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Temporal Qualification and Change with First–Order Binary Predicates

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Abstract. Some temporal ontologies require a way of enforcing the temporal qualification of certain assertions—those about changing entities. In a knowledge representation language based on first–order logic, this is straightforwardly done by having a category of temporal regions and augmenting predicates with an additional argument place for the time at which a given predicate holds.

Here, I address the problem of representing entities changing over time and enforcing temporal qualification in first–order languages with predicates at most binary. It is possible, I argue, using temporal entities known as perdurants (events or processes)—towards which binary languages seem *prima facie* biased. There is however virtually no ontological cost for an ontology which in addition to changing entities recognizes changes, events and processes. Temporal knowledge representation therefore is not a lost cause even with languages with syntax and semantics limited to the representation of binary relations.

Keywords. Temporal ontology, knowledge representation, languages with binary predicates

1. Preliminaries

1.1. Temporal Qualification and Change

Atomic assertions in ontologies are of three sorts: i) an entity instantiates or belongs to a kind, ii) a property inheres in an entity (or, synonymously, an entity exemplifies a property), and iii) an entity is in a certain relation to an entity (or more). We can say that there are two sorts of temporally extended entities. Those which can change over time in some respect or another and those which can not. As illustration, consider the following:

Plato is an adult.

Plato is 1,80 meters tall.

Plato likes Socrates.

and again:

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The death of Socrates is a death from poisoning.

The death of Socrates occurs in Athens.

The lamenting of Plato occurs a few paces from the death of Socrates.

Entities such as Plato and Socrates are endurants; they endure [1]: persist in time but can change. For them, to have a property is in the general case to have it at a time (leaving aside essential and lifelong constant properties, e.g. Plato is a person, he does not know about the American continent). Entities such as the death of Socrates and the lamenting of Plato are perdurants; they perdure: persist in time through the succession of their temporal parts. For them, to have a property is to have it atemporally and to have a transient property is for these entities to have a (so–called "temporal") part which has the property atemporally. So, endurants change (they can have distinct and contradictory properties at different times) but perdurants do not change (rather they have different parts with different, possibly contradictory, properties).

The need for temporal qualification in predication is motivated by the need to account for change in entities and the correlated indexing of their properties and relations to certain times. If an entity does not change in a certain respect, then temporal qualification becomes superfluous. The mere indication of the temporal location of such an entity (the time at which it exists) suffices to indicate the time over which it has the feature in question.

1.2. Representation

Representing change in the respects listed above in endurants using temporal qualification is one of the most straightforward and natural operations in knowledge representation (KR henceforth) with languages with no or few expressive constraints. There are however distinct strategies which are not on a par with respect to their ontological character.

One strategy is to have a non temporal language (allowing for non temporally qualified, I will say "plain", assertions) and then bundle assertions in the right sort of way. There are two such main ways. The first uses a sentential operator taking a sentence and a time and which yields truths when sentences are correlated with adequate times, and falsehoods otherwise. The second builds distinct ontologies and representations for different times.

Either way, this strategy tends to give no ontological status to a category of times (time instants or regions) nor to a category of changes. It puts times in the semantics and models change as discrepancy in the truth value of an assertion over time. [2] It is not, so to speak, an ontological strategy for temporal KR. A variant of the second way adds a dedicated ontology for times and perdurants (among which changes as entities) in a modular framework whose complexity is augmented by the articulation of the two sorts of ontologies. [1]

Another strategy consists in a purely first–order (FO henceforth) logical approach in which temporally sensitive predicates have an argument place for the time at which their plain proxies obtain. Starting from a plain vocabulary, we can then enforce temporal qualification by augmenting the arity of the relevant vocabulary and having a dedicated argument place for predicates taking a time. Relations between entities then are also relations to a time. We go for instance from a plain vocabulary containing *Adult*, *Child*, *likes* to a temporal vocabulary containing: *adultAt*, *childAt*, *likesAt*. This strategy allows ontological commitment to time and, at least in principle, to change. It is moreover a strategy which can deal mono–ontologically with change, endurants, and perdurants. For this reason, this strategy and generally a KR strategy in which all can be done and referred to in a FO logical language will be taken as paradigmatic of ontological KR, and in particular, temporal KR.

The problem I wish to address here is that this strategy is not available when temporal KR is done with languages limited to predicates of arity at most two (I will say "binary languages"). Clearly, the predicate *likesAt* is ternary and not a predicate of a binary language.

1.3. Impoverished Languages

Is the issue ludicrous? It is a mere scholar exercise if our benchmark for a KR language is FO logical or allows for sentential operators. Many KR languages are as expressive as FO ones or more, e.g. KIF [3] or CycL (the language of the Cyc system [4] which allows virtually every sort of representations alluded to). In the research area of the semantic web, however, KR is done with designed computable fragments of FOL (variants of Description Logics [5]) which are binary languages. Therefore, if irreducibly ternary predicates are needed, these are outside the purview of the KR capabilities of these languages.

[6]—but virtually all semantic web related publications—is illustrative of the mode of the default options for temporal KR in binary language, if only by omission of this problem. It gives examples of what is expressible in two particular binary languages, RDFS and OWL. In particular, it says that RDFS allows to:

– state that **Peter** is an instance of the class **Canadian**, and that his **age** has value 48.

OWL allows moreover, among other things, to:

– state that the class **Canadian** is defined precisely as those members of the class **Person** that have **Canada** as a value of the property **Nationality**; and
– state that **age** is functional.

The problem is that assertions with such a vocabulary *prima facie* require temporal qualification. In all generality, nationality is indexed to time and age is only functional when it is a relation between a person, a date, and an age. In both cases, the perspicuous way of representing these relations over a domain of entities—not including sentences—are through ternary predicates allowing for temporal qualification. Short of this, the sort of KR illustrated in the examples above is one done in a temporally circumscribed ontology. And it is therefore not surprising that in the context of description logic, tense logics are paradigmatic. [7]

In first analysis, this situation poses a thorny problem for the representation of bi–categorial ontologies (with both endurants and perdurants) since they require temporal qualification. The purpose of this paper is not finding a mere reduction of temporal predicates in a binary language. We know there are many ways of reducing a predicate's arity (see [8] for some examples). The objective is to find ontologically sound reductions, i.e. which do not require a modification of the ontology, and identify the theoretical underpinnings of a systematic methodology for accomplishing this feat.

In the next section, I briefly argue for the lack of straightforward ontological solutions. In section 3, I examine conditions of reducibility of ternary temporal predicates. In section 4, I describe a method for systematic reduction of these predicates. Finally, in section 5, I propose an interpretation of this method and identify its conditions of ontological soundness.

For lack of space, I sacrifice formal rigor and make no attempt to give proper semantics to the formalism used. Formalism is here both object of discussion and illustrative. I will systematically adopt intuitively helpful naming conventions which should make obvious the intended constraints on the vocabulary or its intended meaning.

2. Fiddling with Ontology

An obvious ontological solution to our problem of representation would be to introduce either relations or facts (states of affairs) as proxy entities for predicates or propositions requiring temporal qualification. It should be clear however that any such solution will constitute a major self–defeating ontological disruption when trying to remain within the boundaries of a bi–categorial ontology of endurants and perdurants. We will take for granted that in the remainder of this paper we will exclusively consider solutions which remain within these boundaries.

The theory of perdurants—more generally unchanging entities—can be couched in a binary language. That of endurants apparently requires temporal qualification of predicates and at least some ternary predicates (e.g. *is a part of at* or *is located in at*). There are two undesirable but straightforward solutions:

1. reduction of endurants to perdurants, which is obviously and precisely problematic because it is a reduction, therefore a radical change in ontology rather than a representation,
2. partial representation of the part of the theory of endurants which bears formulation in a binary language (i.e. leaving out all temporal vocabulary).

These solutions take the syntactic and semantic limitation of a language as representational limitations. But we can not just motivate a reduction on the basis that the representation of an ontology is straightforward and not that of another. It is also unclear that the apparent limitation of the language constitutes a definitive ontological bias which warrants truncating a specification.

Suppose an ontology contains: i) two disjoint categories of endurants and perdurants, ii) the theory of a primitive relation R (e.g. *parthood*) which is similar for, but adapted to, each category. It is natural to have two variants of R, R^3_t (e.g. *partOfAt*) and R^2 (e.g. *partOf*) which are respectively a ternary relation between two endurants and a time and a binary relation between two perdurants (e.g. the axiomatizations of BFO and DOLCE in [9]).

We can ask whether R^3_t is the same as R^2 modulo an argument for time. The question is meaningful only if about relations in intension (obviously they differ in extension). There are two ways of comparing them: i) projecting R^3_t to its non temporal argument places (R^2_t) and compare it with R^2, ii) temporally qualifying R^2 (R^3, it holds whenever the time is a part of the time at which the two original relata co–exist) and compare it with R^3_t. In the first case, direct comparison does not suffice, we need to use a sentential operator to simulate temporal qualification over the two relations. We see easily that at best R^2, respectively R^3, is a constant version of R_t^2, respectively R_t^3.

But not all relations between endurants obtain constantly over the lifetime of their relata. That is precisely where the need for their temporal qualification comes from. So, generally, R_t^2 (respectively R_t^3) is precisely not R^2 (respectively R^3). Preserving constant relations amounts to truncature and making the other constant to reduction.

Only ontologies which deal with endurants through instantaneous (or unchanging extended) states—with plain vocabulary—can do with only one primitive, because they use a method for temporal qualification which belongs to the first strategy discussed in 1.2. For other ontologies, we need to find a reduction of temporal predicates.

3. Fiddling with Predicates I: Decompositions of Relations

Let us focus on the problem of the reduction of ternary temporal predicates in a binary language—our discussion generalizes to higher arity ones. Generally speaking, we do not find the following reduction:

$$\mathrm{R}(x, y, z) \text{ reduces to } \phi(x, y) \wedge \chi(x, z) \wedge \psi(y, z) \tag{1}$$

That is, a ternary predicate with a temporal argument is generally not reducible to a combination of binary predicates of its arguments taken pairwise.

Consider these three facts:

Plato is born in Athens in -427.

Plato is in the Academia in -360.

The beard of Plato is white in -360.

Consider a possible representation with ternary temporal predicates:

$$\mathit{bornInAt}(\mathit{Plato}, \mathit{Athens}, \text{-427}) \tag{2}$$

$$\mathit{isInAt}(\mathit{Plato}, \mathit{Academia}, \text{-360}) \tag{3}$$

$$\mathit{hasColourAt}(\mathit{PlatoBeard}, \mathit{White}, \text{-360}) \tag{4}$$

And consider now the following:

$$\mathit{bornIn}(\mathit{Plato}, \mathit{Athens}) \wedge \mathit{bornAt}(\mathit{Plato}, \text{-427}) \wedge \mathit{isAt}(\mathit{Athens}, \text{-427}) \tag{5}$$

$$\mathit{isIn}(\mathit{Plato}, \mathit{Academia}) \wedge \mathit{isAt}(\mathit{Plato}, \text{-360}) \wedge \mathit{isAt}(\mathit{Academia}, \text{-360}) \tag{6}$$

$$\mathit{hasColour}(\mathit{PlatoBeard}, \mathit{White}) \wedge \mathit{isAt}(\mathit{White}, \text{-360}) \wedge \mathit{isAt}(\mathit{Plato}, \text{-360}) \tag{7}$$

Clearly, (2) reduces to (5). But (3) does not reduce to (6), nor (4) to (7). They do not, that is, provided Plato has not always been in the Academia or, if always there, has not only lived in -360 and that his beard has not always been white or, if always white, that he has not only had a beard in -360. Insisting that the reductions hold is making Plato and his beard in -360 entities in their own right whose existence is circumscribed to this time; it is saying that, actually, Plato and his beard are not endurants but perdurants and that the facts above are about their respective temporal parts in -360. If the equivalence held, the entities in questions would not be entities susceptible of change, but this is the sort of entity we mean to deal with, so we must reject the equivalences.

Why does (2) reduces to (5)? One answer is that it is essential to Plato that he was born in Athens in -427. But what truly makes the difference here is that he was not born somewhere else *too* nor at an other time *too*. *bornIn* and *bornAt* represent functional relations. *Athens* and -427 are both functional images of *Plato* and in that capacity *Plato* makes the link between them. *Plato* is not a relation, he is an individual but, in a way, he is relating the other entities by acting as a central node—I will say a "pivot"—in the restructuring of the fact represented by (2) and (5). This is also why the third conjunct in (5) seems superfluous (although, formally, it has to be entailed by something involving the rest of the expression).

A credible conjecture about (1) is that it applies when at least one of the relata is a pivot in the represented fact. More generally, there has to be something uniquely pointed at and which pinpoints the assertion and articulates the reduction. It is an entity which can not change in the relevant respect, just as *Plato* with respect to his place and date of birth, even if he can change in some other respect. This shows, but merely shows, in which straightforward way temporal qualification is reducible when it is superfluous. Predicates such as *bornInAt* can be regarded as shorthand, syntactic sugar, but are never ineliminable even in a language with ternary predicates.

Is it possible to find a pivot for the decomposition of *hasColourAt* into binary relations? Suppose that *PlatoBeard* continuously exists over a period Δt and that it changes colour during that time so that, for example, it is black at T_1 and white at T_2. We have:

$$\begin{gathered} hasColourAt(PlatoBeard, Black, T_1) \wedge hasColourAt(PlatoBeard, White, T_2) \wedge \\ \neg\, hasColourAt(PlatoBeard, Black, \Delta t) \wedge \neg\, hasColourAt(PlatoBeard, White, \Delta t) \end{gathered} \tag{8}$$

We agree that the decomposition offered in (6) does not apply. The reason is that there is no particular among the related entities with functional relations to the other entities. One solution then is to add one. There is no room here to discuss general strategies as strategies depend on the particularity of an ontology, but we can illustrate one possibility. We want to avoid splitting *PlatoBeard* into temporal parts, so we approach change in colour as a succession of properties of *PlatoBeard* (it goes from black to white after all). *PlatoBeard* has at T_1 a particular quality, a colour, and this colour is throughout its existence of the kind *Black*. Although beards can change colours—they exemplify colour kinds in temporally sensitive ways—it is essential to colour particulars to be of the kind they are, e.g. the blackness of *PlatoBeard* existing at T_1 is essentially a blackness. A perspicuous representation of the first conjunct in (8) is then:

$$\begin{aligned} &hasColour(PlatoBeard, Colour_1) \\ &\qquad\qquad \wedge isAt(Colour_1, T_1) \wedge instanceOf(Colour_1, Black) \end{aligned} \tag{9}$$

Changes in the colour of *PlatoBeard* are successions of its colours, each colour uniquely pinpointing the relevant fact. We thus avoid change of beard, i.e. there are no two numerically distinct beards with different colours because the colour of the beard is not essential to the beard, and Plato change, i.e. there are no two numerically distinct Plato with differently coloured beards because the colour of his beard is not essential to Plato either.

It was easy to add a colour. Starting with a universal *Black*, we instantiate blackness to a particular which is functionally related to its bearer and the time of its existence. But can we do the same for (3)? Here, there is no universal. *Plato*, *Academia*, and -360 are particulars and they simply do not stand in functional relations taken pairwise, and there is no way we can bring a particular by instantiating any of them. Conceiving Plato as having an instance with a functional relation to *Academia* and to -360 is treating Plato as a perdurant with temporal parts (the putative instances of Plato-universal, elements of the Plato-class, or temporal parts of the perdurant Plato serve formally the same purpose).

One indication, however, is that there is a difference between the relations used in (3) and (4). *isInAt* is so to speak the subject of a bare relation. (It maps to the most general cartesian product of subsets of the domain to which map all locational relations at a time.) On the other hand, *hasColourAt* is determinate in one of its respects, it takes only a colour in its relevant argument place, rather than an attribute of a specified kind as would a version of this relation of equal generality to *isInAt*. That sort of determination is not a property of *isInAt* which is a totally general location relation. This suggests that the contrived solution to the reduction of (4) had to do with this determination.

4. Fiddling with Predicates II: Parametrization

Any n-place predicate is rewritable as an i-place predicate for all i such that $i < n$ and preserving the same sense, i.e. allowing to represent the same state of affairs ([10] makes the point about propositional functions). Let us speak of an operation of "parameterization". There can be more than one way of parameterizing a predicate—depending in particular on the order of arguments which will be ignored here for the sake of simplicity.

Parameterization fixes a respect in which the lower arity relation obtains. Emphatically, parameterization is not generalization (neither universal nor existential) in one or more argument place. The general notation and schema for a parameterization is this, where Arg_i is an individual occurring in the i argument place in R^{n}:

$$\ulcorner R^{\mathrm{n\text{-}1}}\, Arg_{\mathrm{i}} \urcorner(x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_n) \equiv R^{\mathrm{n}}(x_1, \ldots, x_{i-1}, Arg_i, x_{i+1}, \ldots, x_n) \tag{10}$$

in contradistinction to either of the following:

$$R^{\mathrm{n\text{-}1}}\, \forall_i(x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_n) \equiv \forall y\, R^{\mathrm{n}}(x_1, \ldots, x_{i-1}, y, x_{i+1}, \ldots, x_n) \tag{11}$$

$$R^{\mathrm{n\text{-}1}}\, \exists_i(x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_n) \equiv \exists y\, R^{\mathrm{n}}(x_1, \ldots, x_{i-1}, y, x_{i+1}, \ldots, x_n) \tag{12}$$

A parameterization of R^{n} in i arguments, for $1 \leq i < n$, is called "i–partial" or simply "partial" and a parameterization in n arguments is called "total".

Let us proceed to the case of temporal predicates, ternary ones for the sake of simplicity (but the procedure generalizes to higher arity ones). Suppose then we start with a temporal predicate R^3. A typical expression using R^3 will be written:

$$R^3(Arg_1, Arg_2, Arg_3) \tag{13}$$

where the Arg_i are individuals. Modulo the order of arguments and the order of iterated parameterization, there are three one–partial, three two–partial, and one total parametrizations of R^3 as shown in table 1 yielding the rewrite of (13). Choices of

Table 1. Prototypical parameterizations of (13).

one–partial	two–partial	total
$\ulcorner R^2 Arg_1 \urcorner(Arg_2, Arg_3)$	$\ulcorner R^1 Arg_1 Arg_2 \urcorner(Arg_3)$	$\ulcorner R^0 Arg_1 Arg_2 Arg_3 \urcorner$
$\ulcorner R^2 Arg_2 \urcorner(Arg_1, Arg_3)$	$\ulcorner R^1 Arg_1 Arg_3 \urcorner(Arg_2)$	
$\ulcorner R^2 Arg_3 \urcorner(Arg_1, Arg_2)$	$\ulcorner R^1 Arg_2 Arg_3 \urcorner(Arg_1)$	

parametrizations in a binary language are: i) a binary predicate, ii) a unary predicate, and iii) a constant. The challenge is to find a suitable interpretation as, for instance, intuitively shown in table 2 and more formally as follows (D is the domain of discourse, as expected):

$\ulcorner R^2 Arg_1 \urcorner$ is a binary relation which holds—possibly *inter alia*—between Arg_2 and Arg_3.

(13) is true *iff* $\ulcorner R^2 Arg_1 \urcorner(Arg_2, Arg_3)$ is true

iff the ordered pair $(Arg_2; Arg_3)$ belongs to a suitable subset of DxD.

$\ulcorner R^1 Arg_1 Arg_2 \urcorner$ is a property of—possibly *inter alia*—Arg_3.

(13) is true *iff* $\ulcorner R^1 Arg_1 Arg_2 \urcorner(Arg_3)$ is true

iff the individual Arg_3 belongs to a suitable subset of D.

$\ulcorner R^0 Arg_1 Arg_2 Arg_3 \urcorner$, in contradistinction to both of the above, is an individual.

(13) is true *iff* $\exists y(y = \ulcorner R^0 Arg_1 Arg_2 Arg_3 \urcorner)$ is true

iff the individual $\ulcorner R^0 Arg_1 Arg_2 Arg_3 \urcorner$ belongs to D.

There is nothing intrinsically wrong with partial parameterizations which in fact can contribute handy shorthand to KR. Using them amounts to creating vocabulary whose use is limited to representing the content of a knowledge base (i.e. a world state) with a fixed context linked to an individual in the domain: e.g. a time, a location, or even an

Table 2. Parameterizations of (3).

one–partial	two–partial	total
platoIsInAt(*Academia*,*-360*)	*PlatoInAcademiaAt*(*-360*)	*PlatoInAcademiaAt-360*
isInAcademiaAt(*Plato*,*-360*)	*PlatoInAt-360*(*Academia*)	
isInAt-360(*Plato*,*Academia*)	*InAcademiaAt-360*(*Plato*)	

attribute. Maybe the historical Plato is not very exciting, but the same procedure could be used for a patient's medical records or an archaeological site. This procedure could also be used for specifying prototypical instances of a category, e.g. anatomical ones. It is more generally a way of specifying any corpus of knowledge in a domain which is marked by a central referent, e.g. the Earth for geography.

This approach might come in handy in small ontologies, but becomes quickly unmanageable in large ones recollecting variant (differently parameterized) vocabulary and dealing with endless variations (e.g. of *isInAt* such as *isInAtT1*, *isInAtT2*, ..., *socratesInAt*, *phedoInAt*, ..., *critoInAcademiaAt*, etc). (A partial solution is to subsume partial parameterizations under predicates defined as in (12). This is only a partial solution and it promotes multiple inheritance, but this is another problem.)

The fatal shortcoming of FO binary languages in this context is that they allow for no explicit account of partial parameterizations, e.g. no way of enforcing the link between the predicate *isInAt-360* and the parameter -360. If it were not for the name, which is completely irrelevant in an axiomatization, we would have no clue that the predicate represents the relation of spatial location in -360. To explicit this link, we need a ternary language and a version of (10) as abbreviating definition. Short of this, we either need a sentential operator or to extend the language in a meta–linguistic way so as to allow attribution of properties to predicates. OWL Full allows certain assertions of the second sort and so would a free logic type of KR language, e.g. SCL [11]. But, even if possible, it is still unclear whether the language—or a binary fragment thereof—could have the resource to spell out what it meant for *platoIsInAt* to be about *Plato* and what it tells about *platoIsInAt*(*Academia*, -360).

The appeal of total parameterization is that its result can be interpreted as an individual, i.e. in the domain rather than as a relation or as a property. We can then legally spell out the links between the parameterization and the parameters in a binary language. It is the most commensurate to the expressive power of the binary FO language. Moreover, nothing short of total parametrization can produce an additional particular. This is because, if the result of partial parameterizations are interpreted as particulars, then the account of the situation is only partial. Or rather, it is partial until the links identifying the parameters are introduced. But that operation amounts precisely to a total parameterization. It is easy to see that it is for similar reasons that our discussion generalizes to higher arity predicates.

5. Ontological Extension, Reduction, and Soundness

5.1. Temporal Qualification and Parameterization

Let us call a parameterization in the temporal argument a “temporal parameterization”. What is the link between temporal qualification and temporal parameterization? Roughly, both operations are converse. Temporal parameterization fixes the value of a temporal predicate in its temporal argument place to define a plain (lower arity) predicate. Temporal qualification is the de–parameterizing of this (temporal) value. It takes the parameter from the intension of the relation and puts it as an additional argument place in the modified extension of that relation. By abstraction over this argument place, we obtain the temporally qualified variant of the plain predicate.

Such an operation is not limited to temporal arguments. Consider ways of representing the fact that Plato is an adult in -400 and the sort of ontologies to which they naturally associate. Table 3 shows four assertions corresponding to non trivially distinct

Table 3. Plato is an adult in -400.

Ontologies	Atemporal	Temporal
Nominalist	In -400: $Adult^1(Plato)$	*adultAt*(*Plato*,*-400*)
Realist	In -400: *exemplifies*(*Plato*,*Adult*)	*exemplifiesAt*(*Plato*,*Adult*,*-400*)

ontologies. Atemporal ontologies recognize a category of times (temporal regions or instants), temporal ontologies do not. Realist ontologies recognize a category of universals (attributes as abstract particulars), e.g. *Adult* exemplified by Plato, but nominalist ontologies do not, as they recognize only Plato and treat exemplification as class membership. Temporal FO predicates are temporal qualifications of atemporal ones. Conversely, atemporal ones are temporal parameterizations of temporal ones (compare $Adult^1$ in an ontology indexed to the year -400 and $\ulcorner AdultAt^1\text{-}400\urcorner$). But the same is true if we go across columns rather than rows (compare $Adult^1$ and $\ulcorner Exemplifies^1 Adult^0\urcorner$).

We see that parameterization and qualification are not ontologically neutral operations. Both are potentially expansive ontological tools as they require introducing particulars, and these particulars could be of a kind which is not recognized by the ontology—leading to a distinct ontology. In addition, parameterization is a potentially reductive tool. For instance, it allows to dispense with a category of time or with universals. But in some cases the expansive outcome of parameterization can be neutral, namely in cases in which the added entities are of kinds which are already recognized by the ontology.

5.2. Temporal Pivot

What are we doing when we totally parameterize a multiple arity predicate? We summon an individual and we link it to the relata of the parameterized predicate by a series of binary relations. For instance, (3) is represented linking *PlatoIsInAcademiaAt-360* (renamed *A*) to *Plato*, *Academia*, and -360, respectively, e.g.:

$$who(A, Plato) \wedge where(A, Academia) \wedge when(A, \text{-}360) \quad (14)$$

We have seen that: i) a ternary temporal predicate is trivially reducible to a combination of lower arity predicates when one of the relata is a pivot (*Plato* in (2)) and ii) in some cases, we can bring in one more entity implicit so to speak in the state of affairs to act as a pivot ($Colour_1$ in (4)). What total parametrization allows is to do the later systematically.

The only question that remains is what sort of entity this is. And the only significant ontological question is whether this entity belongs to a category that is additional to the categories of the ontology from which we started or whether it can fit in the existing ontology. For a start, the pivot obtained through temporal parametrization is a temporal entity, it has a relation to a time. It is credible then to ask whether this is an entity which changes over time or not. If the entity is changing, we are facing the problem of its own change and of temporal qualification again, and we enter a potentially infinite regress. It is credible to think that the entity is not an endurant but a perdurant. If this interpretation is correct, then in order to represent temporal qualification and change in a binary language we need a category of perdurants, the introduction of one of its instances as pivot, and, hence, binary relations to characterize this instance. If this is all we require, we are within the boundaries of a bi–categorial mono–ontological solution represented in a binary language.

Is it, then, possible in such an ontology to find in a principled way a suitable perdurant allowing for the representation of temporally qualified assertions about endurants? Observe first that there is the adulthood of Plato, the part of his life during which he is 1,80 m, the part of his life during which he likes Socrates, the part of Peter's life during which he is Canadian, that during which he is 48, etc. The life of an endurant is the aggregate of all processes (of change and non change) in which that endurant participates—therefore a life and its parts are perdurants. [1] The answer to our question is that lives and parts thereof are pivots for temporal facts about endurants. Is this solution uniform? In particular, could we give a pivot to facts such as that Plato is a person or that he does not know about the American continent? Yes, the life of Plato.

6. Conclusion

Binary FO languages are not capable of a straightforward ontological rendering of temporal qualification and hence of change in the relevant entities. They are not however ontologically biased in the way that only entities which do not change can be represented. But they are ontologically constraining in the sense that they require a category of perdurants involving changing entities to act as pivot in the relevant temporal facts. It is hardly a significant cost for bi–categorial ontologies in which the necessary top–level category is already present and it is no cost at all when the relation between endurants and their lives is recognized. In those cases, the procedure is systematic and ontologically sound and the benefit is clearly greater than ontological reduction or truncated representation. Problems should occur for eliminatist theories which reject processes and event and, in those cases, the languages are simply unable to faithfully allow representation. Then again, fine tuning can always produce wonders.

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