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On the formal semantics of begin and end of states in a model theory for temporal DRT

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Abstract

In this paper we show that the intended meaning of begin and end of states is not embodied in the model theory of temporal DRT as given in *From Discourse to Logic*. As a consequence the non-continuous reading of the present perfect of statives is not expressed quite correctly by Kamp and Reyle. We introduce first order axioms for begin and end of states and events. Further to capture the intended meaning of begin and end of states two second order axioms are needed which say that the end of a state cannot overlap a similar state and that the begin of a state cannot overlap a similar state. This treatment of begin and end of states can be used not only for DRT but for other eventuality-based theories of temporal semantics as well.

Keywords FORMAL SEMANTICS, DRT, TEMPORAL SEMANTICS, MODEL THEORY, STATES, BEGIN, END

In DRT discourses are translated into discourse representation structures which are translated into formulas of first order logic. The model theory uses a Davidsonian eventuality-based semantics. The temporal analysis of sentences in DRT is based on a theory of aspect and a two-dimensional theory of tense.

The theory of aspect uses a system of verb classes: we have statives, accomplishments, achievements and activities. In this theory it is determined whether the eventuality described by a given sentence is an event or a state.

FG-MoL 2005.
James Rogers (ed.).

The motivation for the distinction between state- and event-describing sentences comes from the way temporal localization adverbs like `on Sunday` function. In an event-describing sentence like the following (with an accomplishment in the simple past tense)

`Mary wrote the letter on Sunday`

the localization time of the described eventuality is *included* in the time referred to by `on Sunday`. In contrast, in a state-describing sentence like the following (with an accomplishment in the past progressive)

`Mary was writing the letter on Sunday`

we only know that the localization time of the state in question *overlaps* with the time referred to by `on Sunday`. Note that Mary may have already been writing the letter on Saturday. The time referred to by a temporal localization adverb we call the **adverb time**.

After the described eventuality has been determined, it is localized in time via a two-dimension theory of tense. A central role is played by the **Temporal Perspective Point**, `TPpt`. Two relations are important in this theory: the relation in which `TPpt` stands with the *utterance time* n of the sentence in question, and the relation in which the *adverb time* i stands with `TPpt`. A suitable temporal perspective point has to be choosen out of the context of the preceding discourse. For a single sentence discourse, n is the only available candidate. In sentences with a temporal localization adverb **Adverb** we have the condition **Adverb**(i). If there is no temporal localization adverb present, no condition is put on i.

Now we concentrate on model theory, see Kamp and Reyle (1993, p. 667 ff). [1]

Definition 1 *A structure* $\mathcal{EV} = (\mathsf{EV}, \mathsf{E}, \mathsf{S}, <, \bigcirc)$ *such that* EV, E *and* S *are sets,* $\mathsf{EV} = \mathsf{E} \cup \mathsf{S}$, $\mathsf{E} \cap \mathsf{S} = \emptyset$ *and* $\mathsf{EV} \neq \emptyset$ *is called an* **eventuality structure**.

EV *is called the set of* **eventualities**, E *the set of* **events**, S *the set of* **states**. *Eventualities are denoted by* `ev`, *events by* `e` *and states by* `s`.

[1] One of the referees suggested that the work of Sylviane Schwer might be of relevance to this paper. Schwer (2004) shows an interesting connection between the eventuality structures of Kamp and S-languages. As she is working in a different framework, it will take substantial time to determine the exact relevance of her work to the present question of begin and end of states. Schwer does not treat states as arguments of predicates, so it is not to be expected that she has a solution to the non-continuous reading of the present perfect in the framework of DRT, however. I postpone investigations into Schwer (2004) for a later occasion.

The **precedence** *relation, <, and the* **overlap** *relation,* $\bigcirc$*, are binary relations on* EV *such that for all* $\mathtt{ev_i} \in \mathsf{EV}$*:*

$$\mathtt{ev}_1 < \mathtt{ev}_2 \rightarrow \neg \mathtt{ev}_2 < \mathtt{ev}_1 \tag{P1}$$

$$(\mathtt{ev}_1 < \mathtt{ev}_2 \wedge \mathtt{ev}_2 < \mathtt{ev}_3) \rightarrow \mathtt{ev}_1 < \mathtt{ev}_3 \tag{P2}$$

$$\mathtt{ev}_1 \bigcirc \mathtt{ev}_1 \tag{P3}$$

$$\mathtt{ev}_1 \bigcirc \mathtt{ev}_2 \rightarrow \mathtt{ev}_2 \bigcirc \mathtt{ev}_1 \tag{P4}$$

$$\mathtt{ev}_1 < \mathtt{ev}_2 \rightarrow \neg \mathtt{ev}_2 \bigcirc \mathtt{ev}_1 \tag{P5}$$

$$(\mathtt{ev}_1 < \mathtt{ev}_2 \wedge \mathtt{ev}_2 \bigcirc \mathtt{ev}_3 \wedge \mathtt{ev}_3 < \mathtt{ev}_4) \rightarrow \mathtt{ev}_1 < \mathtt{ev}_4 \tag{P6}$$

$$\mathtt{ev}_1 < \mathtt{ev}_2 \vee \mathtt{ev}_1 \bigcirc \mathtt{ev}_2 \vee \mathtt{ev}_2 < \mathtt{ev}_1 \tag{P7}$$

Eventualities are localized in time at intervals. Intervals are convex sets of instants. A **punctual interval** i is of the form $i = \{t\}$ where t is an instant; n and `TPpt` are punctual intervals. The precedence relation $<$ on the set of instants is asymmetric, transitive and linear. The interval structure associated with the instant structure $\mathcal{T}$ is denoted by $\mathcal{INT}(\mathcal{T})$. Precedence, $<$, and overlap, $\bigcirc$, between intervals i_1, i_2 are defined as follows: $i_1 < i_2$ if $t_1 < t_2$ for all $t_1 \in i_1, t_2 \in i_2$, and $i_1 \bigcirc i_2$ if there is a $t \in i_1 \cap i_2$. The localization function $\mathrm{LOC} : \mathcal{EV} \rightarrow \mathcal{INT}(\mathcal{T})$ from eventualities to intervals is a homomorphism with respect to precedence and overlap. [2]

In Dünges (1998) it is shown that the following holds:

Proposition 1

$$\mathtt{ev}_1 \bigcirc \mathtt{ev}_2 \leftrightarrow \mathrm{LOC}(\mathtt{ev}_1) \bigcirc \mathrm{LOC}(\mathtt{ev}_2) \tag{i}$$

$$\mathtt{ev}_1 < \mathtt{ev}_2 \leftrightarrow \mathrm{LOC}(\mathtt{ev}_1) < \mathrm{LOC}(\mathtt{ev}_2) \tag{ii}$$

A sentence with a stative in the simple present is state-describing and has the temporal property $\mathtt{TPpt} = n, i = \mathtt{TPpt}$. So sentence (4.1) gets formula (4.2). See figure 1.

$$\texttt{Mary lives in Amsterdam} \tag{4.1}$$

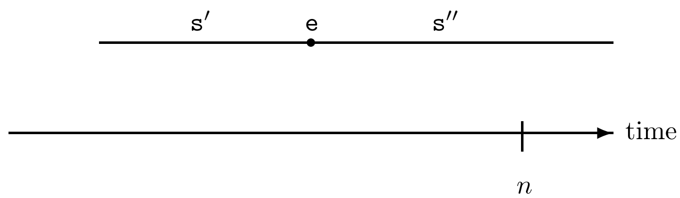
$$\exists i, s, x(i = n \wedge \mathrm{LOC}(s) \bigcirc i \wedge \mathrm{Mary}(x) \wedge \text{live-in-Amsterdam}(s, x)) \tag{4.2}$$

Begin and end of states and events play a role, too. A linguistic motivation for the introduction of the end of a state is the treatment Kamp and Reyle give to the present perfect of statives in sentences without temporal localization adverbs. Such a sentence is state-describing and

[2] There is more to say about LOC, for the present article LOC being a homomorphism suffices, however. For further conditions on LOC see Kamp and Reyle (1993), Dünges (1998) and Dünges (2001).

FIGURE 1: A model for a sentence with a stative in the simple present

FIGURE 2: A model for a sentence with a stative in the present perfect



has the temporal property `TPpt` $= n, i =$ `TPpt`. Here the described eventuality is the result state `s″` of a state `s′` that is referred to by the stative and `s″` is triggered by the *termination* of the underlying state `s′`. Thus the following sentence

`Mary has lived in Amsterdam` (4.3)

is describing a state that comes about through "*termination of the state of living in Amsterdam*", see Kamp and Reyle (1993, p. 567). We call this interpretation of the present perfect of statives the **non-continuative reading**. In Kamp and Reyle (1993, p. 580) we find essentially the following formula for (4.3), where $\supset\!\subset$ stands for the abut relation. See figure 2.

$$\exists i, s', s'', e, x(i = n \wedge \mathrm{LOC}(s'') \bigcirc i \wedge e = \mathrm{end}(s') \wedge e \supset\!\subset s'' \\ \wedge \mathrm{Mary}(x) \wedge \text{live-in-Amsterdam}(s', x)) \qquad (4.4)$$

By the way, formula (4.4) and formula (4.2) can both be true in the same model at n. This is as it should be, as intuitively the truth of `Mary has lived in Amsterdam` does not speak against the truth of `Mary lives in Amsterdam`, if both sentences are uttered at the same time: Mary may have come back to Amsterdam once she left it.

Kamp and Reyle mention, that $e \supset\!\subset s''$ means that s'' "*starts the very moment e ends*", but do not give a formal definition of the abut relation or a complete formal characterization of begin and end of eventualities in Kamp and Reyle (1993).

Let us start with some first order axioms for begin and end of eventualities. Kamp and Reyle introduce the functions begin : $\mathsf{EV} \rightarrow \mathsf{E}$ and end : $\mathsf{EV} \rightarrow \mathsf{E}$ in their definition of a *model*, see Kamp and Reyle (1993, p. 677 ff.). The only conditions they put on these functions are the following

$$\text{begin}(\text{begin}(\mathtt{ev})) = \text{begin}(\mathtt{ev}) \tag{BB}$$

$$\text{end}(\text{end}(\mathtt{ev})) = \text{end}(\mathtt{ev}) \tag{EE}$$

More than that is needed to capture the intended meaning of begin and end of eventualities, however. One intuition that must be reflected by our theory is that begin and end of an event belong to that event, but begin and end of a state do not belong to that state. Why is this so? Consider an event $\mathtt{e}$ described by `Mary wrote the letter`. Assume that $\text{LOC}(\mathtt{e}) = [t_1, t_2]$. Then intuitively there is a state $\mathtt{s}$ described by `Mary was writing the letter` and $\text{LOC}(\mathtt{s}) =]t_1, t_2[$. Meaning postulates for the progressive can take care of this. Intuitively we want $\text{LOC}(\text{begin}(\mathtt{e})) \subseteq \text{LOC}(\mathtt{e})$ but $\text{LOC}(\text{begin}(\mathtt{s})) < \text{LOC}(\mathtt{s})$. In addition, no temporal gaps should be allowed between the begin of a state and the state on the one hand and the state and the end of the state on the other hand.

In order to capture the no-gap intuition we need the **adjacency-**relation, $\supset\!\subset$. We define the adjacency relation between eventualities via the adjacency relation between intervals as follows:

$$i_1 \supset\!\subset i_2 \text{iff} i_1 < i_2 \wedge i_1 \cup i_2 \in \mathcal{INT}(\mathcal{T}) \tag{$\supset\!\subset$1}$$

$$\mathtt{ev}_1 \supset\!\subset \mathtt{ev}_2 \text{ iff } \text{LOC}(\mathtt{ev}_1) \supset\!\subset \text{LOC}(\mathtt{ev}_2) \tag{$\supset\!\subset$2}$$

To begin with, we introduce a partition of the set of events, E, into a set of **punctual events**, PE, and a set of **non-punctual events**, NPE. Punctual events are localized at punctual intervals, non-punctual events at non-punctual intervals. Non-punctual events consist of three parts: begin, middle and end. The **constitutes function** $+ : \mathsf{PE} \times \mathsf{S} \times \mathsf{PE} \rightarrow \mathsf{NPE}$ is a partial function, which puts together these three parts of a non-punctual event. Begin and end of eventualities are punctual events, the middle of an event is a state.

We require the fulfillment of the following axioms:

$$\forall \mathsf{e} \in \mathsf{PE}(\text{begin}(\mathtt{e}) = \mathtt{e} = \text{end}(\mathtt{e})) \tag{LEV1}$$

$$\forall \mathsf{e} \in \mathsf{NPE}(\text{begin}(\mathtt{e}) \supset\!\subset \text{middle}(\mathtt{e})) \tag{LEV2}$$

$$\forall \mathsf{e} \in \mathsf{NPE}(\text{middle}(\mathtt{e}) \supset\!\subset \text{end}(\mathtt{e})) \tag{LEV3}$$

$$\forall \mathsf{e} \in \mathsf{NPE}(\mathsf{e} = +(\text{begin}(\mathsf{e}), \text{middle}(\mathsf{e}), \text{end}(\mathsf{e}))) \qquad \text{(LEV4)}$$

$$\begin{aligned}\forall \mathsf{e} \in \mathsf{NPE}(\text{LOC}(\mathsf{e}) = \text{LOC}(\text{begin}(\mathsf{e}))\cup \\ \text{LOC}(\text{middle}(\mathsf{e})) \cup \text{LOC}(\text{end}(\mathsf{e})))\end{aligned} \qquad \text{(LEV5)}$$

$$\forall \mathtt{s} \in \mathsf{S}(\text{begin}(\mathtt{s}) \sqsupset\!\sqsubset \mathtt{s}) \qquad \text{(LEV6)}$$

$$\forall \mathtt{s} \in \mathsf{S}(\mathtt{s} \sqsupset\!\sqsubset \text{end}(\mathtt{s})) \qquad \text{(LEV7)}$$

Conditions (BB) and (EE) of Kamp and Reyle are met by our functions begin and end as well, because the begin and the end of an eventuality are punctual events and we have axiom (LEV1).

Now we can define the **abut**-relation $\supset\!\subset$ as follows:

$$\mathtt{ev}_1 \supset\!\subset \mathtt{ev}_2 \text{ iff } \text{LOC}(\text{end}(\mathtt{ev}_1)) = \text{LOC}(\text{begin}(\mathtt{ev}_2)) \qquad (\supset\!\subset)$$

Note that there is a subtle difference between the adjacency and the abut relation. The adjacency relation between eventualities does not allow for a time gap between them. In contrast, if $\mathtt{s} \supset\!\subset \mathtt{s}'$ holds, then there is a tiny time gap between the two states, given by LOC(begin($\mathtt{s}'$)).

In order to get inferences like the following:

`Mary wrote the letter` ⊨ `Mary was writing the letter`

we may introduce meaning postulates:

$$\text{write}(e, x, y) \rightarrow (\text{PROG}(\text{write}))(\text{middle}(e), x, y) \qquad \text{(mp:write)}$$

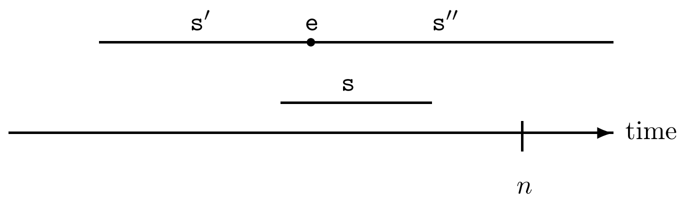
Let us come back to our example `Mary has lived in Amsterdam`. Consider a model $\mathfrak{M}$ and an assignment β such that $(\beta(i), \beta(s'), \beta(s''), \beta(e), \beta(x))$ is a witness for the truth of (4.4) in $(\mathfrak{M}, \beta)$. Let $\mathtt{s}' = \beta(s')$, $\mathtt{s}'' = \beta(s'')$ and $\mathtt{e} = \beta(e)$. We have $\mathtt{e} = \text{end}(\mathtt{s}')$. We get $\text{end}(\text{end}(\mathtt{s}')) = \text{end}(\mathtt{s}')$, by axiom (EE). Thus $\mathtt{e} \supset\!\subset \mathtt{s}''$ means that $\text{LOC}(\text{end}(\mathtt{s}')) = \text{LOC}(\text{begin}(\mathtt{s}''))$.

At first glance everything seems to be in order. But note that the result state that is decribed by `Mary has lived in Amsterdam` is triggered by the *termination* of some stay of Mary's in Amsterdam. And the termination condition is not mirrored in all models for the corresponding formulas.

Where is the problem? Consider again our witness for the truth of (4.4) in $(\mathfrak{M}, \beta)$. Assume that there is a state $\mathtt{s}$ such that $\mathtt{s} = \beta(s)$ and $(\mathfrak{M}, \beta) \models \text{live-in-Amsterdam}(s, x)$. Further, assume that $(\mathfrak{M}, \beta) \models \text{end}(s') \bigcirc s$. See figure 3. Note that $(\mathfrak{M}, \beta) \models \text{live-in-Amsterdam}(s', x)$. Nevertheless, we cannot say, that Mary's life in Amsterdam is terminated at LOC(end($\mathtt{s}'$)).

The trouble is that $(\mathfrak{M}, \beta) \models \text{live-in-Amsterdam}(s, x)$ and $\mathtt{s} \bigcirc \text{end}(\mathtt{s}')$. So `Mary lives in Amsterdam` is true in that model if uttered

FIGURE 3: An intuitively undesireable model for a sentence with a stative in the present perfect



at LOC(end(s′)). Thus the intended interpretation of the termination condition is not reflected in our model.

How can we exclude unwanted models like this one? This question points us to a deeper problem. Namely, it shows that we have still not said all there is to say about the end (and begin) of states.

So far in our axioms about begin and end we have only been concerned with eventualities themselves, but not with the facts they describe. It is time now that we bring them into play. This can be done by considering states with description.

Definition 2 *Let $\mathfrak{M}$ be a model and β an assignment in $\mathfrak{M}$. Let ${}^{\mathsf{s}}X^n$ be a variable for a n-place state predicate and $x_1, \ldots x_n$ variables for individuals. Then ${}^{\mathsf{s}}X^n(-, x_1, \ldots, x_n)$ is called a* **description**.

Let s *be a state in $\mathfrak{M}$. Let $\mathsf{s} = \beta(s)$ and $(\mathfrak{M}, \beta) \models {}^{\mathsf{s}}X^n(s, x_1, \ldots x_n)$. Then* s *is called a* **state with description** ${}^{\mathsf{s}}X^n(-, x_1, \ldots, x_n)$ **in** $\mathfrak{M}$ **relative to** β. *Let* s *and* s' *be states with the same description in $\mathfrak{M}$ relative to β. Then* s *and* s' *are called* **similar states**.

In the undesireable model for `Mary has lived in Amsterdam` that was depicted in figure 3, s and s′ are similar states.

We require that the end of a state with description cannot overlap with a similar state. And we require that the begin of a state with description cannot overlap with a similar state. The following two second order axioms do this job.

$$ {}^{\mathsf{s}}X^n(s, x_1, \ldots x_n) \rightarrow (\neg \exists s'({}^{\mathsf{s}}X^n(s', x_1, \ldots x_n) \wedge \text{LOC}(\text{end}(s)) \bigcirc \text{LOC}(s'))) \quad (\text{No}\bigcirc\text{EndS}) $$

$$ {}^{\mathsf{s}}X^n(s, x_1, \ldots x_n) \rightarrow (\neg \exists s'({}^{\mathsf{s}}X^n(s', x_1, \ldots x_n) \wedge \text{LOC}(\text{begin}(s)) \bigcirc \text{LOC}(s'))) \quad (\text{No}\bigcirc\text{BeginS}) $$

This move solves our problem with the non-continuous reading of the present perfect of statives. But it is more than a technical trick for a problem with one type of sentences. These axioms capture something important about the meaning of begin and end of states, as they help to express the idea that a certain condition is *terminated* (at the end of a state describing that condition) or *started* (at the begin of a state describing that condition).

Alternatively we may consider the following two axioms:

$$^{\mathsf{s}}X^n(s, x_1, \dots x_n) \rightarrow (\neg\exists s'(^{\mathsf{s}}X^n(s', x_1, \dots x_n) \wedge s \bigcirc s' \\ \wedge \neg \,\mathrm{LOC}(s) = \mathrm{LOC}(s')) \quad (\mathrm{No}\bigcirc\mathrm{S})$$

$$^{\mathsf{s}}X^n(s, x_1, \dots x_n) \rightarrow (\neg\exists s'(^{\mathsf{s}}X^n(s', x_1, \dots x_n) \wedge s \supset\!\subset s') \wedge \\ \neg\exists s'(^{\mathsf{s}}X^n(s', x_1, \dots x_n) \wedge s' \supset\!\subset s)) \quad (\mathrm{No}\supset\!\subset\mathrm{S})$$

Proposition 2 *The fulfillment of both* (No$\bigcirc$BeginS) *and* (No$\bigcirc$EndS) *implies the fulfillment of both* (No$\bigcirc$S) *and* (No$\supset\!\subset$S) *and vice versa.*

These axioms are quite strong. At first glance it might seem that they are interfering with the so called **principle of homogeneity** or the **subinterval property**, as proponents of interval semantics would have it.

The subinterval property is formulated by Dowty (1986, p. 42) as follows:"*A sentence is* stative *iff it follows from the truth of ϕ at an interval I that ϕ is true at all subintervals of I. (e.g. if John was asleep from 1:00 to 2:00 PM. then he was asleep at all subintervals of this interval ...)*"

As temporal DRT is not a theory of interval semantics, where the truth of a sentence is evaluated with respect to intervals of time, the subinterval property can not be rendered *literally* into the framework of DRT. But it might be tempting to introduce the concept of substates and to require the fulfillment of the following second order axiom, see figure 4.

$$(^{\mathsf{s}}X^n(s, x_1, \dots x_n) \wedge i \subseteq \mathrm{LOC}(s)) \rightarrow \exists s'(^{\mathsf{s}}X^n(s', x_1, \dots x_n) \\ \wedge i = \mathrm{LOC}(s')) \qquad (\mathrm{SUB})$$

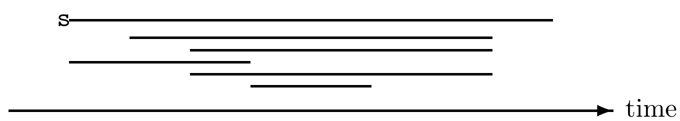
Definition 3 *Let* s *and* s' *be similar states such that* $\mathrm{LOC}(\mathsf{s}') \subseteq \mathrm{LOC}(\mathsf{s})$ *then* s' *is called a* **substate** *of* s. *If* $\mathrm{LOC}(\mathsf{s}') \subset \mathrm{LOC}(\mathsf{s})$ *then* s' *is called a* **proper substate** *of* s.

But note the following result

Proposition 3 *Let* s *be a state with description. Let* $i \subset \mathrm{LOC}(\mathsf{s})$ *and* $i \neq \mathrm{LOC}(\mathsf{s})$.

Then (SUB) *does not hold in presence of axiom* (No$\bigcirc$S).

FIGURE 4: A state `s` with some substates



No harm is done, however, as we do not need axiom (SUB). We will demonstrate this in the following.

So, how do we treat examples that require the principle of homogeneity, without having axiom (SUB) at our disposal? We propose that in the framework of DRT the sentence

$$\texttt{John was asleep from 1:00 to 2:00} \tag{4.5}$$

should be translated in the following way:

$$\exists i, x, s(i < n \wedge i \subseteq \text{LOC}(s) \wedge \text{from1:00-to2:00(i)} \wedge \text{asleep}(s, x) \wedge \text{John}(x)) \tag{4.6}$$

We require that from1:00-to2:00(i) means that $i = [t_1, t_2]$ where t_1, t_2 are the instants referred to by "at 1:00" and "at 2:00", respectively. The unusual condition $i \subseteq \text{LOC}(s)$ is necessary for the temporal localization adverb `from 1:00 to 2:00`. Note that for an adverb like `on Sunday` we use $\text{LOC}(s) \bigcirc i$ - but for `from 1:00 to 2:00` this condition would yield plainly wrong results.

Now given a witness $w = (\beta(i), \beta(x), \beta(s))$ for (4.6) and a standard semantics for terms like "at 1:00", then w is a witness, too, for the formulas for

$$\texttt{John was asleep from A to B} \tag{4.7}$$

for all `A`, `B` such that $1:00 \leq \texttt{A} < \texttt{B} \leq 2:00$.

Thus in DRT we do not need an axiom like (SUB) to capture the gist of the principle of homogeneity.

Moreoever, note that (SUB) introduces spurious substates which seem to have no place in a truly eventuality-based theory of temporal semantics. Thus we can do away with that axiom without having to shed a single tear.

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