Descriptions and Explanations of Temporal Variation

Tillmann Pross*
University of Stuttgart
Institute for Natural Language Processing

Abstract

This paper presents ongoing research on the semantic representation and model-theoretic evaluation of descriptions referring to abstract objects of temporal variation, i.e. events and states ("eventualities"). While common ontologies for temporal entities are geared to the surface of natural language descriptions (in the spirit of [Vendler, 1957], [Davidson, 1967]), I propose to model the relation between descriptions and temporal entities by a constitutional ontology of distinctions among temporal variations based on the type of explanation which is used for the segmententation, identification and consequent description of the respective temporal entity. With respect to explanations of temporal variation, recent investigations propose a threefold distinction between causal, behavioral and intentional explanation [Dennett, 1989, Dretske, 1988, Hartmann and Janich, 1991] which I adopt to enrich the representational formalism of Discourse Representation Theory (DRT, [Kamp et al., 2007]) with operators that specify how temporal processes are related to descriptions by means of explanatory identification of temporal entities. Technically, this can be achieved by an integration of branching-time logic (CTL*, [Emerson, 1990]) into the framework of DRT, a direction of research which except for [Asher and Singh, 1993] has not received the attention it probably deserves. In addition the proposed treatment of temporal entities allows for an elegant integration of insights from artifical intelligence [Schank and Abelson, 1977], psychology [Zacks et al., 2001] and linguistics [Kamp, 2007]. I illustrate my proposal for an action-theoretic ontology of temporal entities by an analysis of accomplishments, where I argue that the temporal profile of an accomplishment is identified by an intentional explanation of temporal variation.

*prosstn@studenten.ims.uni-stuttgart.de

1 Introduction

This paper presents ongoing research on the semantic representation and model-theoretic evaluation of descriptions referring to abstract objects of temporal variation. I argue for a novel interpretation of temporal entitities (usually called "eventualities" in the linguistic jargon) as abstract objects derived from explanations of temporal variation. In doing so, I do not follow the traditional logical analysis of descriptions of eventualities in the tradition of [Davidson, 1967] and [Moens and Steedman, 1988] (which in turn may explain the unfamiliar formulation of the topic of this paper). In addition, I aim at replacing the ontology of temporal profiles to which natural language descriptions can refer in the spirit of [Vendler, 1957] with an action-theoretic extension [Dennett, 1989, Dretske, 1988, Hartmann and Janich, 1991] of psychological research on event segmentation [Zacks et al., 2001, Zacks and Swallow, 2007]. Formally, my proposal extends the framework of Discourse Representation Theory (DRT, [Kamp et al., 2007]) with operators that specify how temporal processes are related to descriptions by means of explanatory construction of eventualities. Technically, this boils down to an integration of branching-time models (loosely following the ideas of computational tree logic (CTL), [Emerson, 1990]) into the framework of DRT. For reasons of space and time, I only present the basic ideas

underlying the action-theoretic treatment of temporal entities and omit most of the formal details.

2 The traditional approach

Traditional approaches to temporal variation usually follow Donald Davidson's logical analysis of action sentences [Davidson, 1967], where he proposed to capture the logical properties of natural language descriptions of actions with the introduction of a new class of ontological entity besides individuals; events. Events are supposed to be "entities in the world with their own observer-independent grounds of existence" [Kamp, 2007]. The following example illustrates Davidson's approach to the logical form of predicates that refer to actions[1].

(1) build a house: $\exists e.\exists x.\exists y.agent(x) \wedge house(y) \wedge build(e, x, y)$

While the Davidsonian analysis of reference to temporal entities seems to be acceptable at a first glance, important information contained in the predicate "build a house" is not represented in it's logical form. First of all, this concerns the observation of [Vendler, 1957], who noticed that the temporal profile to which verbal descriptions refer differs for specific types of predicates with respect to their "lexical-aspectual" class, in the case of "build a house" that of an accomplishment. It distinguishes the building of a house that the process of construction (i.e. the building) brings about the house and that it is this result that "casts its shadow backward" [Vendler, 1957, p. 146] in that it actually identifies the preceding activities as the building of a house. That is, the temporal profile of such a phrase goes beyond a simple event but is constituted by a more fine-grained substructure of processes, pre- and postconditions. One can try to cope with this property of descriptions of temporal entities by establishing a substructure of events as [Moens and Steedman, 1988] have proposed it with their theory of "event nucleus", where an event consists of a preparatory state, a culmination and a consequent state. A very simple minded approach can combine Vendler, Davidson and the theory of event nucleus within the framework of Discourse Representation Theory [Kamp et al., 2007] as shown in the following examples:

(2) build a house[2]

$$\boxed{\begin{array}{l} x, y, e \\ e : build(x, y) \\ house(y) \end{array}}$$

Meaning Postulate 1:

$$\boxed{\begin{array}{l} x, y, e \\ e : build(x, y) \\ house(y) \end{array}} \Rightarrow \boxed{\begin{array}{l} s^{res} \\ e : build(x, y) \\ e)(s^{res} \\ s^{res} : house(y) \end{array}}$$

Meaning Postulate 2:

$$\boxed{\begin{array}{l} x, y, e \\ e : build(x, y) \\ house(y) \end{array}} \Rightarrow \boxed{\begin{array}{l} s^{prep} \\ e : build(x, y) \\ s^{prep} \subseteq e \\ s^{prep} : \neg house(y) \end{array}}$$

While this way of representing the semantic information contained in the example comes closer to the intuition about what "build a house" actually means, there are still important problems to be solved.

- First, the probably most obvious problem is associated with the adequate representation of the result of the event of building, i.e. that the house is supposed to come into existence *if* the process of building is properly finished. This is hard to capture within the standard framework of formal semantics because
  - The condition $s^{prep} : \neg house(y)$ in meaning postulate 2 does not capture the crucial point about a thing's coming into existence. It is not the case that the referent y is no

[1] For reasons of space and time, I can not discuss the interactions between tense, grammatical aspect and lexical aspect here. I have thus chosen to discuss only lexical entries. In addition, I do only discuss the Vendler class of accomplishments in detail.

[2] There exist of course more sensible theories about creation verbs resp. accomplishments in DRT, e.g. [Kamp and Bende-Farkas, 2005] thus the representation pictured here certainly does wrong to the current state of the art in DRT.

house but that y does not exist at all at this preparatory stage of building.

– It is subject to doubt whether the existence of a house is really a logical consequence of the building resp. a causal effect of the activities that make up the building or if "build a house" just makes a claim about the agent's intentions.

Basically, these problems have been tackled from two sides; syntactically with the introduction of additional predicates for "staged" existence, becoming and causation [Dowty, 1979] that specify the relation between the building and the house and semantically with a non-monotonic formulation of implication [van Lambalgen and Hamm, 2004]. Both approaches have to face the fact that describing an action as "build a house" neither logically implies nor causally forces the house to come into existence. Instead, "build a house" intuitively describes the intention of the agent of building a house and it is this attitude of the agent towards the existence of the house that relates the activities of building to the existence of the house. In addition, it should be mentioned that the given preparatory and consequent states are not only distinctive for the building of a house as there are other predicates that can describe the same constellation[3].

- Second, there is an ontological problem. Davidsonian events are supposed to be atomic model-theoretic entities such as individuals are. But the theory of event nucleus requires that events are splitted up in parts, which does not cohere with their fundamental ontological status.

- Third, and this problem is closely related to the preceding one, the theory of event nucleus relies on a notion of state that has to be established at first (and preferably without reference to events to avoid a circular definition).

- Fourth, Vendler classes can be coerced one into another, depending on the amount and type of information that specifies the temporal entity. That is, the Vendler Classes are not distinct in the sense that there is a unique mapping between predicate and temporal profile.

At first sight these points may seem negligible and solvable by the goodwill of the logician in charge of analysis, but they hint at some deeper problem of the traditional account to temporal entities that definitely appears when the model-theoretic treatment of representations of the above type is taken into consideration (definition 1). The DRS itself does not provide information about the building of a house besides the trivial fact that it is an event of building [4]. As a matter of course, this information does not suffice to *identify* the building of a house. Perhaps the evaluation of DRS-conditions for events can say more about the specific identity of "build a house"?

Definition 1 *Evaluation of DRS event conditions (simplified) [see Kamp et al., 2007, p. 115]*
Given a set of events and states EV structured by $<$, a Universe of individuals U and an Interpretation function I,

- $g \vDash_M e : R(x_1, \ldots, x_n)$ *iff*
  $\langle g(e), g(x_1), \ldots, g(x_n)\rangle \in I(R)$

Where g is an assignment that maps e onto an element of EV and $x_1, \ldots, x_n$ onto elements of U.

In simple words, the DRS-condition that represents the building of a house is satisfied in a model iff the event referent e can be mapped to an event and the other discourse referents to individuals such that R can be embedded by the interpretation function I. Coming back to the above question about the identification of "building a house", there is no additional information about what makes up the building of a house besides the trivial fact that it is "true" iff "build a house" is contained in the model. That is, neither the DRS nor it's evaluation conditions say

[3] The use of pre- and poststates has to face a lot more problems than I can discuss here, i.e. the amount of information contained in these states as well as their temporal extent.

[4] Given the problems of meaning postulates as spelled out above I do not consider them as providing instrumental information

something about what makes up the *temporal profile* of building a house that serves it's identification. Instead, the semantics of an event is only concerned with the proper embedding of it's arguments but not it's temporal profile.

There exists a final possibility that may help out in solving this problem. In DRT, events are related to a time-structure by means of a location function *LOC* that maps events to intervals of time. While this function seems to go in the direction of an answer to the question about the identification of events, the actual function of *LOC* has unfortunately never been spelled out in a way that it specifies the location of a given event. In addition, if actually spelled out, the function *LOC* would give a purely quantitative identification of the respective temporal entity. But the identification of "build a house" goes beyond the statement of a certain amount of time, as the corresponding temporal entity is distinguished by it's status as intention of the performer of the action.

The loose ends of the traditional analysis of temporal entities entail further problems:

- Given a certain description, it is not possible to say something about why the event starts resp. ends which in turn makes it difficult to justify a quantitative identification.
- As both events and states are equally mapped onto intervals, there is no criteria (and need) to distinguish an event from a state besides their symbolic representation. This problem is eminently critical as the event nucleus relies on the distinction between events and states.
- The interpretation of temporal entities in the sense spelled out in definition 1 is no interpretation in that it *explains* the entity, i.e. that it says something about what makes a set of intervals an entity besides the trivial fact that it is an entity.

All in all, this critical examination gives rise to the question whether the traditional way of treating the reference to temporal profiles employs the right means at all. In other words, how should the temporal reference of a predicate be identified, if no "essential and established facts" [Searle, 1969, p. 169], i.e. an *explanation* of the identification about the entity in question is available? In addition, the many-to-one relation between predicates and temporal profiles makes it difficult to develop such a theory of explanatory identification from the surface of natural language. Instead, we should seek to develop a theory of how descriptions relate to temporal profiles based on a theory how temporal profiles and consequently temporal entities are constituted at all and this is what the second part of this paper is about.

3 Eventualities as abstract objects of temporal variation

Luckily, the way humans deal with temporality is not only of interest to linguistics but also to other branches of science, in particular psychology and philosophy. Recent psychological experiments [Zacks and Tversky, 2001, Zacks and Swallow, 2007] suggest that given a certain perception of temporal variation, humans structure the perceived temporal variation along the lines of "goal relationssships and causal structures" [Zacks and Tversky, 2001][5]. Consequently, the temporal entities resulting from event segmentation are to be understood as structures of temporal profiling imposed on perceptions of temporal variation[6]. The psychological insight that it is structured sequences of action that allow for the segmentation of temporal variation and that these structures are present in mind when segmenting events is

[5]It should be noted that while my approach to the treatment of temporal entities shares this starting point with [van Lambalgen and Hamm, 2004] the way I proceed with this psychological insight is fundamentally different. Hamm and Lambalgen develop their formalism along a strictly physical understanding of temporal variation, whereas my proposal allows for other types of segmentations such as behaviour or intentions. In addition, the Hamm and Lambalgen propose a proof-theoretic treatment of planning whereas my approach involves a possible-worlds semantics.

[6]This seems to be the right point to make a note about my jargon: The term temporal variation as I understand it refers to an uninterpreted, unsegmented sequence of action from which no temporal entities such as events have been extracted. Segmentation then establishes temporal profiles, i.e. structures on the temporal varation. Finally, a temporal entity represents a temporal profile (or higher-order constructions of temporal profiles).

in accord with one of the fundamental assumptions of DRT, namely that humans make use of mental representations (in particular when interpreting utterances). We can thus establish a natural relation between DRT and the psychological theory of event perception structures if we introduce plan-goal and causal structures as mental entities of representation. Before I proceed in spelling out how the fusion of DRT and the theory of event segmentation may be established, something more has to be said on the structures of temporal variation. The question how humans explain temporal variation is one of the major topics in philosophy, especially action theory. While classical approaches focus on causal [Davidson, 1963] or rational [Anscombe, 1957] explanations, more recent investigations propose a threefold distinction of explanations:

- the physical, design and intentional stance [Dennett, 1989]
- the varying ability to have (meaningful) mental representations [Dretske, 1988] in machines, animals and humans
- the culturally founded discrimination of movements from behaviour and intentional actions [Hartmann and Janich, 1991]

Leaving issues of notation aside, all these approaches to the explanation of temporal variation have in common that they distinguish between three types of explanation: causal physical movement, behaviour (in it's literal sense as goal-directed action triggered by desires) and intentional action (in the sense that it is rationally controlled behaviour). Structurally, these types of explanation are interrelated as both behavioural and intentional actions make use of the fundamental principles of causality to achieve their goals resp. intended ends. Behaviour and Intentions differ in that behaviour refers to a sequences of actions under the control of the agent that serve the realisation of a goal triggered by a certain desire whereas intentions include an additional involvement of rational choice and commitment [Bratman, 1987]. If we apply these considerations to the psychological insight that temporal entities are segmented along the lines of causal and planning structures, we should make use of all three types of explanations to extract entities from a given temporal variation. In particular, a temporal entity such as the building of a house is to be segmented with the help of an intentional explanation.

Given these preliminary thoughts on the explanation of temporal variation and resulting temporal entities, we can now come back to specifying how this can be captured in the framework of DRT. For reasons of space, I will keep this as simple as possible and refer the reader to the forthcoming more detailed work [Pross, 2008]. In the following, I assume that temporal variation is captured by a set-theoretic model structure of timepoints whereas temporal entities go into the representational framework of discourse representation structures, i.e. temporal variation is modeled by a tree-like structure of possible times as shown in figure 1. Formally, such a structure can be achieved along the lines of Branching Time Logic resp. CTL* ([Emerson, 1990] or the adoption to DRT proposed in [Asher and Singh, 1993]). I omit the formal details here and only give a rough sketch of how the model is supposed to look like.

With respect to the structure of temporal variation, the model should contain a set of times T, where each $t \in T$ is annotated with the states of affairs that hold at the respective time. In addition, T is partially ordered by $<$ such that $<$ is allowed to branch. In a first step, we should then determine how to relate this structure to representations of temporal entities. Second we can then examine how representations of temporal entities relate to natural language descriptions of these temporal entities and refer to specific profiles of temporal variation. We can interpret the model structure such that it serves the proposed theory of temporal entity extraction in terms of causal, plan-goal and intentional structures as follows:

- Transitions between times constitute the smallest units of causality, i.e. the atomic units of temporal variation which we can pool to a set A [7].

[7] The notion of "atomic" requires a note on the granularity of atomic actions. In this paper, the atomic actions have a

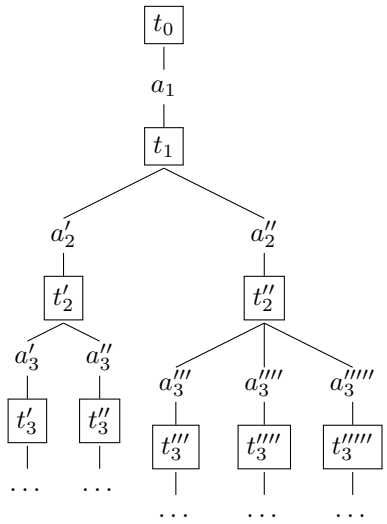

Figure 1: Branching-time structure. The arrows indicate a a path through the tree. Each time is associated with the currently holding state of affairs. In this drawing, t_1 is the current position of the agent in time, as from this point on future possibilities branch while the past is determined.

- Sequences of atomic transitions constitute a path. I assume for the sake of simplicity that plans correspond to such paths, where the final state the path correspond to the plan's goal. [8]

- Intentions are formed by distinguished sets of plans adopted by the agent. [9]

quite high granularity that should be lowered for reasonable results.

[8] Usually one would suppose that plans are not just sequences of action but that they involve decisions for one or the other option of action based on the epistemic states of the agent and the current states of affairs. For reasons of space and simplicity, I assume that plans are sequences of action whereas a not so simple-minded approach would use program-like planning structures (see e.g. [Singh, 1994],[Inverno et al., 2004]

[9] As intentions are inherently tied to actions, the probably most natural solution to intentions should consult on an operational semantics defined in terms of algorithmic specifications how intentions result from desires by means of choice and commitment. For ease of exposition, I adopt a simplistic solution that treats desires and intentions by means of assignment functions.

I introduce new DRS-conditions that allow to refer to specific constellations of temporal variation:

Definition 2 *DRS-conditions for temporal entities*

- *Atomic actions: If K is a DRS, x a discourse referent, then $x\mathsf{DO}K$ is a condition*

- *Plans: If K is a DRS, x a discourse referent, then $x\mathsf{DES}K$ is a condition*

- *Intentions: If K is a DRS, x a discourse referent, then $x\mathsf{INT}K$ is a condition*

The crucial point is now to connect the syntactic representation with the model in terms of semantic evaluation. Several ways exist to formulate a semantics for DRS-conditions as given in definition 3. Again, I adopt a simplistic approach, where I make use of a class of assignment functions that assign activities (DO), plans (DES) and intentions (INT) to referents at a certain time and restrict the requirement that the agent indeed has these attitudes towards her activities to times (and not intervals).

- $x\mathsf{DO}K$ is satisfied at t_0 iff there exists a path from t_0 to t_n s.th. K is true at t_n. It is allowed that $t_0 = t_n$, i.e. $x\mathsf{DO}K$ can also be satisfied at a time.

- $x\mathsf{DES}K$ is satisfied at t_0 iff there exists a path from t_0 to t_n such that K is true at t_n but not at $t_0, \ldots, t_{n-1}$ and K is among the agent's desires at t_0.

- $x\mathsf{INT}K$ is satisfied at t_0 iff there exists a path from t_0 to t_n among the agent's intentions at t_0 such that K is true at t_n.

This statement about the relation between representations of temporal entities and temporal variation captures only the fundamental structural aspects. In particular, it does not capture what we actually identified as the crucial point about the identification of temporal entities - the specific quality that was employed to constitute the corresponding temporal profile. This can be achieved by refining the relation between representation and model in a way that

(a) states the status of temporal entities as distinct objects of mental representation (b) designates their unique quality with a name that allows to connect representations with specific constraints on the temporal profile of the corresponding model structure.

Definition 3 *Lexical representation of temporal entities. If name is a name for a temporal entity, K a DRS, x a discourse referent then*

- $\boxed{\begin{array}{l} ev : x\mathsf{DOK} \\ ev = name \end{array}}$ *(causal)*
- $\boxed{\begin{array}{l} ev : x\mathsf{DESK}_{goal} \\ ev = name \end{array}}$ *(plans)*
- $\boxed{\begin{array}{l} ev : x\mathsf{INTK}_{end} \\ ev = name \end{array}}$ *(intention)*

are conditions.

At this point, it should have become clear why eventualities are abstract objects of temporal variation. Representations of temporal entitites prescind from the detailed structure of temporal variation by subsuming specific parts of the respective temporal variation under causal, plan-goal or intentional structures of temporal profiles. It is the condition $ev = name$ that allows to connect the representation of the temporal entity with information about the temporal profile. Preferably, this information should be located in the lexical entry for the respective predicate. That is, the lexical entry of "build a house" consists of a semantic representation and a temporal profile of the involved temporal entities. As the temporal profile is concerned with actions and identification, it seems reasonable to assume that the temporal profile constitutes the pragmatic part of the lexical entry. For "build a house" the pragmatic profile should specify which temporal structures constitute the building of a house: the buying of materials, the adoption of construction plans, the actual steps of building etc. whereas the semantics representation states that these plans are part of the agent's intentions and specifies referents involved in the agent's plans and conceptions of reality[10]. Technically, the most simple way to check the proper location of the temporal profile of a predicate consists in an attempt to unify the temporal profile with the existing model structure. We should thus refine the lexical entry of predicates in the following way:

Definition 4 *Representation and temporal profile of temporal entities The lexical entry for a temporal entity consists of a semantic (SEM) and pragmatic (PRG) part, where* OP *is one of the operators* DO,DES,INT*:*

SEM $\boxed{\begin{array}{l} ev : x\mathsf{OPK} \\ ev = name \end{array}}$,

PRG a path that specifies the temporal profile of $ev = name$

The evaluation conditions have to consider the close connection between semantics and pragmatics. The unification of the pragmatic profile with the given model structure relies on a proper binding of referents included in the semantic representation to the entities contained in the model at that time.

Definition 5 *Evaluation of temporal entities A temporal entity has a temporal profile iff*

SEM $\boxed{\begin{array}{l} ev : x\mathsf{OPK} \\ ev = name \end{array}}$
can be embedded into the Model structure $\{U, I\}$ *at t such that*

PRG $ev = name$ *can be unified with the Model structure* $\{T, <, A\}$ *given the bindings of [SEM] at t.*

In turn, this finally allows for the grounding of the function *LOC* in the lexical specification of the pragmatics of the respective predicate.

[10]This view on the pragmatic nature of temporal structures implies an important difference to the traditional account to semantics: pragmatic profiles are part of the model structure and not of the representation language and it's semantic connection to the model. In turn, this has as a consequence that pragmatic profiles can not be treated within the common architecture of semantic embedding of representations but makes the model itself part of the meaning of a representations.

4 Application to "build a house"

I can now employ the machinery developed in the last section to give an analysis of "build a house". It has been mentioned along the way that I suggest an analysis of accomplishments as referring to a temporal profile constituted by intentional explanation. Before I state the lexical entry for "build a house", I want to elaborate on the reasons that motivate the assumption of an intentional interpretation of accomplishments. The probably most obvious reason to do so is due to the fact that describing an agent's actions as "build a house" does not require the actual coming into existence of the house in terms of logical implication or causal effects. Instead, the house is merely an envisioned result that is presupposed to explain the agent's actions, i.e. the coming into existence of the house is presupposed such that it can cast it's shadow backward on the preceding complex actions, thus allowing to explain these actions as making up the building of a house. The following lexical entry for "build a house" captures this fact in that it states that the existence of the house is the intended end of the agent's performance of actions and thus bypasses the problem of "staged" existence.

Example 1 *"build a house".*

$$SEM \begin{array}{|l} \hline x, ev \\ ev : x\mathit{INT} \begin{array}{|l} \hline y \\ house(y) \\ \hline \end{array} \\ ev = build \\ \hline \end{array}$$

PRG t_0 – *make-plan* – t_1 – *collect-material* – t_2 – *lay-bricks* – t_3 – *make-roof* – t_3

- *"build a house" refers to a scheduled or active plan, i.e. an intention of the agent of which one assumes that it will result in the envisioned result. That is, the actual existence of the house is no necessary component of "build a house" but the SEM conditions only require that the intended end of building points to a time where $house(y)$ can be embedded into the model.*

5 Summary and Outlook

Based on a critical examination of the traditional account to descriptions of temporal entities referring to temporal variation I have proposed a framework that bypasses the problems of the traditional analysis by recurring to the psychology and philosophy of temporal segmentation which allows for grounding the evaluation and analysis of descriptions of temporal entities in causal, goal-directed and intentional structures of temporal entity segmentation. Future research on this topic has to examine how exactly temporal profiles and explanations associate to descriptions (first steps in this direction have been undertaken by e.g. [Kamp, 2007]). Another promising direction of further investigation concerns the analysis of tense and grammatical aspect in terms of causal, plan-goal and intentional structures. Finally, and this is probably the most interesting application of the proposed treatment of temporal entities, the proposed theory of reference to temporal reference can help in providing a robot with the ability to properly deal with the temporal profiles of natural language descriptions [Pross, 2008].

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