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A Priorean Approach to Time Ontologies

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Abstract. Any non-trivial top-level ontology should take temporal notions into account. The details of how this should be done, however, are frequently debated. In this paper it is argued that "the four grades of tense-logical involvement" suggested by A.N. Prior form a useful framework for discussing how various temporal notions are related in a top-level ontology. Furthermore, a number of modern ontologies are analysed with respect to their incorporation of temporal notions. It is argued that all of them correspond to Prior's first and second grade, and that none of them reflect the views which Prior's third and fourth grade represent. Finally, the paper deals with Prior's ideas on a tensed ontology and it is argued that a logic based on the third grade and will be useful in the further development of tensed ontology.

1 Introduction

In post-Medieval logic ontology, conceived as the study of being or existence, was regarded as a very important field of study. Indeed, philosophers and logicians in the 17th and 18th century were the first to establish the very word 'ontology' as a technical term naming the study of being or existence as such. One of the first philosophers to do so was Christian Wolff (1679-1754) who wanted to construct a logical system with which he could account for existence and non-existence. According to Wolff a 'being' or an 'entity' is whatever can be thought without involving any logical contradiction. This means that Wolffian ontology does not answer the question regarding what there is in the actual world. This question has to be answered within the so-called special metaphysics. In the 20th century, most philosophers interested in ontology have accepted the logical approach to ontology, but they have not been satisfied with the Wolffian notion of existence. In contrary, they mainly wanted to discuss the actual world, and not only the possible, but non-real worlds. Stanislaw Le niewski (1886-1939) seems to have been the first logician to suggest a formal (deductive) calculus of ontology. The core of this contribution is mereology which deals with the part–whole relation between objects. In the 1950s another Polish logician, C. Lejewski, extended the Le niewskian calculus introducing a so-called 'chronology', according to which objects are conceived as corresponding to durations.

In the works of Edmund Husserl (1859-1938) and Martin Heidegger (1889-1976) there is a strong emphasis on ideas of time as a very important background for the study of ontology. This means that there is an essential relation between ontological inquiry and the study of the concept(s) of time (see [8]). In his philosophical logic

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A.N. Prior (1914-69) put a similar emphasis claiming that temporal aspects are crucial for any satisfactory approach to reality.

Willard Van Orman Quine (1908-2000) was one of the most influential 20th century philosophers who contributed to the further development of ontology. In his "On What There Is" [23]. Quine introduced a view of ontology as the study of the ontological commitments of natural science (see [26]). According to Quine's view the ontologist should derive a network of claims about what actually exists using the natural sciences as his main source. In addition the ontologist should attempt to establish what types of entities are most basic. For Quine first-order predicate logic is crucial in the determination of what actually exists. According to his so-called 'criterion of ontological commitment' the ontologist can conclude that the ontological commitment of a scientific theory implies the existence of certain entities (such as electrons) if the theory presupposes that these entities are values of bound variables when formulated in first-order predicate logic.

A.N. Prior found Lejewski's as well as Quine's ideas on ontology very challenging, and he offered an idea of ontology which may be seen as an alternative to both approaches. Prior accepted the importance of Lejewski's attempt to involve time in the description of objects, but he found that the incorporation of time had to be carried out in a different manner. Prior's accepted Quine's idea that the ontologist should try to establish what types of entities are most basic, but he rejected the Quinean idea of letting ontology depend on what kinds of variables we are prepared to bind by quantifiers. In his writings Prior produced a highly original way of dealing with the temporal aspects of reality and the notions of quantification. In fact Prior suggested four conceivable theories regarding the temporal aspects of reality (the so-called four grades of tense-logical involvement). In section 2 we are going to describe these theories in some details and we shall see how they allow for different scopes of quantification. Each of the four theories suggests an ontology explaining how the various temporal notions and concepts (such as 'past', 'present', 'future', 'before', 'after', 'instant', 'duration') are mutually related. Although Prior stated that all four theories are possible, he himself clearly favoured the last of them (i.e. the 4th grade of tense-logical involvement).

For at least two decades formal ontologies have been studied intensively within various parts of computer science (see Sowa [27], [28]). Knowledge representation is obviously one of the computer science disciplines in which formal ontology has turned out to be particularly important. According to T.R. Gruber [10] the term 'ontology' is used in this field as standing for *»a specification of a conceptualization«*, or to put it differently »a description (like a formal specification of a program) of the concepts and relationships that can exist for an agent or a community of agents«. This may be said to bring us back to the Wolffian notion of existence according to which an entity exists if it can be thought of without any contradiction.

During recent years one of the most influential ideas within formal ontology has been the idea of a top-level ontology, which should include a small number of highly general categories. The benefits of such a top-level ontology is obvious when it comes to the development and application of information systems. Although very few believe that it will be possible ever to reach a universal agreement on the formulation of a non-trivial top-ontology, everybody working with information systems will accept the view that the problem of classification is crucial for the formulation of such systems. For this reason, the debates on formal ontology and classification should go on, and everybody working with information systems and knowledge engineering should

be aware of the ontological challenges to which the problems of concept handling give rise.

Prior did not pursue Lejewski's idea of a durational logic. However, other workers in temporal logic have done so. Their works show that the ontological relations between durations and instants are by no means given. Section 3 deals with the construction of formal ontologies in the light of the works within durational logic.

In section 4 we shall discuss the analysis of temporal notions according to some of the most well-known top-level ontologies, and we shall argue that most authors of modern ontologies, apparently without much reflection, assume something like Prior's first or second grade of tense-logical involvement. In section 5 we intend to discuss these Priorean ideas of a tensed ontology. We shall see that there is still much to be done in order to carry out the full Priorean program.

2 Prior's Four Grades of Tense-Logical Involvement

In his famous paper 'The Unreality of Time' [15] John Ellis McTaggart (1866-1925) suggested a distinction between A- and B-series, which in fact corresponds to a distinction between the following two sets of temporal notions:

A-notions: past, present, future
B-notions: before, after, 'simultaneous with'

Since McTaggart, philosophers and logicians have discussed intensively which of the two sets is the ontologically more fundamental one for the philosophical description of time. During the 20th century several authors have tried to answer this question of temporal ontology in a formal manner. In fact, this discussion has turned out to be essential for the formulation of temporal logic. A.N. Prior (1914-69) who was the founder of modern temporal logic paid very much attention to this problem. In his brilliant and very important paper from 1968, 'Tense Logic and the Logic of Earlier and Later' [21: 117ff.], Prior introduced four so-called grades of tense-logical involvement. These four grades can be understood as four different ways in which the question of temporal ontology can be answered.

The first grade defines tenses entirely in terms of objective instants and an earlier-later relation. For instance, a sentence such as Fp, 'it will be the case that p', is defined as a short-hand for 'there exists some instant t which is later than now, and p is true at t', and similarly for the past tense, Pp, i.e.

(DF) $T(t,Fp) \equiv_{def} \exists t_1: t < t_1 \wedge T(t_1,p)$
(DP) $T(t,Pp) \equiv_{def} \exists t_1: t_1 < t \wedge T(t_1,p)$

Given that $G \equiv_{def} \sim F \sim$ ('it is always going to be the case that …') and that $H \equiv_{def} \sim P \sim$ ('it has always been the case that …') it easily follows that

(DG) $T(t,Gp) \equiv \forall t_1: t < t_1 \supset T(t_1,p)$
(DH) $T(t,Hp) \equiv \forall t_1: t_1 < t \supset T(t_1,p)$

According to this view, tenses can be considered as mere meta-linguistic abbreviations, so this is the lowest grade of tense logical involvement. Prior succinctly described the first grade as follows:

> …there is a nice economy about it; it reduces the minimal tense logic to a by-product of the introduction of four definitions into an ordinary first-order theory, and richer [tense logical] systems to by-products of conditions imposed on a relation in that theory. [21: 119]

In the first grade, the tense operators (*P*, *F*, *G*, and *H*) are simply tools with which we can establish a handy way of summarizing the properties of the before-after relations, which constitute the B-theory of McTaggart. Hence, in the first grade temporal instants are viewed as something primitive and objective. Together with the before-after-relation they are seen to be determining for a proper understanding of time and reality. According to this view tenses are deemed to have no independent ontological status. The same can be said about the modal operators, □ and •, which correspond to necessity and possibility, respectively. These operators can be defined in the following way:

$$\Box p \equiv_{def} \forall t: T(t,p)$$
$$\Diamond p \equiv_{def} \exists t: T(t,p)$$

The time ontology of the first grade can be presented in the following way:

1st grade	
Primitive notions	Instants. The before-after relation (<). The truth-function ('true at an instant'), *T(t,p)*. First order logic.
Derived notions	Tenses: past (*P*), always past (*H*), future(*F*), always future(*G*). Modalities: necessity (□), possibility (•).

This time ontology seems to be the dominating and most common way of understanding the temporal aspect of reality. The weaknesses of this approach are, however, rather obvious. The most important problem is that the first grade does not include any idea of 'now'. In this system the present time can only be represented as an arbitrary instant. This is of course quite acceptable, if we take the view which Albert Einstein expresses in a letter to Michele Besso in the following way:

> There is no irreversibility in the basic laws of physics. You have to accept the idea that subjective time with its emphasis on the now has no objective meaning. [Quoted from [18: 203]]

If the 'Now' and consequently also the other A-concepts are purely subjective, all we have to bother with when dealing with the objective world are the B-series.

Viewed in this way reality is just a four-dimensional co-ordinate system. Times are nothing but clock-readings and dates. Prior described this position in the following way:

> Whether the events are the case or merely have been or will be, is of no concern to the scientist, so he uses a language in which the difference between being, having been, and being about to be becomes inexpressible. [20: 323]

However, Prior has argued that the following shows that even Einstein was a bit uncertain regarding the status of the 'Now':

> Einstein himself once said to Carnap that the problem of the Now worried him seriously. He explained that the experience of the Now means something special for men, something different from the past and the future, but that this important difference does not and cannot occur within physics. [21: 136-137]

Prior, himself, insisted that 'the Now' is real, and consequently that the distinction between the tenses is real (see [9: 47]). In his view it would be mistaken to assume that the 'Now' and the tenses can be derived from the logic of earlier and later. For this reason he had to reject the first grade and turn to an ontology in which the tense-logical aspect of reality is assumed to be fundamental.

In the second grade of tense logical involvement, the 'Now' is in fact accepted as a primitive notion. Formally, in this theory 'the Now' can be treated as a prepositional constant, *n*. This means that according to this view A- and B-concepts are treated on a par. Specifically, a bare proposition *p* is treated as a syntactically full-fledged proposition, on a par with what Rescher and Urquhart [24] called 'chronologically definite' propositions such as *T(t,p)* ('it is true at time *t* that *p*'). The point of the second grade is that a bare proposition with no explicit temporal reference is not to be viewed as an incomplete proposition. One consequence of this is that an expression such as *T(t,T(t',p))* is also well-formed, and of the same type as *T(t,p)* and *p*. In fact, p can be understood as being equivalent with *T(n,p)*. i.e. *p* is true if and only if *p* is true now. Prior showed how such a system leads to a number of theses, which relate tense logic to the earlier-later calculus and vice versa [19: 119].

The philosophical implication of this second grade of tense logical involvement is that one must regard the basic A- and B-theory concepts as being on the same conceptual level. Neither set of concepts is conditioned by the other.

2nd grade	
Primitive notions	Instants. The Now, *n*. The before-after relation (<). The truth-function ('true at an instant'), *T(t,p)*. First order logic.
Derived notions	Tenses: past (*P*), always past (*H*), future(*F*), always future(*G*). Modalities: necessity (□), possibility (•).

However, Prior also rejected the idea that time is made up of objectively existing instants. Formally this understanding of time can be expressed in terms of the third or

fourth grade of tense-logical involvement. According to Prior the crucial idea of the third grade "consists in treating the instant-variables *a*, *b*, *c*, etc. as representing propositions." [21: 124]

Such instant-propositions describe the world uniquely at any given instant, and are for this reason also called world-state propositions. Like Prior we shall use *a*, *b*, *c* ... as instant-propositions instead of t_1, t_2, ... In fact, Prior assumed that such propositions *are* what ought to be meant by 'instants':

> A world-state proposition in the tense-logical sense is simply an index of an instant; indeed, I would like to say that it is an instant, in the only sense in which 'instants' are not highly fictitious entities. [19: 188-189]

The traditional distinction between the description of the content and the indication of time for an event is thereby dissolved. This means that ordinary propositional logic in insufficient here. With his formulation of the third grade, Prior actually became the first logician to explore the formalism of hybrid languages which are now known in so-called hybrid logic (see http://www.hylo.net).

The axioms of the logical language, which embodies the third grade of tense logical involvement, are in the first place the following axioms of a basic tempo-modal logic:

(A1)	p, where p is a tautology of the propositional calculus
(A2)	$G(p \supset q) \supset (Gp \supset Gq)$
(A3)	$H(p \supset q) \supset (Hp \supset Hq)$
(A4)	$p \supset GPp$
(A5)	$p \supset HFp$
($\Box$1)	$(p \supset q) \supset (\Box p \supset \Box q)$
($\Box$2)	$\Box p \supset p$
($\Box$3)	$\Box p \supset \Box\Box p$
($\Box$G)	$\Box p \supset Gp$
($\Box$H)	$\Box p \supset Hp$

In addition, in order to deal with the instant propositions involved in the hybrid language of the third grade Prior added the following axioms:

(I1)	$\exists a: a$
(I2)	$\sim\Box\sim a$
(I3)	$\Box(a \supset p) \vee \Box(a \supset \sim p)$
(BF)	$\Box(\forall a: \phi(a)) \equiv \forall a: \Box(\phi(a))$

where *a* stands for an instant proposition, whereas *p* stands for any proposition. Given these axioms and some standard rules of reference Prior was able to prove a number of interesting theses for this hybrid language corresponding to the third grade. He argued that within this system *T(a,p)* as well as the before-after-relation can be defined in terms of the tenses and a primitive necessity-operator $\Box$. Formally, this can be done in the following way:

$T(a,p) \equiv_{def} \Box(a \supset p)$
$a<b \equiv_{def} \Box(b \supset Pa)$

Prior demonstrated convincingly, that T and $<$ defined in this way fulfill everything which holds for the corresponding notions in the first grade. (See [21: 124 ff.]) For instance, Prior proved that the formulae (DF) and (DP) hold with instant propositions instead of temporal instants.

In the third grade all of temporal logic can be developed from the purely 'modal notions' of past, future, and necessity. The corresponding time ontology can be presented in the following manner:

3rd grade	
Primitive notions	Tenses: past (P), future(F). Modality: necessity ($\Box$). - Hybrid logic.
Derived notions	Instants. The before-after relation ($<$). The truth-function ('true at an instant'), $T(t,p)$. Derived tenses: always past (H), always future(G). Derived modality: possibility ($\bullet$).

In some logics the truth-function involves not only propositions and instants, but also chronicles (i.e. 'totally ordered subsets of instants') cf. [31: 211]). In these logics the truth-functions becomes $T(t,c,p)$, where t is an instant belonging to the chronicle c. $T(t,c,p)$ can be read 'p is true at t on c'. However, this complication is not needed in the third grade, where the instant propositions also include the information corresponding to the chronicle.

The fourth grade may be seen as a continuation of the third grade, from which all definitions are carried over. However, according to the view corresponding to the fourth grade a tense logical definition of the necessity-operator can be established, if the future operator is understood as corresponding to 'possible future' and not some sort of 'factual future' (i.e. in this case 'future' has to be take in the Peircean sense cf. [31: 220]). This means that in the fourth grade the only primitive operators are the two tense logical ones: P and F. Within the hybrid logic all other notions can be defined from these two tense operators. This means that the corresponding time ontology can be presented in the following way:

4th grade	
Primitive notions	Tenses: past (P), future(F) - Hybrid logic.
Derived notions	Instants. The before-after relation ($<$). The truth-function ('true at an instant'), $T(t,p)$. Tenses: always past (H), always future(G). Modalities: necessity ($\Box$), possibility ($\bullet$).

Prior himself favoured this fourth grade. It appears that his reasons for wanting to reduce modality to tenses were mainly metaphysical, since it has to do with his rejection of the concept of the (one) true (but still unknown) future.

In the systems corresponding to the third and the fourth grade of tense-logical involvement it is assumed that it is possible to quantify over instant propositions. If Quine's so-called 'criterion of ontological commitment' is accepted, it follows that instants (conceived as instant propositions) actually exist in reality. However, Prior did not accept this conclusion. In fact, Prior rejected Quine's criterion. According to his idea of existence we do not have to accept the existence of instants just because we are prepared to bind them by quantifiers. Existence is rather a question of "what variables we take seriously as individual variables in a first-order theory, i.e. as subjects of predicates rather than as *assertibilia* which may be qualified by modalities" [21: 220]. When viewed in this way, we can conclude that instants do not exist in reality. As Prior put it, "they don't exist; rather, they are or are not the case". [21: 220]

3 The Role of Durations in Time Ontology

The notion of a 'duration' is obviously important, when it comes to the study of temporal ontology. Several logicians have tried to formulate a logic of duration. In fact, already the medieval logician John Buridan (ca. 1295-1358) regarded the present as a duration and not as a point in time. Indeed, he made a number of important contributions to the development durational logic (see [31: 43 ff.].

The first modern logician to formulate a calculus in this field was A.G. Walker [29], who considered a structure $(S,<)$, where S is a non-empty set of periods. The '$a<b$'-relation is to be considered as 'strict' in the sense that no overlap between a and b is permitted, and the ordering is supposed to be irreflexive, asymmetrical, and transitive. In addition he considered the notion of overlap, which can be defined as:

$$a \mid b \underset{def}{\equiv} \sim(a<b \vee b<a).$$

Walker formulated an axiomatic system using the following two axioms:

(W1) $a \mid a$

(W2) $(a<b \wedge b \mid c \wedge c < d) \supset a < d$

Using a set-theoretic method base Walker demonstrated that it is possible to define instants in terms of durations. For this reason it may be reasonable to view a temporal instant as such a 'secondary' construct from the logic of durations. In the 1950s C. Lejewski worked out a so-called 'chronology' according to which objects are conceived as corresponding to durations. This work should actually be seen as an extension of the Leśniewskian calculus, which appears to have been the first formal ontology. [25: 18 ff.]

In 1972 Charles Hamblin [11] independently also put forth a theory of the logic of durations. He achieved his results using a different technique involving the relation:

$$a \text{ meets } b \underset{def}{\equiv} a<b \wedge \sim(\exists c: a<c \wedge c<b))$$

A decade later, similar considerations have been put forward within artificial intelligence research, notably by James Allen and Patrick Hayes [3], [4], [5], [6], who has analysed further details of durational logic. Allen and Hayes have shown that two arbitrary durations (in linear time) can be related in exactly 13 ways.

It has been argued in [31: 304 ff.] that Walker's and Hamblin's theories are equivalent when seen from an ontological point of view. They all support the claim that just as durations (temporal interval) set-theoretically can be constructed from an instant-logic, it is possible to do the opposite i.e. to construct instants mathematically from durations. In fact, all the durational theories put forth so far appear to give rise to the same ontological model. Given the set of instants and the before-after relation we may define chronicles as linear ordered subsets of the total set of total set of instants.

The theories formulated by Walker, Hamblin, and Allen can all be said to be B-theoretical. It is however also possible to take an A-theoretical approach to durational logic. This can in fact be done in two different ways. Already John Buridan suggested these two alternative ideas for the construction of the logic of tenses. Firstly, the tenses, past and future, can be taken absolutely, in the sense that no part of the present time is said to be past or future. Secondly, tenses can be taken in the relative sense, according to which "the earlier part of the present time is called past with respect to the later, and the later part is called future with respect to the earlier." [7: 175]

In addition, Buridan pointed out that if some thing is moving now, then there is a part of the present during which it is moving, and hence, it is moving in some part of the present, which is earlier than some other part of the present. Therefore, if the thing is moving, then it was moving (if the past is taken in the relative sense). For this reason, the Aristotelian sophism must be conceded if the past is understood relatively. In a modern formal language Buridan's idea of a relative past can be stated in the following way:

$$T(I_n, P_{rel} A) \equiv_{def} \forall I': included(I', I_n) \supset (\exists I'': I'' < I' \wedge T(I'', A))$$

whereas the absolute past can be defined as

$$T(I, P_{abs} p) \equiv_{def} \exists I_1: I < I_1 \wedge T(I_1, p)$$

In modern durational logic a similar distinction has been introduced by Röper and others (see [31: 312 ff]). It turns out, that given that time can be viewed as a structure like the ordered set of real numbers and that durations are just open intervals, it can be shown that $P_{rel} \equiv G_{abs} P_{abs}$. There are of course a lot of details to be worked out here. But in the cases in which this equivalence holds, we obviously do not need to take both sets of tenses as primitives since the relative tenses can be derived from the absolute tenses.

It will be possible to combine the distinction between durations and instants with the above discussion about Prior four grades. If we assume Prior's third grade and that durations should be derived from instants we get an ontology, which can be outlined as indicated in the schema below:

3rd grade extended with durations

Primitive notions	Tenses: past (*P*), future (*F*). Modality: necessity (□). - Hybrid logic.
Derived notions	Instants. Chronicles. The before-after relation (<). A truth-function: *T(t,p)* Derived tenses: always past (*H*), always future (*G*). Derived modality: possibility (•).
Secondary derived notions.	Durations. Durational absolute tenses: P_{abs}, H_{abs}, F_{abs}, G_{abs} Durational relative tenses: P_{rel}, H_{rel}, F_{rel}, G_{rel}

On the other hand, if we assume Prior's third grade and that instants should be derived from durations things become much more complicated. But although there are a number of open questions regarding the precise procedures, it is very likely that it will be possible to develop an ontology based on durational tenses and hybrid logic.

4 Analysis of Some Current Time Ontologies

In light of the growing number of available ontologies, and the emerging need to collect information from different ontological descriptions, it becomes increasingly important to evaluate ontologies. It is sometimes said that the better ontology is one, which fulfills its purpose. There is obviously some truth in that, but if the purpose includes interoperability or the ability to merge with other ontologies, this question becomes much more complex. In the process of designing ontologies, the ontologist must on one hand take into account competing or comparable efforts and on the other hand pay special attention to the main purpose of the ontology. The Cyc ontology, for instance, is concerned with encompassing common knowledge whereas the DAML Time ontology deals with how to handle web documents. Clearly, the purpose of the ontology is reflected in the choice of words and concepts as well as in matters like expressive power and granularity.

The question of how to evaluate and compare ontologies must extend beyond matters of aligning lists of concepts, and also take into account the deeper lying intention and metaphysical positions behind the respective ontologies. These questions are broad and complicated, not least because top-level ontologies by nature deal with many different domains. In order to describe and compare different ontological approaches, a larger framework is needed. Top-level ontologies are likely to diverge in many other areas than that of temporal notions. In fact, we believe that a similar effort may be appropriate in several other dimensions than the one under consideration here. However, considering the fundamental status of time, this seems an appropriate place to start. In order to analyze temporal notions in ontologies, we suggest using Prior's four grades. Once the framework has been properly established, the procedure of comparing ontologies simply consists in looking for the relevant primitives from which other notions are defined, and map them to one of the grades. It turns out that such an analysis at the surface level is quite simple, and it is likely that it can be

automated, but also that slight differences in terminology and style of representation may complicate such analyses tremendously.

In order to compare some influential time ontologies we shall in the following examine their primitive and derived notions. To our knowledge, most ontologies that deals with temporal notions have *instants* as well as *intervals* as primitives, and as such, they are only slightly different. The DAML Time ontology [12] refers to this as *instants* and *intervals*, and the Suggested Upper Merged Ontology (SUMO) [13] uses *time-points* and *time-intervals*. In OpenCyc [17] TimeInterval is seen as a direct generalization of TimePoint, indicating that TimePoints are defined in terms of intervals, but in effect TimePoints are treated as primitive notions.

The before-after relation is also common to most time ontologies although it is expressed in different ways. In SUMO an *earlier* relation is defined over *intervals* and a *before* relation is defined over *time points* (instants). DAML Time uses only a *before* relation from which all other temporal relations are defined, and OpenCyc has two primitive temporal predicates (*after* and *simultaneousWith*) for defining an order between temporal elements. No before-relation is formally defined in OpenCyc, but the documentation clearly shows how the semantics of '*before'* is distributed over several complex temporal predicates. This choice in ordering corresponds to McTaggart's B-series.

Corresponding to the truth-function *T(a,p),* most ontologies have predicates that link events to times, such as the (holdsIn TEMP-THING FORMULA) of OpenCyc which says that a formula is true at every moment in the extent of TemporalThing i.e. TimeInterval or TimePoint. Ontologies that satisfy these conditions qualify as first grade ontologies. The crucial distinction between first and second grade is the notion of *Now* and the consequences thereof.

In DAML Time this predicament is partially avoided by considering concepts like '*now'* and '*today'* as deictic times, relative to some document or utterance. The documentation briefly mentions the possibility of defining *past* and *future* in terms of this deictic 'now' and the before relation. [12: section 7]. A similar but more explicit solution is used by the TERQAS group [22] associated with the TimeML effort [2]. In identifying temporal attributes of events for Question Answering systems, the TERQAS group distinguishes between absolute and relative time according to the document date [1: section 4]. Likewise, SUMO has no formal definition of '*now'* but the provided mapping between SUMO and WordNet points to 'now' as simply a time point. In consequence hereof, '*past'* and '*future'* does not share ontological status with *time-intervals*, but are defined as functions that map a TimePosition to the TimeInterval which it meets and which begins / ends at PositiveInfinity / NegativeInfinity. In his treatment of processes, John Sowa follows a similar line of reasoning, but in addition, he explicitly defines '*past'* by means of the indexical '*Now'* and the B-like relation '*succession'* [28: 207]. But where he in [27] was primarily concerned with representing grammatical structures [28] goes one step further in accounting for the special status of *now*.

Common to these approaches is that '*now'* is treated as an arbitrary indexical defined in terms of the before-after relation. A more developed notion of now is found in OpenCyc. This ontology does, as the only top level ontology that we are aware of, have the notion of '*Now'* as a primitive, and should therefore be considered a time ontology of the second grade. Surprisingly, OpenCyc has no definitions of '*past'* and '*future'* as anything other than grammatical constructions, but as we have seen, the

tempo-logical notions of *past* and *future* can be derived in both the first and second grade.

> #$Now is a special #$TimePoint which denotes the current moment from the perspective of the instantiation of #$CycTheCollection that is currently being run (i.e. #$Cyc). […] Thus the referent of #$Now does not vary with the #$Microtheory in which one asks (#$indexicalReferent #$Now ?X). Instead, the referent of #$Now varies from moment to moment down to the resolution of #$Cyc's central processing unit. [17]

Prior strongly suggested that in building a temporal ontology we should take the durational existence of things or objects into account. He pointed out that talk about events »is really at bottom talk about things, and that what looks like talk about changes in events is really just slightly more complicated talk about changes in things« [21: 16]. Recently, Karl Erich Wolff and Wendsomde Yameogo [30] have introduced a conceptual analysis involving objects and their so-called 'life tracks'. This approach mainly corresponds to Prior's first grade. Something similar can be said about Pavel Kocura's approach [14] with the addition that this work also involves a durational logic (e.g. reasoning about time intervals).

In 1993 Bernard Moulin [16] has demonstrated how temporal information in discourses can be modelled using the notion of a time coordinate system. In a very clear manner he has shown how the idea of a time axis, i.e. a set of 'time points' and total order relation, <, can be used in the definitions of time intervals, temporal objects and situations. Moulin has also shown how relations like 'during' and even rather complicated tenses can be defined in his model. His approach turns out to be a rather elaborated version of Prior's first grade extended with temporal objects and time intervals (defined from 'time points').

After having reviewed a number of contemporary and influential time ontologies, we have not found any that goes beyond the second grade of tense-logical involvement. None of the ontologies relate time and modality, and only DAML Time silently supports (allows for) branching time models, which certainly gives rise to an interesting challenge.

5 Towards a Tensed Ontology

There is no reason to believe that the struggle between A-theorists and B-theories will ever be settled. This means that we will probably in all foreseeable future have to deal with different time ontologies based on different philosophical positions. It is, however, worth noting that the logic based on Prior's third grade, which take instants as well as durations into account, seems to be the most general language, we have considered in this study. In fact, all concepts from all the time ontologies considered can be translated into such a logical language. This means that a logical language based on the third grade and extended to include durations as well as instants will qualify as a language in terms of which time ontologies may be compared. In particular, such a language will be fit for Prior's ideas of a tensed ontology. None of the other grades can provide a similar platform for comparison between ontologies. There are, how-

ever, a number of problems, which should be solved in order to carry out the full Priorean program.

The most common relation in theories of formal ontology is that of a sub-category corresponding to statements of the form 'x is a y'. Prior argued, however, that a satisfactory ontological system should also take tensed variations of such statements into consideration. This means that we should study statements like 'x has been a y" and 'x is a future y' in an ontological context (see [19: 162 ff].

Things become rather complicated, since Prior promotes the idea that new entities come into being as time passes. Some perfectly sensible statements now, would be non-statable in the past. This means for instance, that we can now say things about the past events, which could not be stated at all when the events took place. This logic of statability is incorporated in Prior's system Q, according to which the following theses hold:

$$F(n)(\forall x{:}\phi(x)) \supset \forall x{:}F(n)\phi(x)$$
$$P(n)(\exists x{:}\phi(x)) \supset \exists x{:}P(n)\phi(x)$$
$$\forall x{:}P(n)\phi(x) \supset P(n)(\forall x{:}\phi(x))$$

whereas 'the mirror-images':

$$P(n)(\forall x{:}\phi(x)) \supset \forall x{:}P(n)\phi(x)$$
$$F(n)(\exists x{:}\phi(x)) \supset \exists x{:}F(n)\phi(x)$$
$$\forall x{:}F(n)\phi(x) \supset F(n)(\forall x{:}\phi(x))$$

do not hold. The reason for this asymmetry is that "the values of bound variables may receive additions but no deletions as time passes" [19: 172]. A full logic corresponding to Prior's idea of a tensed ontology will have to integrate Prior's third grade of tense-logical involvement and his Q-system. To the best of our knowledge nobody has tried to formulate a formal ontology corresponding to his idea of a growing conceptual framework. There is obviously a lot to do in order to carry out the full Priorean program about tensed ontology.

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