle-T*. In fact, for each subtype *S* of *Bird*, we can have a collective *C* such that $\forall x(x::S \leftrightarrow memberOf(x,C))$. Moreover, as discussed in depth in [20], the *member of* relation has a number of properties shared with the instantiation relation, namely, it is an irreflexive, asymmetric and anti-transitive relation. Additionally, resultant properties of instances of a powertype (e.g., number of living instances, average height, life expectancy) seem at first to be indeed properties of a population/collective.

This view, however, also faces some challenges. Firstly, as a mereological sum, *Eagle-I* has an *extensional identity* criterion. As a consequence, any change in its membership would create a different individual. In other words, when Joe is born or when it dies, it would create a new *Golden Eagle* species. This seems to be an absurd conclusion. We would not want the species *Golden Eagle* (*Eagle-I*) to necessarily change at each variation of the extension of the type *Golden Eagle* (*Eagle-T*). Of course, the population of *Golden Eagle*s changes. But this seems to be an indication that *Eagle-I* (the species) is not the same as the *Golden Eagle* population (the collective).

Secondly, a mereological sum depends on the existence of at least one its members in order to exist. However, *Eagle-I* can exist in an extinct phase having the property *number of living instances = 0* and having no members at all! In this case, if *Eagle-I* is a mereological sum of instances, it would not exist at all, instead of existing in that particular phase and having that particular property.

One way out of this situation would be to have *Eagle-I* to be not the sum of the extension of *Eagle-T* at a given world, but the sum of the union of the extension of *Eagle-T* in all possible worlds. In other words, *Eagle-I* is the sum of all possible eagles that ever existed, will ever exist and could possibly have existed or possibly will exist. As defended, for instance, by [21], our psychological conception of a type seems to account for an extension that considers all its possible instances.

This move solves the first of our previous objections: *Eagle-I* would not change when Joe comes into existence since, being a possible *Golden Eagle*, Joe is already a member of *Eagle-I*. This amendment, nonetheless, faces challenges of its own. In particular, it does not meet our criteria for having *Eagle-I* as an entity that can qualitatively change maintaining its identity and could have been different from what it is. As the sum of all possible individuals of that type, *Eagle-I* is (by definition) always the same in all possible worlds! Hence, it cannot go through phases; it cannot change any of its properties; it cannot exist *having no living instances* (i.e., it cannot exist as an extinct species).

Instances of Powertypes as Variable Embodiments

In order to advance towards an ontological interpretation of powertypes that meets the desiderata discussed in our second section, we propose a slight variation of Kit Fine's *Theory of Embodiment*. This theory is described briefly in the sequel. For a complete description of the approach, one should refer to [12].

In this theory, Fine starts by recognizing that there is both a formal and a material aspect to parthood. As also put by [22], genuine objects are *integral individuals* and not mere mereological sums. Integral objects, but not sums, obey a *unifying principle* that binds all parts together, thus, individuating the whole. This unity principle is akin to what Fine calls the *form* of the whole. For Fine, a number of individuals *"$x_1 \ldots x_n$ standing on a relation R"* form a *Rigid Embodiment* (symbolized as $x_1 \ldots x_n/R$). For instance, a set of flowers $f_1 \ldots f_n$ standing on the relation of being bunched form a "bunch of flowers". He then puts forth a number of postulates for rigid embodiments. For instance, a rigid embodiment $x_1 \ldots x_n/R$ exist in world w iff R holds of the x_i's in w; if a rigid embodiment $x_1 \ldots x_n/\mathrm{R}$ exist in world w then it is located in p in w iff at least a x_i is located in p in w. Moreover, two rigid embodiments $x_1 \ldots x_n/R$ and $x_1' \ldots x_n'/R'$ are the same iff $x_i = x_i'$ and $R = R'$, i.e., if they have the same components standing in the very same unifying relation R.

One should notice that an entity such as a *Golden Eagle* collective in the previous discussion can be seen as a rigid embodiment in Fine's sense. At any given world w, it is composed of exactly the instances of the type *Golden Eagle* at w. In other words, the *Golden Eagle* population at w is the sum of the entities that stand in the relation of *being an instance of the Golden Eagle type (Eagle-T) at w.* If at any world, the extension of the latter changes, we have a different rigid embodiment (collective, population). However, differently from a mere mereological sum, a *Golden Eagle* population starts to exist as soon as instances of the type *Golden Eagle* exist. Moreover, these collectives are unified by a genuine unifying principle, namely, by the closure system defined by the instantiation relation to the type S, i.e., $\forall x,w(x::_w S \leftrightarrow memberOf(x,C,w))$, where C is the collective – e.g., the population of *Golden Eagle*, S is the appropriate subtype of *Bird* - e-g., *Eagle-T* - and $x::_w S$ symbolizes that x is an instance of S in w).

In addition to rigid embodiments, Fine proposes the notion of *Variable Embodiments*. He explains this notion by using the following simple analogy: *"We may talk of 'the water in a river.' But this phrase may be understood in two rather different ways. On the one hand, it may be taken to signify that given quantity of water that is, at a given time, the water in the river. In this sense of the phrase, the water in the river at one time is rarely, if ever, the same as the water at another time. On the other hand, the phrase may signify a variable quantity of water—that water, whatever it is, that is in the river. It is in this sense of the phrase that we may say that the water in the river is rising, since it is the very same thing that was once relatively low and now is relatively high. I take it that the water in the river in the second sense—what we may call the variable water—is now constituted by one quantity of water and now by another. But what is the variable water? Clearly, it is not any one of the quantities of water that is in the river at any one time. Nor is it the aggregate of all such quantities… In the case of the variable water, there is a function, or "princi-*

ple," that determines which quantity of water constitutes the variable water at any given time."

For Fine, a variable embodiment is thus an individual *f* that at each world *w* picks up a particular rigid embodiment according to a given principle *F* (the rigid embodiment is in this case termed *the manifestation of f at w*). Fine also defines a number of postulates for variable embodiments, including: a variable embodiment *f* is present at *w* iff it has a manifestation at *w*; if *f* is present at *w* then it has the location of its manifestation at *w*. Furthermore, Fine defines what he calls a *transfer principle* recognizing that there are a number of properties of the variable embodiment that hold in virtue of the properties possessed by its manifestation at that time.

In the remainder of this paper, we defend the view that instances of powertypes should be interpreted as variable embodiments of particular kind. However, before we do that, one should notice that, under this interpretation, an instance of *Bird Species* is a genuine endurant, obeying a determinate principle of identity. As an endurant, an instance of *Bird Species* only contingently exists, it can have essential and accidental properties, it could have been different from what it is. For instance, it is a *regularity property* of a *Bird Species* that it has feathers of a certain kind. This is trait of the species itself (that it bestows to the entities it classifies) not a property of its rigid embodiment (the sum of its members in that world). The same can be said for the direct property of being a *recognized Bird Species*. In contrast, there are *resultant properties* of the species that are *transferred* from properties of its rigid embodiments (e.g., average height, number of living instances).

Furthermore, in line with Fine's theory, a variable embodiment can also fail to be manifested in a given world *w*. Like we can refer to Aristotle now, although he is not present now (he is not manifested by a sum of parts standing a particular set of complex relations), we can refer to the Dinosaurs now (and state that they have zero living members now) although they are not manifested now.

The Identity of Instances of Powertypes

For a variable embodiment *f,* Fine calls the principle *F* selecting the *manifestation of f at w* the *principle of variable embodiment*. In our view, this principle should be thought as a principle of individuation and principle of identity supplied by the *kind* that *f* instantiates. In other words, deciding what changes an individual can undergo (i.e., its possible different manifestations) while remaining numerically the same individual is exactly the purpose of a *principle of identity* [23]. This idea is in line with the postulate of identity put forth by Fine for variable embodiments: two variable embodiments *f* and *g* are the same iff the principle *F* (of *f*) is the same as *G* (of *g*). This is in line with the view formalized in [23], with the difference that in the latter there is an explicit acknowledgement that principles such as *F* and *G* must be sortal-supplied.

For instance, consider *E* (e.g., the variable embodiment *Eagle-I*) an instance of a powertype *BS* (e.g., *Bird Species*). Consider that *E* is associated with a type *E'* (e.g., *Eagle-T*), we have that the principle of variable embodiment *F* (i.e., the principle of identity) for *E* is the principle of application of *E'*, which is in turn the principle of individuation and unity for the rigid embodiments picked up by *E* in different worlds. For instance, take the type *Eagle-T*. Associated with this type there is a unique instance of *Bird Species* that is the variable embodiment associated to *Eagle-T*, namely, *Eagle-I*. In each world *w*, *Eagle-I* is constituted by a unique rigid embodiment EP_i (instance of *Bird Species Population*) such that EP_i is the unique individual constituted by exactly those elements that are instances of *Eagle-T* in *w*. *Eagle-I*, in turn, remains the same individual as long as it picks up rigid embodiments that are constituted exactly by instances of *Eagle-T*.

One should notice that the type *Bird Species* in the interpretation defended here truly represents a substance sortal, i.e., a rigid type that provides a uniform principle of identity for its instances [15, 23]. As previously mentioned, two *Bird Species* are the same iff they have the same principle *F* of variable embodiment (i.e., the principle of application of the unique type to which they are associated). Moreover, *Bird Species* is indeed a substantial universal in the sense that its instances are endurants. The advantage of modeling powertypes as substantial universals is that now we can use all the well known and proven design patterns for representing substantial universals [15] for modeling powertypes as well. In particular, instances of these types can instantiate both sortal and mixin types as well as rigid and anti-rigid types (e.g., phases and roles) [15]. As illustrated in figure 1, a particular *Bird Species* can instantiate different phases in different worlds and can play roles while participating in genuine material relations.

The *isClassifiedBy* Relation

If we take this interpretation of instances of powertypes as variable embodiments, then what would be the nature of the *isClassifiedBy* relation between an individual golden eagle (e.g., Joe) and a variable embodiment such as *Eagle-I*? Some of the formal meta-properties of this relation relation can be derived from the particular type of non-standard "parthood" invoked by Fine in his theory. Fine defines a notion of temporal part of variable embodiment at *w* derived from the timeless parts of its manifestations at *w*. For instance, he states that a car *x* at *w* is manifested by a sum of car parts standing in a proper automotive relation at *w*. All parts of the rigid embodiment *y*, which is the manifestation of *x* at *w*, are temporal parts of *x* at *w*. It is important to notice that the notion of parthood employed by Fine in this construction does not allow for *unrestricted transitivity of parthood*. For instance, since the parts of a rigid embodiment must be bound by the unifying relation *R* (the so-called principle of rigid embodiment), it is not the case that all parts of *y* at *w* are parts of *x* at *w*, only those parts that are also selected by relation *R*. In [20], we have shown a similar construction using the notion of integral objects and their unifying relations. In a nutshell, if we have an entity *x* unified by relationship *R* that has as parts an entity *y* unified by relationship *R'*, then, the parts of *y* are only parts of *x* if being unified by *R'* implies being unified by *R*.

Now, let us take the case of species and the materialization relation. Let us suppose that *x isClassifiedBy* a species *X* in *w*, which in turn *isClassifiedBy* a species *X'* in *w*. For instance, we have Joe, which *isClassifiedBy Eagle-I* in *w*, which in turn *isClassifiedBy* the variable embodiment *Bird Species-I* in *w* (constituted in *w* by the *Bird Species* that exist in w). Notice that: (i) Joe *isClassifiedBy Eagle-I* in *w* iff it is part of the *Golden Eagle* population in *w*; (ii) Joe is part of the *Golden Eagle* population in *w* iff Joe::*Eagle-T*; (iii) *Eagle-I isClassifiedBy Bird Species*-I in *w* iff it is part of the *Bird Species* population in *w*; (iv) *Eagle-I* is part of the *Bird Species* population in *w* iff *Eagle-I*::*Bird Species*. Therefore, we have that Joe would *be classified by Bird Species*-I in *w* iff Joe::*Bird Species*. However, this can never be the case because being selected by the principle of application of Eagle implies not being selected by the principle of application of *Bird Species*, i.e., it is not the case that the unifying principle *R* of *Eagle-I* implies the unifying principle *R'* of *Bird Species-I*. Actually, *R* implies not *R'*! For this reason, we have that the *isClassifiedBy* relation is an anti-transitive relation.

We must emphasize, however, that what really characterizes the *isClassifiedBy* relation is its special purpose in connecting base types, their subtypes and their instances, with powertypes and their instances: if a type *T* is a base type of a powertype *X* then we have that: (i) for every subtype *T'* of *T*, there is a unique instance T'_X of *X* such that T'_X is associated with *T'*; (ii) for all elements *x*, we have that *x* instantiates *T'* iff *x isClassifiedBy* T'_X.

Variable Embodiments, Types and Resemblance Structures

We should highlight that the view that takes entities such as *Eagle-I* to be concrete individuals is in line with the conception of universals as concrete *resemblance structures* in the literature of formal ontology [11]. We believe that this view could be considered in an attempt to generalize this account towards other types of universals (universals that are not represented by powertypes). For instance, take the universal *Red*. In the interpretation of universals ultimately as resemblance structures, the *type/property/predicative term Red* can be considered as an abstraction extracted from the concrete resemblance structure *RED*. *RED*, in turn, is a concrete individual (integral object) unified by the relation of *exact resemblance* between red tropes [11]. So, we have that a trope *x* is an instance of *Red* iff *x* is a part of the structure *RED*. Since entities are created and destroyed, their tropes are also created and destroyed. So, the resemblance structure *RED* should not be conceived as the mereological fusion of exactly resembling red tropes existing now but as a variable embodiment that in each world *w* picks up a rigid embodiment fusing all exactly resembling red tropes existing in *w*.

In the same spirit, in an ontology that allows for the existence of tropes, an individual such as Joe can be considered as a variable embodiment that is manifested by different bundles of tropes (rigid embodiments) in different worlds. As such, the type Eagle itself can be defined as a resemblance structure that is constituted in each world by resembling Eagle-bundles.

We also believe that this move could be repeated for a level above the level of types such as Red or *Golden Eagle*. For instance, in our running example, we certainly could consider that *Eagle-I* (the instance of the type *Bird Species-T)* materializes *Bird Species-I* (a instance of Biological Taxon) that is itself a variable embodiment manifested by sums of existing species in a given point in time. This move is the basis to account for cascaded powertypes and multi-level approaches based on clabjects [10]. This is an issue to be investigated in future work.

Final Considerations

Since the late 1980s, there has been a growing interest in the use of foundational ontologies to provide a sound theoretical basis for the disciplines of conceptual modeling and knowledge representation. This has led to the development of ontology-based conceptual modeling techniques whose modeling primitives reflect the conceptual categories defined in a foundational ontology. Despite the advances in ontology-based conceptual modeling, an ontological account for what we have termed here powertypes (i.e., types whose instances exhibit both type-like and instance-like properties) in multi-level modeling was still lacking. This paper has addressed this gap by proposing that instances of powertypes can be understood using the ontological notion of variable embodiment.

There are two possible considerations that could be made regarding the analysis conducted here. Firstly, one could object that the view of universals referred to in the third section of the paper is a particular view of universals, and that there exist conceptions of universals in which universals are concrete entities that can qualitative change, etc. To the first objection, we would respond that one such a view is the view that interprets universals as concrete resemblance structures. In this view, the primary ontological entities are these resemblance structures; types become ontologically secondary, being mere abstractions extracted from these structures. In our running example, the type *Eagle-T* represents the principle of application extracted from the ontologically primitive resemblance structure *Eagle-I*, which, in turn, is unified by a complex notion of resemblance between *Golden Eagle* trope bundles.

A second possible objection could be one against our statement that mereological sums obey an extensional principle of identity pointing to the existence of non-classical mereologies. To the second objection, we would respond that one such non-classical mereology is Fine's theory of embodiments.

In summary, we here outline a view that allows for having types as abstract predicative terms but consider that they do not suffice to capture all aspects of a universal as concrete variable embodiments. Moreover, we consider that these universals have parts, but as variable embodiments they are subject to a non-classical mereology.

Finally, we should mention that our arguments against interpreting powertypes instances as higher-order universals do not necessarily amount to argument against the use of Higher-Order Logics (HOLs) to represent the relations between powertypes, their instances and the instances of their instances. Given that we do not assume a one-to-one correspondence between universals in reality and predicates in our language, the acceptance of higher-order predicates (either representing formal universals or as abstract predicative terms extracted from resemblance structures) does not imply the acceptance of higher-order abstract universals. However, given the challenges imposed by standard semantics of HOL (e.g., non-decidability and the lost of properties such as completeness, compactness and holding of the Skolem-Löwenheim theorem) and the careful work needed for developing alternative semantics, it is not uncommon that one would consider alternative formulations that would include instances of powertypes as reified individuals in the domain of quantification [7]. The approach presented here provides an ontological interpretation for these concrete individuals, which exist in time, can bear modal properties and can qualitatively change while remaining numerically the same.

Acknowledgements. This research is funded by the Brazilian Research Funding Agencies CNPq (grants number 311313/2014-0, 485368/2013-7 and 461777/2014-2) and CAPES/CNPq (402991/2012-5). Victorio A. Carvalho is funded by CAPES.

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