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Particular Types and Particular Dependence

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Abstract. Particular types are designated in this paper as types dependent on an individual, such as *SpouseOfHenryVIII* dependent on `HenryVIII`. Other notable possibilities include car models, biological species, and various geological formations. A characterization and formal representation is provided for particular types that (1) introduces particular dependence between a type and an individual; (2) is grounded in this dependence and some defining relation for the type; and (3) provides a multi-level ontology pattern, using lakes as exemplars. This expands the range of types available to geographical ontology and beyond.

Keywords. particular type, particular dependence, geographical and geoscience ontology, multi-level modelling

1. Introduction

There are many varieties of context-dependent types. Some, such as roles, have received considerable attention in applied ontology, while others, such as those dependent on an individual, remain on the margins despite their wide use in natural language and science. Straightforward examples of the latter include *MyFriend*, *CaliforniaLake*, and *CanadianCitizen*, which can be instantiated only in the context of a distinct individual, i.e. `me`, `California`, and `Canada`, respectively. In this paper we suggest the name "particular type" for such types, and argue they are more prevalent and significant than commonly held. We also propose a structure for them consisting of: (1) some essential relations between the individual and each instance of the type, (2) a condition for determining instances of the type, which requires the essential relations, and (3) a metaphysical dependence between the type and individual, inasmuch as the type could not exist essentially without the individual. This structure is quite apparent in many particular types, e.g. each *SpouseOfHenryVIII* is in a marriage relation to `HenryVIII` such that the type could not exist essentially without him [27], and all non-`HenryVIII` individuals in this relation instantiate the type. In other cases the structure is less evident, e.g. artifact models such as *ToyotaCorolla* have car instances made according to a specific design (an individual akin to a blueprint), such models could not exist without their design, and all car individuals

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related to the design in this way instantiate the model. It is particularly noteworthy that this structure seems to account for the contextual nature of particular types.

Particular types can exist in any domain, though the emphasis in this paper is on geoscientific types such as *RiftValleyLake*, which is dependent on `RiftValleyFaulting`, a process individual occurring in Africa. Additional examples include *Great Lake* (causally tied to a particular geological environment in North America), *Polar eco-region* (causally tied to the Earth's polar environment), and *Dakota Sandstone* formation (causally tied to a particular geological environment in the USA). More contentiously, a species such as *Human* might also be a particular type, with each instance being able to interbreed with a certain population, be in a historical relation to an ancestor, or be in an occurrence relation to an ecological niche [24]. As these examples demonstrate, particular types can be found widely and be quite significant.

This paper introduces a characterization and ontology representation for particular types, with the following original contributions: (1) the development of particular dependence as an unusual variety of metaphysical dependence between a type and an individual; (2) the grounding of particular types in particular dependence as well as in defining conditions; and (3) a formal expression in a multi-level ontology pattern. The paper is organized with Section 2 outlining particular types, Section 3 discussing related work, Section 4 providing a formalization, Section 5 discussing relevant issues, and Section 6 concluding with a brief summary.

2. Particular Types

Types and categories are used synonymously in this paper to encompass generalizations such as universals, properties, classes, and kinds, with their names italicized throughout. Relation names are also italicized. The instantiation relation holds between a type and another entity, such that an instance is something that instantiates a type, while a type is instantiated by an instance. An extension is a collection of all instances of a type, with each instance being a member of the extension. Individuals are entities that cannot be instantiated, but can instantiate a type, and individuals are presented in the courier font.

The relation between instances of a particular type and some individual is called a defining relation in this paper. It is denoted by an n-ary relation ($n > 1$) in which at least one argument is filled by an individual, and another argument is filled by a variable that stands for instances of the type. The remaining arguments are unrestricted, and could include additional individuals with the particular type then tied to each individual. An example involving a single individual is $causedBy(x, \texttt{RiftValleyFaulting})$, which is a defining (binary) relation for $RiftValleyLake(x)$, meaning that each instance of $RiftValleyLake(x)$ is caused by `RiftValleyFaulting`.

What counts as an individual in a defining relation will vary according to ontological commitments. It might be an object-like or process-like individual, e.g. for particular types such as *SpouseOfHenryVIII* or *RiftValleyLake*, respectively. It might even be an abstract or quality individual, e.g. for particular types such as *MultipleOf2* (assuming the number 2 is an individual) or *PersonTallerThanMyHeight*, respectively. Moreover, defining relations are not limited to any specific category of relation, such as intrinsic or extrinsic, formal or material, or other variations [17], inasmuch as a defining relation can fall into any of these categories. A key characteristic of a defining relation, then, is the association to an individual and not the specific nature of the individual or relation itself.

Another key aspect of a particular type is its defining condition, which is a necessary and sufficient condition for determining and partly characterizing an instance of the type. Importantly, each defining condition includes defining relations, though the defining condition is broader. In fact, defining conditions and relations are distinguished in two ways. Firstly, defining conditions are typically complex relations composed of defining relations and possibly other things. Secondly, a defining condition is concerned with what is an instance and what characterizes the type, while a defining relation is about how a type's instances relate to essential individuals. For example, while a defining relation for *RiftValleyLake* is $causedBy(x, \texttt{RiftValleyFaulting})$, the defining condition consists of $causedBy(x, \texttt{RiftValleyFaulting})$ and $Lake(x)$, meaning that each instance of *RiftValleyLake* is a lake instance causally related to `RiftValleyFaulting`, and if a lake instance has such a causal relation then it instantiates *RiftValleyLake*. This also illustrates that a defining condition need not be exclusively composed of defining relations, but may include things such as properties or even other relations.

As an additional key characteristic, a defining relation must be essential to a defining condition, and thus also to a particular type, inasmuch as removal of the relation from the condition would cause the altered condition to fail in being necessary and sufficient for the type; e.g. removal of the $causedBy(x, \texttt{RiftValleyFaulting})$ relation from the *RiftValleyLake* defining condition. This limits what qualifies as a defining relation, as it excludes relations that do not help define the type. For example, relations such as being existentially dependent on the `Earth`, or part of the `collection of African lakes`, are not defining relations for *RiftValleyLake* as they do not impact its defining condition.

While it is proposed here that every particular type necessarily has some defining condition, this is somewhat of an open question. Both empirical and theoretical investigations question the prospect of necessary and sufficient conditions for many mental concepts, linguistic terms, and philosophical ideas [23][28], though some scientific, logical and mathematical notions are thought to exhibit such conditions (e.g. [13]). Indeed, particular types follow the logical pattern for paradigmatically definitional types, which appear to be inherently relational: e.g. *Bachelor* defined as an unmarried man is structurally similar to *RiftValleyLake* defined as a lake caused by certain rifting. The existence of defining conditions also seems to hold despite their absence from subsuming types, e.g. if *Lake* does not have a defining condition, then it is still possible to define *RiftValleyLake* as a lake with a causal connection to a rifting process. A defining condition may even contain several defining relations with distinct individuals, as well as other constraints, combined in various ways to form complex particular types, such as *EthiopianRiftValleyLake* narrowing *RiftValleyLake* to instances located in `Ethiopia`.

This unavoidable link to individuals leads to a further strong claim: a particular type depends existentially and essentially on those individuals. For example, the type *RiftValleyLake* could not exist, nor be the way it is, without the `RiftValleyFaulting` individual existing and being as it is. This contingency is specified as particular dependence in this paper and, significantly, it is essential to a particular type alongside its defining condition. Indeed, one implies the other, as each particularly dependent type has a defining condition, and each defining condition contains some individuals (in defining relations) on which the type is particularly dependent. Together these aspects comprise a rich description for a particular type, which would be incomplete with the absence of either.

The cumulative effect of these essential aspects is to limit the extent of application of a particular type, and thus account for its context dependence, as it cannot be instantiated free of the individuals on which it depends and to which its instances are related essentially. Thus, while particular types can have multiple instances, such as `LakeTanganyika` and `LakeVictoria` being instances of *RiftValleyLake*, a lake with the same attributes as `LakeTanganyika` located in Europe, or on another planet, would not be a *RiftValleyLake*, because of the absence of the required relations to the `RiftValleyFaulting` individual. Due to this contingency particular types are quite unlike universals [1], which are globally applicable. However, given the significance of some possible particular types it seems useful to explore their underspecified structure, primarily for use in domain ontologies.

3. Related Work

Although particular types are discussed in philosophical and applied ontology, related notions are also found in geographical information, cognition, and biological ontology.

Geographical Information Science: in the geographical domain, situated categories are similar to particular types, but are much narrower as they are singularly dependent on a process individual and the need for a defining relation is not recognized [5][6]. Once this relation is taken into account, particular types would subsume situated categories with examples such as *RiftValleyLake* then an instance of both.

Cognitive Science: various cognitive categories that are ad-hoc or goal-oriented, such as *Things-used-to-stand-on-to-change-a-light-bulb* [4], appear bound to specific situations and thus superficially similar to particular types. However, ontological analysis indicates these are anti-rigid types, i.e. roles, having instances as temporary members that vary by situation, such as chairs or tables. As these categories are not particularly dependent on such situations, they are not particular types.

Biological Ontology: a recent turn in biological ontology suggests a species is an entity, variously a type or individual, defined at least partially by relations holding between some individual and the entity's instances or parts. Such relations form singly necessary and jointly sufficient conditions, possibly in conjunct with other essential properties, for determining membership in the entity's extension or whole [11][24]. Although not without debate [14], if the entity is indeed interpreted as a type then it would appear to exemplify a particular type, albeit limited in scope to biological ontology.

Applied Ontology: foundational ontologies such as DOLCE or BFO include dependence relations [2][21], but not those in which a type is dependent on an individual. Consequently, while particular types can specialize categories from such ontologies, they cannot be fully characterized with the available dependence relations. Moreover, particular types are not the primary focus of such ontologies, which target universally applicable categories rather than types limited to local application.

Support for particular types is also lacking in prevalent systems of meta-categories. Meta-categories are types that have other types as instances, and that govern the character of those instances. For example, *Sortal* is a well-known meta-category with instances that must specify an identity condition, among other things [1][18][19]. The type *Car*, as a *Sortal* instance, then specifies that car individuals are distinguished by vehicle number. Other aspects possibly specified by a meta-category include essential and accidental properties, as well as necessary and sufficient conditions. For example, *ParticularType* can be introduced as a meta-category specifying that its instances, such as *RiftValleyLake*, must have a defining condition and the essential property of being particularly dependent

	`individual`	`type`
`individual`	Specific	Generic
`type`	*Particular*	Notional

Table 1. Metaphysical dependence varieties between common kinds of dependent (left) and dependee (top) .

on some individual. This meta-category is absent from systems of meta-categories, such as in OntoClean or UFO [18][19], and multi-level frameworks (e.g. [8][16]).

Some support for particular types is, in contrast, found in saturated roles [22]. Saturated roles are anti-rigid particular types with a defining relation in which all arguments are individuals except one, the variable over which the type ranges. $SpouseOfHenryVIII(x)$ is then a saturated role if its defining relation is $marriedTo(x, \texttt{HenryVIII})$, but $GiftToJohn(x)$ is not a saturated role if its defining relation is something gifted by someone to John, $gifted(x, y, \texttt{John})$. Consequently, all anti-rigid particular types defined strictly by a binary relation are saturated roles, whereas such types defined strictly by a relation with more than two arguments are not necessarily saturated roles. This focus on relations to individuals corresponds to the insight that a particular type is dependent on some individual, albeit the dependence claim is stronger as it asserts the type could neither exist, nor be the way it is, without the individual; also, the formal framework for saturated roles can only partially, but not fully, express particular type structure.

Philosophical Ontology: philosophically, particular types are often excluded from sparse ontologies due to their limited scope of application [1]. This contrasts with the central position of some particular types within their domain, such a car model, biological species or geological formation, though there is considerable philosophical concern about whether at least some particular types, such as a species, e.g. *Human*, are individuals rather than types [26]. This concern is a serious objection to not only some, but possibly all particular types and is further considered in the Discussion section.

The dependence of a type on an individual is also unconventional. Prevalent varieties of metaphysical dependence, that is, dependence characterized by metaphysical properties such as existence or essence, include specific, generic, and notional dependence [25]. By most accounts these varieties have distinct kinds of relata, either types and individuals [25][27], or more generally types and instances [10][15], though they are typically exemplified using the former, i.e. types and individuals. Specific dependence then holds between individuals/instances (except see [27], where the dependent is either a type or individual), generic dependence holds between individuals/instances and types, and notional dependence holds between types. While these relata distinctions do not account for all the differences between varieties, they do play an important role and further help differentiate particular dependence. Specific and generic dependence can be grouped into ontological dependence, with notional dependence excluded as a variety of ontological dependence [25]. Metaphysical dependence is also distinguished from other notions of dependence, such as functional, legal, or logical [25].

Specific dependence is exemplified by a lake and its container: it would not be the same lake with a different container, e.g. a lake in the Grand Canyon would not be `LakeTanganyika`. Generic dependence is exemplified by a wet lake and some water matter: a wet lake must have some water matter amounts, but not any specific amounts. In notional dependence, a type depends intrinsically on another type, such as a water supplier and consumer: for every water supplier instance there must be a consumer instance, and these are not necessarily ontologically dependent as a municipality is neither specifically nor generically dependent on the households to which it supplies water. Table 1 arranges these varieties of dependence by common kinds of relata, and introduces particular dependence as the metaphysical dependence between a type and individual.

Explicit treatment of particular dependence is scarce. It is either subsumed by a more general variety of specific dependence between a dependent (either a type or individual) and a dependee individual [27](pp. 31-32), or is regarded as notional dependence for a limited case in which instances of the dependent type are not ontologically dependent on the dependee individual [25](pp. 296-297). The latter does not generalize to all cases of particular dependence, and the former, while valid, is too coarse as it does not enable the accurate characterization of particular types, which requires the dependent to be only a type. It is therefore necessary to distinguish particular dependence from the other varieties.

4. A Multi-level Framework for Particular Types

Three important characteristics of particular types have emerged thus far: (1) particular types have some defining relation and condition, (2) they are particularly dependent on some individual, and (3) they instantiate a meta-category called *ParticularType* that requires a multi-level framework for its representation. These characteristics are elaborated formally in this section using *RiftValleyLake* as a running example.

4.1. Foundations

A formal representation of particular types is founded on several key precepts including the modality of necessity, the instantiation relation between types and instances, as well as pertinent notions of existence.

Necessity here refers to metaphysical necessity, meaning non-accidental and foundational rather than, for example, logical, legal, or physical [10]. It can be narrowed to mean essential necessity, such that it is an essential property of something that a certain proposition holds [15]. As per convention, the $\Box$ operator denotes necessity, which is interpreted here to be essential necessity holding for the dependent entity in a dependence relation. While various logical systems exist for this modality, it is not vital here to commit to a specific system, though S5 might suffice.

The instantiation relation, denoted by *iof(x,y)* (A1), is a primitive here holding between an instance and a type, such that the instance is a member of the type's extension, and an individual cannot be instantiated, but instantiates the *Particular* type (defined in [7]). *iof(x,y)* is irreflexive, asymmetric and anti-transitive. The anti-transitivity is particularly pertinent in a multi-level framework, because it entails that $iof(x,y)$ can only hold between adjacent levels. For example, a meta-category such as *ParticularType* cannot be instantiated by an individual, such as `LakeTanganyika`, as it can only be instantiated by a type at the next lower level, such as *RiftValleyLake*. A meta-category is then a higher-level type that is instantiated by some type. Though $iof(x,y)$ (in A1) can be derived from a stronger form (in [7]), it suffices for our purposes in this paper.

(A1) $\forall x,y\ iof(x,y) \rightarrow \neg iof(y,Particular)$

Existence refers to metaphysical existence, rather than other notions such as existential quantification in logic [10]. It is used in a timeless sense here, not predicated relative to any time. Something thus exists, or not, and notions of when or how long are not valid. While temporal distinctions for existence are important to distinguish some entities, such as objects from processes–i.e. object individuals exist wholly at a time, but process individuals do not–they are not required for particular types. Existence of individuals ($EXISTS_i$) and types ($EXISTS_t$) is defined via the (negated) instantiation of *Particular* (A2, A3). Something is thus either a type or individual, or does not exist. Several consequences can be derived from this: if something instantiates a type, then the type exists (T1 from A1, A3) and the instance also exists either as an individual (T2 from T1, A2) or type (T3 from T1, A3); moreover, *Particular* exists because it cannot instantiate itself (T4 from A3). Aristotelian types are thus not adopted: these are types that exist only if instantiated, but this would be too restrictive for some particular types, e.g. it can be useful for a car model to exist if its car design exists, though its cars are never made. More strongly, it is possible here for types to exist that cannot be instantiated, for example a round square [15]. Even more strongly, there is a lack of clear grounds for impossible types in this framework, suggesting any type can exist even if not instantiable.

The extensional specializes relation (SP_e) has each instance of the narrower type also an instance of the broader type (A4). The extensional proper specializes relation (PSP_e) additionally asserts that the extension of the narrower type is a proper subcollection of the broader extension (A5), and the specializes relation (SP) is a primitive that further asserts the intension is also narrower, to avoid cases of extensional overlap but intensional disjointness (after [22]). If a type specializes an existing broader type, then the specialization also exists (A7); consequently, any specialization of *Particular* exists in this framework (T5 from A7, T4). As a final foundational element, specific dependence between individuals is defined conventionally, such that if the dependent exists then so does the dependee, essentially, while ruling out self-dependence (A8).

(A2) $\forall x\ EXISTS_i(x) \equiv \exists y\,[iof(y,Particular) \wedge x = y]$

(A3) $\forall F\ EXISTS_t(F) \equiv \exists G\,[\neg iof(G,Particular) \wedge F = G]$

(T1) $\forall F,x\ iof(x,F) \rightarrow EXISTS_t(F)$

(T2) $\forall F,x\ (iof(x,F) \wedge iof(x,Particular)) \rightarrow EXISTS_t(F) \wedge EXISTS_i(x)$

(T3) $\forall F,G\ (iof(G,F) \wedge \neg iof(G,Particular)) \rightarrow EXISTS_t(F) \wedge EXISTS_t(G)$

(T4) $EXISTS_t(Particular)$

(A4) $\forall F,G\ SP_e(F,G) \equiv (\forall x\ iof(x,F) \rightarrow iof(x,G))$

(A5) $\forall F,G\ PSP_e(F,G) \equiv SP_e(F,G) \wedge \neg SP_e(G,F)$

(A6) $\forall F,G\ SP(F,G) \rightarrow PSP_e(F,G)$

(A7) $\forall F,G\ (SP(F,G) \wedge EXISTS_t(G)) \rightarrow EXISTS_t(F)$

(T5) $\forall F\ SP(F,Particular) \rightarrow EXISTS_t(F)$

(A8) $\forall x,y\ SD_i(x,y) \equiv \Box(EXISTS_i(x) \rightarrow EXISTS_i(y)) \wedge (x \neq y)$

4.2. Particular Dependence

Metaphysical dependence is most commonly framed as necessary co-existence with the following structure: necessarily, the dependent exists if the dependee exists [10][15][25][27]. Particular dependence follows this framing, with the dependent specializing *Particular*, which cannot be contingent, and the dependee being an individual (A9). The dependent type is then truly contingent, as it cannot exist without the dependee existing.

(A9) $\forall P, z\ PD(P, z) \equiv \Box(EXISTS_t(P) \rightarrow EXISTS_i(z)) \land SP(P, Particular)$

This framing has several known problems. The most notable for particular dependence include: (1) necessary or always-existing dependees[10][15][25], such as abstracts (e.g. the number 2) or spiritual entities, resulting in every existing particular type being particularly dependent on them; (2) necessarily existing dependents, which entail the dependee to exist necessarily [15]; and (3) impossible dependents [15], which then particularly depend on all individuals.

Ruling out necessary dependees is a possible solution to the first problem (e.g. [25]), but it disallows, for example, indigenous ontologies in which water bodies are dependent on specific spiritual individuals. An alternate solution is to adopt essential necessity [15], causing the dependence to then hold only in cases for which the dependee is essential to the dependent. The dependent and dependee do not just necessarily co-exist then, they do so in some way vital to the dependent, making the implication between them (in A8, A9) gain force and approach the strength of a relation [10].

A concern about essential dependence involves entities that co-exist essentially without being metaphysically dependent, such as causes with essential effects [10]. However, this example does not apply to particular dependence, because effects are commonly seen as caused by individuals rather than types. Moreover, even if a particular type is particularly dependent on an essential effect of its instances, the dependence still seems valid: if types are atemporal, as herein, then temporal discord is avoided, such as the dependent type not existing until the effect exists; but if types are temporally indexed, then such scenarios could still be plausible. As a result, it is not evident that particular dependence requires alternatives to essential necessity, such as those founded on explanation [10].

As for the second problem, necessarily existing dependents can be ruled out for non-necessary dependees (A10), because such dependents are not existentially contingent and thus cannot depend on a contingent entity. Other combinations are valid: non-necessary dependents and dependees, e.g. *RiftValleyLake* and *RiftValleyFaulting*, necessary dependents and dependees, e.g. *MultipleOf2* and the number 2, as well as non-necessary dependents and essentially necessary dependees, e.g. *RiftValleyLake* and `God` in some ontology.

(A10) $\forall P, z\ (PD(P, z) \land \neg\Box EXISTS_i(z)) \rightarrow \neg\Box EXISTS_t(P)$

The third problem, regarding impossible dependents, is less of a concern due to the lack of strong grounds herein for impossible types. This then forgoes the need to explore other forms of dependence, such as definitional dependence [15].

Particular dependence is irreflexive, asymmetric, and anti-transitive, mainly due to the fact that the dependent is a type and the dependee is an individual. Also noteworthy is that a type can be particularly dependent on its own instance, for example, *John'sEmployee* is particularly dependent on John and John can employ himself. More significantly, each dependent type must have some defining condition involving the dependee individual in a defining relation. Specifically, a type is particularly dependent on an individual if and only if the individual is an argument in a defining relation (and condition) for the type. The number of such relations will be small, because few will be essential to a defining condition. This is a strong notion that ensures dependent types are not only related to the dependee individual in some way, but more forcefully in some essential way.

Instances of the type and the dependee individual can also be related via specific dependence, but not via generic or notional dependence, as the dependee cannot be a type. For example, each instance of *RiftValleyLake* is causally related to RiftValleyFaulting and specifically dependent on it, assuming some causal dependencies are ontological (e.g. [20] p. 91). The specific dependence is then necessary but not sufficient, as not everything specifically dependent on RiftValleyFaulting is an instance of *RiftValleyLake*. In general, specific dependence can singly be necessary but not sufficient, neither necessary nor sufficient, or both necessary and sufficient, for a particular type; but when it is necessary it might also be a defining relation. Moreover, particular dependence is variously preserved under composition with specific dependence: some types are particularly dependent on a specifically dependent individual and others are not. For example, if HenryVIII is specifically dependent on his life (a process-like entity), then *SpouseOfHenryVIII* is particularly dependent on him, but not on his life–his spouses are neither married to his life nor in any other essential relation to it; in contrast, *ThingCotemporalWithHenryVIII* can conceivably be seen as particularly dependent on him as well as his life. Particular dependence is also fully preserved under specialization of the dependent (A11), e.g. *ShallowRiftValleyLake* is particularly dependent on RiftValleyFaulting.

(A11) $\forall P, P', z \; (PD(P,z) \wedge SP(P',P)) \rightarrow PD(P',z)$

4.3. Multi-level Representation

We adopt a multi-level approach from [7] to illustrate implementation, as well as anchor the *ParticularType* meta-category and its instances, particular types, in a comprehensive framework. The framework is a first order logic theory that partitions an ontology into fixed levels connected by instantiation relations. For example, LakeTanganyika is an instance of *RiftValleyLake*, which is an instance of *ParticularType*, and each is at an adjacent level. Each level has a top type that subsumes all other types at that level, and the top types are renamed slightly here to *Particular*, *1stLevelType*, *2ndLevelType*, and *3rdLevelType* (not shown). Each type instantiates the top type from the next higher adjacent level, and possibly some of its specializations, such as *RiftValleyLake* instantiating *1stLevelType*, *LakeType*, *ProcessLakeType*, and *ParticularType*. Although *Particular* is instantiated by individuals, which are the lowest possible entity in an instantiation chain, the partition of individuals is not named or topped. Meta-categories then govern how their instances are organized, with meta-categories referring more precisely to any type that is not a specialization of *Particular*. As shown in Figure 1, the meta-category *ProcessLakeType* provides grounds for organizing specializations of *Lake* by different causal processes, such as rifting. A power type is the most general governing meta-category for a certain type, called the base type, e.g. *LakeType* is a power type for the base type *Lake*; these are related by the *isPowertypeOf* relation. A base type has only one power type and each power type has only one base type. See [7] for a full description of the framework.

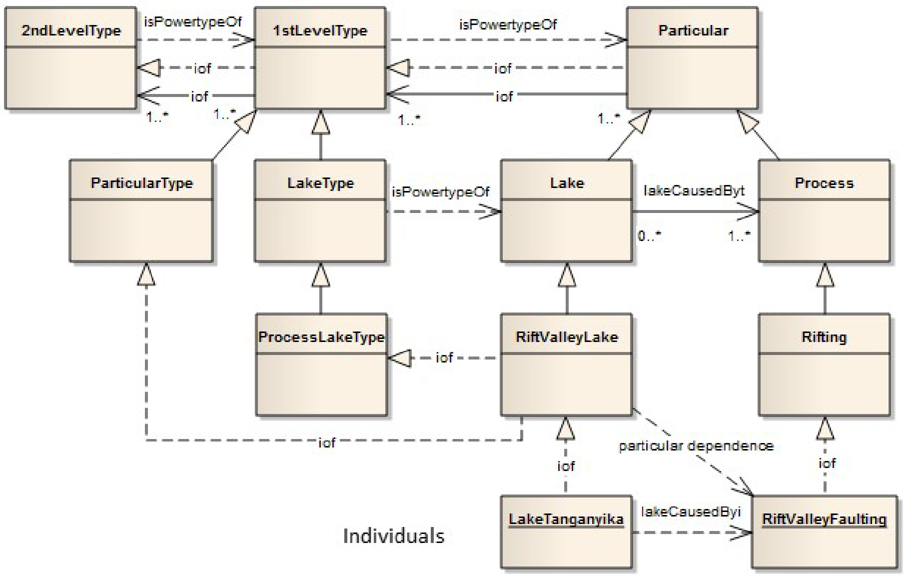

Figure 1. Multi-level pattern for particular types. A closed arrow solid line is specialization; an open arrow solid line is a relation between types (holding between instances); a closed arrow dashed line is an iof occurrence; an open arrow dashed line is another relation occurrence, e.g. $isPowertypeOf$ or $particular\,dependence$.

4.4. Representing Particular Types

Representation of the *ParticularType* meta-category is challenged by the need to state that each instance, which is a particular type, must have some defining condition. To avoid a higher-order logic, a defining condition is first collapsed into a defining relation, which is reified into a quantifiable type that specializes *Particular*. For instance, the defining condition $causedBy_i(x, \texttt{RiftValleyFaulting}) \wedge iof(x, Lake)$ can be collapsed into the defining relation $lakeCausedBy_i(x, \texttt{RiftValleyFaulting})$, which can be reified into the $LakeCausation$ type and quantified. Relations between types and between individuals may be reified differently, but only the latter is relevant for a particular type to capture its defining relations. Reification of relations between individuals goes as follows: for an n-ary defining relation $R(x_1, ..., x_n)$, introduce r as an instance of the reified type and for each argument x_j of the the relation $R(x_1, ..., x_n)$ introduce a binary relation (between individuals) named r_j^* that holds between r and the argument filler (A12).

(A12) $\forall x, r\ [r_1^*(x, r) \rightarrow iof(x, Particular) \wedge iof(r, Particular)] \wedge \forall x, r\ [r_2^*(x, r) \rightarrow iof(x, Particular) \wedge iof(r, Particular)] \wedge ... \wedge \forall x, r\ [r_n^*(x, r) \rightarrow iof(x, Particular) \wedge iof(r, Particular)]$

For example, the $lakeCausedBy_i(x, y)$ relation is reified into the *LakeCausation* type (Ex10 and Ex11). Note that while all relations *could* be reified, it is possible some *should* be reified [17], though the ontological status of reifications is not of concern here as they are used strictly as a logical device to enable quantification over defining conditions.

Particular dependence can now take into account the characteristic that each dependent type must have a defining condition, reified into a type (R^*) (A13). The *Particular-*

Type, *PType*, meta-category is then characterized by its particular dependence on some individual (A14). This captures the notion that particular dependence is an essential property for particular types, meaning that the property is necessary and rigid as it must be present and does not change. It can also be trivially derived that each particular type has some defining condition (T6, from A14, A13). Furthermore, the *PType* meta-category is not a power type itself (A15), because its instances cannot be restricted to being specializations of any specific base type, as they can range across any *Particular*, and *Particular* already has *1stLevelType* as its power type. As a consequence of not being a power type and being instantiated by some *Particular* type, the *pType* meta-category is a specialization of *1stLevelType* (T7). Particular types are also preserved under specialization, in that any specialization of the type is also a particular type (T8, from A11, A14).

(A13) $\forall P,z\ PD(P,z) \equiv \exists R^{*}[SP(R^{*},Particular) \wedge [\forall x\ iof(x,P) \leftrightarrow \exists r,x_2,...,x_n\,[iof(r,R^{*}) \wedge r_1^{*}(x,r) \wedge r_2^{*}(x_2,r) \wedge ... \wedge r_n^{*}(x_n,r) \wedge (x_2 = z \vee ... \vee x_n = z)]]]$
(A14) $\forall P\ iof(P,PType) \equiv \exists z[PD(P,z)]$
(T6) $\forall P\ iof(P,PType) \equiv \exists z,R^{*}\,[SP(R^{*},Particular) \wedge iof(z,Particular) \wedge [\forall x\ iof(x,P) \leftrightarrow \exists r,x_2,...,x_n\,[iof(r,R^{*}) \wedge r_i^{*}(x,r) \wedge r_2^{*}(x_2,r) \wedge ... \wedge r_n^{*}(x_n,r) \wedge (x_2 = z \vee ... \vee x_n = z)]]]$
(A15) $\neg\exists P[isPowerTypeOf(PType,P)]$
(T7) $SP(PType, 1stLevelType)$
(T8) $\forall P,P'\ (iof(P,PType) \wedge SP(P',P)) \rightarrow iof(P',PType)$

4.5. Example

The formalization for particular types is exemplified here via application to *RiftValleyLake*, as shown in Figure 1. Reifications are omitted in Figure 1 as they are used only as a logical device, but they are included in the formalism below strictly for illustration purposes.

1stLevelTypes: The *LakeType* meta-category specializes *1stLeveltype* and is a power type for *Lake* (Ex1), while the *ProcessLakeType* meta-category specializes *LakeType* (Ex2). The $causedBy_i(x,y)$ relation between individuals is partially described via the specific dependence of a product on a cause (Ex3), and is refined for lake products as a relation between individuals (Ex4) and types (Ex5). This enables specification of necessary and sufficient conditions for *ProcessLakeType*: specializations of *Lake* are distinguished by distinct causal processes, such as lakes caused by rifting or volcanism (Ex6).

(Ex1) $SP(LakeType, 1stLevelType) \wedge isPowertypeOf(LakeType, Lake)$
(Ex2) $SP(ProcessLakeType, LakeType)$
(Ex3) $\forall x,y\ causedBy_i(x,y) \rightarrow SD_i(x,y)$
(Ex4) $\forall x,y\ lakeCausedBy_i(x,y) \equiv causedBy_i(x,y) \wedge iof(x,Lake)$
(Ex5) $\forall F,G\ lakeCausedBy_t(F,G) \equiv (iof(x,F) \rightarrow \exists y[iof(y,G) \wedge lakeCausedBy_i(x,y)])$
(Ex6) $\forall F\ iof(F,ProcessLakeType) \equiv SP(F,Lake) \wedge lakeCausedBy_t(F,Process)$

Particulars: specializations of *Particular* include *Lake*, *RiftValleyLake*, *Process*, *Rifting*, and *LakeCausation* (Ex7, Ex8, Ex9), with *LakeCausation* reifying $lakeCausedBy_i(x,y)$ (Ex10, Ex11). `RiftValleyFaulting` instantiates *Rifting* (Ex12), and *RiftValleyLake* instantiates both *ProcessLakeType* (Ex13) and *PType* (Ex14), such that *RiftValleyLake* is particularly dependent on `RiftValleyFaulting` (Ex15). A defining condition for *RiftValleyLake* consists of lakes caused by `RiftValleyFaulting`, stated in reified (Ex16) and nonreified forms (ExT1, from Ex16, Ex11, Ex4).

(Ex7) $SP(Lake, Particular) \wedge SP(RiftValleyLake, Lake)$
(Ex8) $SP(Process, Particular) \wedge SP(Rifting, Process)$
(Ex9) $SP(LakeCausation, Particular)$
(Ex10) $\forall r\ iof(r, LakeCausation) \equiv \exists x, y\,[lakeCausedBy_i(x,y) \wedge r_1^*(x,r) \wedge r_2^*(y,r)]$
(Ex11) $\forall x, y\ lakeCausedBy_i(x,y) \equiv \exists r\,[iof(r, LakeCausation) \wedge r_1^*(x,r) \wedge r_2^*(y,r)]$
(Ex12) $iof(\texttt{RiftValleyFaulting}, Rifting)$
(Ex13) $iof(RiftValleyLake, ProcessLakeType)$
(Ex14) $iof(RiftValleyLake, PType)$
(Ex15) $PD(RiftValleyLake, \texttt{RiftValleyFaulting})$
(Ex16) $\forall x\ iof(x, RiftValleyLake) \equiv \exists r\,[iof(r, LakeCausation) \wedge r_1^*(x,r) \wedge r_2^*(\texttt{RiftValleyFaulting}, r)]$
(ExT1) $\forall x\, iof(x, RiftValleyLake) \equiv causedBy_i(x, \texttt{RiftValleyFaulting}) \wedge iof(x, Lake)$

Individuals: *RiftValleyLake* is instantiated by `LakeTanganyika` (Ex17), which is caused by `RiftValleyFaulting` (Ex18).

(Ex17) $iof(\texttt{LakeTangenyika}, RiftValleyLake)$
(Ex18) $causedBy_i(\texttt{LakeTangenyika}, \texttt{RiftValleyFaulting})$

5. Discussion

A serious concern for particular types is the objection they are not types at all, but are individuals instead. This arises most forcefully from debates on biological species, where a prominent view holds a species to be an evolutionary unit structured as an individual whole with members of its population as parts [26], e.g. `Human` as a whole with `John` as part. The main supporting argument holds that species are concrete, that is, spatiotemporally located with a finite lifespan and changing characteristics, whereas types are considered abstract and atemporal. Applying this to particular types, regardless of the spatiotemporality of dependees, might then cast each such type to be an integral whole [25] with the defining condition becoming a unifying condition, such that something is a part of the whole if and only if it satisfies the defining condition's consequent; e.g. `LakeTanganyika` is part of `RiftValleyLakes` if and only if it is a lake caused by `RiftValleyFaulting`. Apart from more conformance to some scientific trends, this approach also simplifies representation by avoiding meta-categories and multi-level frameworks, e.g. `Human` shifts to an individual that is an instance of *Species*, which specializes *Particular*.

Problems do arise, however, with transitivity and similarity in this mereological approach. Transitivity of parthood leads to undesirable parts in many approaches, e.g. John's finger as a part of the `Human` species [26]. The problem with similarity is the lack of accounting for common characteristics, either prototypical or essential, variously shared by the parts of some wholes. For example, humans prototypically have fingers, toes, etc., shared by many but not all persons, while a car model has a template, its design, that *must* be instantiated by each car of that model. In contrast, the spouses of Henry VIII do not necessarily share characteristics needed for their marriage beyond those common to other humans, so the similarity requirement is neither ubiquitous nor equal across particular types. Where required, it might be acheived by augmenting the unifying condition with a similarity condition for variable adherence to a prototype or template. Things are then a part of such wholes if and only if they satisfy the defining consequent plus the similarity condition, which loads much of the ontological heavy lifting onto the unifying condition.

In contrast to the mereological approach, the instantiation relation between a particular type and its instances is not transitive, and possesses some means to account for common characteristics through the imposition of a common structure on instances. However, these means are variously interpreted and deployed in ontology engineering, with prototypes being problematic and the focus of recent refinements [9]. Particular types are also evolutionary units indirectly, as their particular dependence on an individual will likely cause some (accidental) characteristics of the type to change in tandem with shifts in the individual, but the (essential) defining condition and relations cannot change without it being a different type. In this sense, a particular type strikes a balance between operating as a type versus an individual, and may be an alternative, or supplement, to other approaches. For instance, the mereological and particular type-based approaches can co-exist, if required, and this might even be optimal for capturing the spectrum of key characteristics, e.g. of a species [12]: then the parts of the whole would be identical to the instances of the particular type [11], and the whole's similarity condition and the type's instantiation relation would need to be aligned. However, the purpose here is to explore a general framework for particular types, and not advocate for a specific approach to a domain.

A final concern is the practicality of particular dependence. For application purposes it might be tempting to omit particular dependence from the characterization of particular types, and limit it to a defining condition. However, this neglects the guiding role particular dependence can play in identifying and validating defining conditions, especially in cases where the dependence is evident but the condition is not - then the dependence can act as a clue to determining the defining condition. In other cases, it can help test candidate conditions to ensure adequate inclusion of the dependee individual.

6. Summary

Particular types have been on the margins of applied ontology, somewhat recognized but minimally structured. In this paper, we name the type and characterize it as having the essential property of being dependent on an individual, as well as having some defining relation that is essential to the necessary and sufficient conditions for being an instance of the type. This requires the introduction of particular dependence between a type and an individual, and a meta-category for particular types that specifies their structure. This is exemplified formally using a multi-level framework to represent the *RiftValleyLake* type, which is particularly dependent on a specific rifting process in Africa. While many of the examples presented here are geoscientific in nature, particular types are far-ranging and not limited to the geoscientific or even geographical realms. They can be found in any area of interest and might encompass other important types, such as *CarModel* or possibly even *Human*. As such, their ontological relevance is greater than might at first be expected. Ongoing work includes a detailed exploration of particular types for the geosciences, the generalization of particular dependence for multi-level frameworks, and the investigation of other expressive multi-level frameworks and languages for particular types (e.g.[3]).

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