The Pragmatics of Aspect

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Abstract

Reference to spatio-temporal entities is a core feature of human natural language competence and a main field of investigation in formal linguistics. Common formalisms exploring the semantics of Aktionsarten face problems with regard to the representation of the properties of aspectual expressions which go beyond their purely temporal dimension. In this paper I will argue that these problems are due to the lack of a formal representation of how the meaning of Aktionsarten is determined by the way they are explained from a given set of perceptual data. The respective instrument of explanation used to explain an action going on in a real-world-scenario, reflected by the use of Aktionsarten in natural language, fixes the amount and type of involved additional non-temporal information. The relationship between the expressions which are available as descriptions of action going on and the corresponding explanation types is the key to the proper analysis of reference to spatio-temporal entities in natural language. The extension of DRT devised in this paper provides a transparent representation of the non-temporal information involved in the proper use of Aktionsarten.

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"Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig verfasst habe und dabei keine andere als die angegebene Literatur verwendet habe. Alle Zitate und sinngemäßen Entlehnungen sind als solche unter genauer Angabe der Quelle gekennzeichnet."

Tillmann Pross
Stuttgart, 23.08.2005

1 Introduction

This paper is about time and its manifestations in natural language, eventualities. We use to talk about eventualities in our everyday life without spending much thought on the way we actually do it. But if one takes a closer look at the way how and why certain expressions of natural language are used to characterize and refer to eventualities, things get surprisingly complicated. On the one hand, this is due to the fact that the analysis of eventualities "covers a complex spectrum of interconnected phenomena" (Kamp et al., 2004, p. 74), on the other hand giving proper definitions of eventualities in terms of a formal language with an appropriate semantics is a demanding task because "our pretheoretical conception of what events are is fundamentally underdetermined" (Kamp and Reyle, 1993, p. 505). Smoothing out this difficulties is a challenge formal semantics has still not mastered exhaustively. The objective of this paper is the construction of an extension of Discourse Representation Theory (DRT, see the standard reference (Kamp et al., 2004) for more information) which is able to capture aspects of expressions involving eventualities which go beyond the purely temporal dimension of eventualities. The non-temporal properties of eventualities constitute an important part of the meaning of expressions dealing with the description of action going on. In order to acquaint ourselves with the fundamental problems we have to face in the subsequent discussion, we will start with a little thought experiment.

Thought Experiment
Imagine a set of photos taken on a boat trip, where one side shows pictures taken during the trip and the other side has a text on it written when the photo was shot and meant to describe what can be seen on the other side.
All that can be seen first is the photographs but not the respective text. The pictures show the following scenarios:

(1) A white sail.

(2) A vibrating engine.

How can one give a description of what is shown in the respective picture? This poses no problem for the case of (1): the correct description would be "picture one shows a white sail". Things are different for (2): How can we see from the picture that the engine is vibrating? Intuitively, it is not possible to say what a picture must look like in order to show a vibration. Which information is missing in the picture that leads to this fallacy?
In order to approximate an answer to this question, we may turn around the setup:

Thought Experiment Turnaround
Now the side with the text on it is shown and it is known that the following sentences are meant to describe the picture on the other side:

(1') The sail is white.

(2') The engine is vibrating.

The question is now: What should the pictures on the other side look like in order to make the sentences (1') and (2') an acceptable description of what is

shown in the picture? In other words, what is the mental representation which should be build in order to make a claim about the acceptability of the descriptions regarding the actual scenario?
For the case of (1'), the answer is simple: the representation should assign the property of being white to the entity which is a sail. Thus, the picture on the other side must show a white sail.
How are things for (2')? What kind of property is assigned to an engine when it is vibrating? And how can such a property be identified from a picture? Intuitively, there is no simple way to display the property that the verb "vibrate" describes within a single picture.[1]
Why is it possible to express the property spelled out in (1') in a picture, but not that in (2')?
To answer this question, the setup of the experiment is changed again. Now a video tape is shown, where the sentences written on the backside of the pictures are spoken comments. First, only the comments can be heard and the scenario described by the comment should be constructed from the description. Again, the property of being white can easily be formulated: the entity sail has the property of being white throughout the whole video. The substantial difference to the static setup with photographs is that the vibration of the engine can be expressed now: the vibration of the machine is a rhythmic movement of the machine between two points in space during the whole video. The difference between (1') and (2') appearing in the modification of the experiment from a static to a dynamic setup is due to the different kind of spatio-temporal entity (1') and (2') refer to. While (1') refers to a "'static" spatio-temporal entity, (2') refers to a "moving"[2] entity. From the experiment, even more information about such static and moving entities can be derived: an expression describing a static spatio-temporal entity refers to a single snapshot[3] (one picture), containing information about the *state of affairs* at a certain moment[4]. The information which is provided in one snapshot does not suffice for the identification of movement. At least two snapshots at two distinct moments and information about the order of succession of the snapshots is needed to correctly determine movement. Thus, there is a correspondence between the difference of expressions describing static and dynamic scenarios on the one hand and the information single and multi-snapshots provide on the other hand. Is there a systematic explanation for this correspondence?
The answer to this question is rather a pragmatic than a semantic one. This is an interesting fact, because the linguistic analysis of eventualities has focused on the problem as a genuinely semantic one. But the kind of conditions which are of interest for judging the acceptability of certain verbs with regard to the description of a given scenario are quite similar to the analysis of speech acts [5].

[1] One can surely think of some kind of photographic trick, such as unsharpening the engine with movement traces. But this does not give clear information about the property expressed in the picture, because it could also be possible that the shooter of the photo is vibrating.

[2] A terminological note: In the following, the term "movement" will refer to physical movement, such as a ball rolling off a table.

[3] A snapshot should be understood as a perception of the state of affairs holding in the world at a certain time.

[4] One can of course speak of a stative description holding for a certain amount of snapshots, but the information which kind of state is holding can be extracted from one snapshot

[5] Where speech acts are the paradigmatic example for pragmatic phenomena in natural language

It is not of primary interest which conditions are true for a sentence like (2') to hold but which circumstances must be satisfied to make proper use of the verb "vibrate" and this includes, as we have seen, a certain amount and constellation of cognitive "material" and respectively an ordered set of snapshots. The interaction between cognition and thought of and speech about eventualities has gained increased interest in the last few years. An interesting direction of research in this area is the application of methods from artificial intelligence. One of the main representatives of this new approach to the treatment of eventualities is "The proper treatment of events" (van Lambalgen and Hamm, 2004), where the theory of event calculus (well known from artificial intelligence) is applied to the linguistic theory of Aktionsarten. The insight that grounds this approach is the fact that "Verbs or VPs refer to events, where an event is a way of conceptualizing a certain portion of space-time"(van Lambalgen and Hamm, 2004, p. 84). The way this conceptualization is actually performed is the topic of "The proper treatment of events", and it will also be the domain this paper is about. Even if I agree with the statement mentioned above, we will encounter major differences to the van Lambalgen/Hamm approach as this paper progresses. The differences will appear with respect to the methods used as well as in the overall analysis of eventualities. The difference between the van Lambalgen/Hamm-approach and the theory proposed here becomes especially apparent in the handling of information: the problem inherently built in the van Lambalgen/Hamm-approach is it's lack of specifications about how to gain non-temporal information about eventualities from a given set of basic data representing action going on. The theory which is devised in the subsequent chapters is at least a hint on how non-temporal information is assumed, introduced and used with regard to the explanation of action going on and the use of Aktionsarten.

2 Time and action

This is a more theoretical part laying out the basis for the development of the subsequent parts of this paper. It should be clarified how explanations determine the non-temporal information involved in the conceptualization of action going on and how these explanation types are reflected by the use of eventualities in natural language.

2.1 Explaining action going on

Recall the introductory thought experiment, where two different types of scenario-descriptions were asserted. First, there were expressions describing dynamic scenarios, second there were expressions describing stative scenarios. Intuitively, time does play a more prominent role in the case of a dynamic scenario than in stative constellations.[6] Thus we will discuss how time comes into play by analyzing the example of the vibrating machine which illustrates a dynamic scenario. Consider the following examples (3) and (4).

(3) The machine is vibrating for an hour.

(4) The machine is performing a rhythmic movement between two points in space.

The two sentences (3) and (4) describe action going on, but they do it with the use of different concepts of time regarding the characterization and identification of the action going on.
Sentence (3) identifies the vibration by its temporal location, the interval of time for which the machine performs the action of vibration. But what exactly is the action of vibration? The duration of the vibration does not say anything about the properties of the vibration itself. The duration cannot uniquely identify the existence of a vibration by distinguishing it from other types of action a machine may perform. What is given in sentence (3) is a *quantitative* description of the action going on, because it focuses on the *measurement* of the vibration in quantitative terms ("for an hour"). But if nothing is known about the kind of action vibration refers to, then it is not clear what should be measured at all.
Sentence (4) identifies the vibration by a circumscription of the kind of action vibration refers to. This description is a *qualitative* identification of the vibration, as it states properties of the vibration going beyond its temporal circumference. The way such explanations are used to characterize action going on hint that time has a certain relation to the explanation of action going on. Thus it will be useful to determine which instruments of explanation can be applied to observed action going on.
We will postpone the discussion about the explanation of static scenarios to chapter 2.2.2, and start with a presentation of the instruments which are used to explain dynamic scenarios. We already came to know movement, such as the vibration of a machine. The instrument which is used to explain such purely physical movement focuses on the force which is exerted on a certain *patient*. This force is not supposed to have any goal, e.g. it is not possible to say that a ball which is rolling off the table intends to fall down. Thus, physical movement

[6] To which extent this is true will be discussed in chapter 2.2.2.

is explained in terms of pure **causality**. There is no additional information that is needed to explain the vibration of a machine; one needs only to know about its physical states and the physical laws they have to follow.
There exist two further types of explaining action going on which involve the instruments of goals and intentions. Consider the following sentences:

(5) The ship is calling at Monkey Island.

(6) The ship is sailing to Monkey Island.

How do these sentences differ from (1) and (2) and from each other?
For (5), there is no longer a forced physical movement between two spatial points as in the case of the vibrating machine, but the sentence implies that after the action of landing has taken place, the ship is on Monkey Island. This implication, even if not explicitly mentioned in (5), belongs to the meaning of the landing of a ship. A further difference to (1) and (2) is that the landing can be split up in several actions under the viewpoint of the actual performance of landing: the sails must be shortened, the anchor has to be set and the landing bridge has to be installed[7]. All these subparts of the described complex action going on are subsumed under a certain goal: that of landing, which trivially requires the assumption that all the subsumed actions lead to the goal of landing. These descriptive "abstractions"[8] over complex sequences of actions under the consideration of a goal are called **strategies**. In turn, knowledge about the goal of a sequence of actions is required if we want to explain the sequence as strategic behavior. In contrast to the explanation of physical movement, the information about the physical state of the agent is not sufficient, as a goal is nothing physical [9]. Thus additional information has to be assumed in order to explain an agent's behavior in the form of a *goal*. The term behavior in this context surely needs some further specifications. By the term behavior, I refer to the performance of a strategy (which is the technical term for behavior) leading to a goal which is set unconscious. Thus it is commonly assumed that behavior cannot be suspended and that the setting of a behavior's goal is merely due to physiological needs. For the analysis of natural language expressions, it may be surprising to speak of a landing ship in terms of strategic behavior; but by ascribing the ship a certain goal it becomes agentive. This means that in order to reach a goal, the agent must be able to perform actions; the thing involved in the performance of a strategy becomes animated.
For (6), things are slightly more complicated, because if the sailing of the ship is in progress, the ship has not yet reached Monkey Island but after the successful completion of the sailing, the ship is *supposed* to be on Monkey Island, otherwise it is not possible to ascribe a destination to the sailing. In other words: the proper use of the verb "sail to" is not ensured until the ship actually reaches monkey island. In order to properly identify the action of sailing toward Monkey Island, additional information is needed in form of assuming

[7]The granularity of such specifications of verbal expressions referring to sequences of action depends on the knowledge about what a "prototypical" landing is. There is more on this topic in chapter 4.2. Of course this is not the only way to explain the landing of a ship. More on the ambiguity of explanations in chapter 5.7

[8]An abstraction does take place in the way that the single actions which constitute the landing are not mentioned in the verb "call at".

[9]At least it has not yet been determined with physical methods how one can measure goals.

that the captain has the **intention** to reach Monkey Island and that the movement of the ship is not coincidentally directed to Monkey Island. Assuming such information about the sailing is of course a way of explaining action going on that is subject to doubt. Why do we nevertheless use such a form of "rationalization"? This kind of intentional explanation, "an idealizing, abstract, instrumentalistic interpretation method [...] has evolved because it works and works because we have evolved." (Dennett, 1991, p. 634) and is the rational way to explain the behavior of complex systems for which we assume that they set their goals conscious. This point constitutes the main difference between strategic and intentional explanation: while the goal of a strategy is not set conscious, but merely due to physiological needs, the setting of an intentional goal requires a conscious choice. Intentional explanations are quite complex, as one can see from the following explanation scheme for intentional acts.

Definition 1 *The syllogism of intentional acts (Hubig, 2002, p. 18)*
Let

- x *be the actor,*
- P *be a subjective, (imagined as being possible to realize) means*
- Q' *be a subjective, (imagined as being possible to realize) goal*
- Q'' *be the actually realized goal*
- M *be an outer, real existing means*

Then the general form of an act is:

$$\begin{array}{c} x \textit{ intends that } Q' \textit{ via } P \\ \underline{P \textit{ via } M^{10}} \\ x \textit{ doing } M \textit{ brings about } Q'' \end{array}$$

This formulation sets up an important point which was already mentioned when we discussed (6) and noted that even if it is uncertain whether the ship will indeed reach Monkey Island it is rational to suppose it does so. The uncertainty of an intentional explanation is due to the tension between thought and reality: there is no guarantee that the realization of an intention will really bring about the efforts which were intended. The realized goal Q'' and the intended goal Q' do not necessarily have to be equal. An intention in this sense is the *direction* of a mental goal Q' toward its realization Q''.[11] The lack of knowledge about what will actually be the case if the intention is realized is reflected by the way intentions are used to characterize an agent's behavior: they are ascriptions which are made on a more ore less plausible basis of knowledge. The experience

[10]This line constitutes the crucial point of the explanation scheme for intentional acts. The transition from P(thought) to M(reality), displayed as *via*, involves the choice of the right real means M to realize the subjective means P and plays the role of a link between intention and reality.

[11]A result of this fundamental lack of knowledge about future realities is that only the realization of an intention can give hints about the success of the use of a certain means to realize the intention. The data about the realized goal *Q"* can also be used to alter the imagined goal *Q'* in order "synchronize" thought and realization of an action.

of difference between *Q'* and *Q"*, and this is important for the further argumentation, gives a first hint about the way in which change is recognized: we may recognize change only through the discrepancy between what we think the world to be and what the world actually is like. By this, change is mediated by a cognitive feedback-circle between thought and reality which ensures up-to-date information about the real world.
To sum up the structural properties of explanations of action we have identified so far, we may give the following figure:[12]

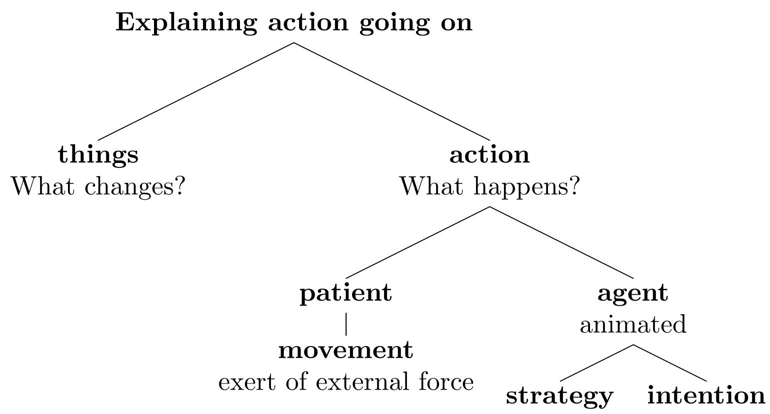

Figure 1: Instruments for the explanation of action

We have not yet established ties to the linguistic theory of eventualities which is commonly subsumed under the notion of "Aktionsarten" (van Lambalgen and Hamm, 2004, p. 83). The term Aktionsarten already suggests that we have to deal with a certain classification of action going on and indeed Aktionsarten correspond to what has been visualized in the tree above in a way that will become clear in the subsequent discussion. Before the connection between explanations of action and Aktionsarten is spelled out in detail, the common concepts of the linguistic analysis of eventualities will be presented in the next part.

2.2 The reflection of action in natural language: events and states

2.2.1 The Vendler-Classification

The first attempt to systematically categorize verbal constructions under the aspect of their spatio-temporal reference was made by Zeno Vendler (Vendler, 1967), who brought up a number of tests that should distinguish types of verbal constructions by their spatio-temporal reference. The tests for the Vendler-Classes are based on restrictions on the form of time adverbials and phrases the verbs can take, the entailments of the ascription and the ways and position in which they may occur. Vendler's analysis distinguishes the following verb classes:

Definition 2 *The Vendler classes (Aktionsarten):*

[12]The theory of action proposed here is based on the theory of methodical culturalism, (Hartmann and Janich, 1991, p. 70ff).

(1) States: be white, know, love, be beautiful

(2) Activities: vibrate, run, push a cart

(3) Achievements: call at, begin, reach, arrive

(4) Accomplishments: sail to, cross the street, build a house, write a letter

In the footsteps of Vendler's categorization, numerous attempts have been made to implement these classes in different formal frameworks. Among them are Dowty's formalization in the framework of Montague Grammar (Dowty, 1979), and several formalizations surrounding DRT; the DAT-formalism developed in (ter Meulen, 1997), and the situation-oriented approach in (Bartsch, 1995). We will use the DRT-approach presented in (Kamp et al., 2004) as basis, which will be introduced during an explanation of what events and states are meant to be in contemporary linguistics.

2.2.2 Change

It is obvious that the most fundamental distinction which can be drawn in the description of temporal properties of the world is that between states and events. But what are the characteristic properties of such eventualities? First, events involve the *change* of some condition, while states do not, they "involve the continuation of some condition" (Kamp and Reyle, 1993, p. 507). But what exactly is change? Informally, a notion of change has already been introduced in the introductory thought experiment. In order to identify a happening of change at least two ordered snapshots of a scenario are required, containing information about the state of affairs at the time before and after the happening of change takes place. In opposition, the information about a state is contained in one snapshot. In such a setup, change may be reduced to the differences between members of a set of ordered snapshots: *Change is the experience of difference between two temporally ordered snapshots*[13]. The difference between events and states may also be expressed in terms of the information contained in the required amount of snapshots: while for the identification of change information about the effects of an action going on is required, states do not have any effects and consequently the required information is contained in one snapshot.
For the proper formalization of change, this account to change is still not accurate enough, as we have not drawn a distinction between what is changed and what changes. This distinction is needed in order to identify the entity to which action may happen. Consider an example, where the leaves of a tree are green in one snapshot and brown in the next snapshot. What has changed through these two snapshots? Is it the state of the leaves having a specific color or is it the state of the leaves being green? Intuitively, the color of the leaves *has changed* because the property of the leaves of being green *is changed* by some kind of action going on. This acuteness needs to be captured in the concept of change we are going to adopt because it will deliver the explanation for stative Aktionsart. The type of explanation stative Aktionsart describes, and this will be spelled out in the following, is closely connected to the conceptualization of things, as stative Aktionsart reflects a things's holding of a

[13] It is a trivial fact, but it should nevertheless be mentioned that in order to give states an intuitively appealing meaning, we need to view states as very slow types of change.

property. In order to clarify this correspondence,we need to take a look at the concept behind the ontological structure of things because we want to specify that ontological property which *is* changed and that property which *changes*. In the Aristotelian tradition, the thing itself is a *substance* which has a number of *attributes* such as "color", which in turn are determined by *accidental* stipulations, such as "green"(cp. (Aristotle, 2005b)). We will use the modern jargon for this ontological structure by differentiating the following concepts:

- the *thing* itself (substance)
- the *potential* state (attribute),
- the *instantiation* of a potential state (accident)[14]

Such an ontological conception implies that things are identified by the instantiations of their potentials.[15] The instantiation is what is changed by an action and the potential is what changes, but the thing itself can not change, as a substance has no perceivable "change area", into which change may launch. Consequently, the expression "the thing is changing" means that one of the perceivable instantiations identified with the thing itself changes. A thing can be identified from the instantiations it bears, whereas an action must always apply its effects to some thing in order to be identifiable. This ontology of things is reflected in natural language, where descriptions can express change with the use of events which change a certain state. Events in turn are descriptions of action going on, whereas states are descriptions of things. This means that natural language expressions involving states may describe instantiations as well as potentials of things. In the preceding discussion we already stated the ways action going on can be explained but how are things explained? How does the explanation of things affect the information involved in the use of stative Aktionsart? The explanation of things involves *information about the instantiations of potentials* the thing holds. This information is expressed by stative Aktionsart. Thus, we can conclude that stative Aktionsart does not involve any information about effects, goals or intentions but only about what the instantiation is like held by the thing.[16] In other words, things are explained with respect to change as those spatio-temporal entities which provide the basis for change to occur, and thus constitute the necessary ontological condition for the experience of change.

2.2.3 Action sentences and the event nucleus

We have already adumbrated that there is a close connection between the explanation of action going on and eventualities. Indeed, the examination of the

[14]Additionaly, one can think of a state as functional state (the instantiation of the potential at a certain time. This notion of state is similar to the notion of a parametrized fluent in the event calculus (see (van Lambalgen and Hamm, 2004))).

[15]This is actually the way things get treated in DRT. A formula such as "$red(x)$" should get an interpretation in a way that the potential color of the substance x is instantiated with red. The potential color is covert in such a formalization in the way that red gets an interpretation as instantiation of a potential.

[16]That things and states are closely connected in natural language becomes clear through another point: states are not just there, it is always some thing which is in a certain state. Examples such as "It is raining" claim that the weather is such that it is raining, and we may assume that for all such sentences there is a covert subject which holds the state expressed by the respective predicate.

manifestation of events in action sentences is the starting point for the semantic analysis of natural language reference to spatio-temporal entities in Donald Davidson's "The logical form of actions sentences" (Davidson, 2001). The goal of this influential paper is the dissection of the "logical form of simple sentences about actions" (Davidson, 2001, p. 105). Davidson endeavored to clarify the semantic content of adverbial modifiers such as "slowly" in order to correctly determine the entity such modifiers refer to. He noted that such modifiers do not refer to an individual but to an event, a description of some kind of action going on. Consequently, Davidson saw an obvious need to introduce a new ontological class besides individuals into formal semantics, the class of events. A sentence like (7) gets an analysis in the Davidsonian framework as in (8):

(7) The machine vibrates slowly.

(8) $\exists e \exists x machine(x) \wedge vibrate(e, x) \wedge slowly(e) \wedge at(e, t)$

What exactly has been done here? There is a new existential quantified entity, the event e, which has somehow been extracted from sentence (7). The event of vibration itself is not explicitly mentioned in (7) but has nevertheless been identified by transforming the verb into an object, by applying a reification (or nominalization, as it is called in linguistics) to the verb. Reification has become a standard procedure in formal semantics and artificial intelligence, but it lacks a formal explanation of what the criteria for the identification of the event may look like in the sense of an explanation, it just introduces events "ad-hoc". This becomes a problem if one tries to map the properties of the Vendler-Classes to the Davidsonian analysis. In this case, one needs to split up the ontological type of events in several subparts[17] which should open up the possibility to encode information about the identification of the event (its corresponding explanation, its reason, its causes). This is what has been done by (Moens and Steedman, 1988). The general structure of the "Event Nucleus" introduced there is presented in table 1.

preparatory state:	conditions that hold before the event has happened
culmination:	the happening of the event itself
consequent state:	conditions that hold after the event has happened

Table 1: Event Nucleus (Moens and Steedman, 1988)

With such assumptions about the subatomic structure of events, it is possible to express the temporal properties of the non-stative Vendler-Classes as shown in the list above, but not those properties which go beyond the temporal. Because the theory of event nucleus focuses on the analysis of events, states have to be treated with other means, such as the definition of an own ontological class of states.

- **Activities** have no built-in culmination point and focus on the description of the *action going on*. A physical movement, such as the vibration of a machine is not directed to any "target" state. This makes it difficult to locate an activity in a reasonable way in the event nucleus: how should

[17] Which seems to be an odd idea, if one takes events as ontological category, how would one split up individuals?

one reduce a vibration to a preparatory or consequent state of something that does not exist?

- **Achievements** focus on the *culmination point* of an action going on. The culmination point is the time when the preparatory state shifts to the consequent state. Whether one can really detach a culmination point from the action bringing about the culmination is subject to doubt because the culmination point (or goal) of a strategic action such as the landing of a ship is merely a side-effect of the performance of the respective strategy but no distinct entity.

- **Accomplishments** focus on the way the *transition* from the preparatory state to the consequent state is performed. No exact time point can be singled out, where the happening of an accomplishment takes place, but the event consists of the performance of a strategy which is supposed to bring about a change from the preparatory state to the consequent state. As already mentioned, for the case of a ship sailing to Monkey Island, the actual reaching of Monkey Island is not expressed by the accomplishment "sail to" but it is rather presumed that the captain of the ship has the intention to reach Monkey Island. Representing the uncertainty of the actual outcome[18] of an intentional act is not possible in the theory of event nucleus.

2.2.4 Analysis in DRT

A slightly different view is held in recent bottom-up oriented DRT[19] (Kamp, 2005). The information about preparatory (s^{prep}) and result states (s^{res}) is encoded in form of meaning postulates. For the Vendler-Classes, we have lexical entries as in figures 3, 4, 5, 2. For the semantics see the standard references for DRT, (Kamp and Reyle, 1993), (Kamp et al., 2004). An expression of the form $e : R(x_1, ..., x_n)$ is an event-expression, $s : R(x_1, ..., x_n)$ a state-expression, $R(x_1, ..., x_n)$ a n-ary predicate, s^{res} and s^{prep} are referents for the consequent or preparatory states.

Lexical DRS:

x s
s: white(x)

Figure 2: State: be white

Even with this more fine-grained attempt to capture event structure, there remain problems unsolved: "because it is so difficult to determine precisely what

[18] Please note that this is foremost the case for descriptions in the present or future tense, but for descriptions in the perfect it is commonly suggested that the ship actually reaches Monkey Island. This problem is of marginal interest, as we stick to examples in the present tense and do not say anything about the interaction of tense and aspect.

[19] In classic DRT (Kamp and Reyle, 1993, p. 556–566) it is done in the following way: An Aktionsart is a set of aspectual properties, pertaining to the basic aspectual schema for the class in terms of the event nucleus, whether the verb itself makes available a culmination point and whether (in those cases where the schema includes a culmination point) the episodes described by simple clauses include a period leading up to the culmination point. This distinction is expressed in terms of two binary operators: STAT and PERF, where +STAT -STAT refer to events and states and +PERF refers to result a state and -PERF does not refer do a result state

Lexical DRS: $\begin{array}{|l|}\hline \mathrm{e}\quad \mathrm{x} \\ \hline \mathrm{e{:}\ vibrate(x)} \\ \hline \end{array}$

Figure 3: Activity: vibrate

Lexical DRS: $\begin{array}{|l|}\hline \mathrm{e}\quad \mathrm{x} \\ \hline \mathrm{e{:}\ call\text{-}at(x)} \\ \hline \end{array}$

Meaning Postulate: $\begin{array}{|l|}\hline \mathrm{e}\quad \mathrm{x} \\ \hline \mathrm{e{:}\ call\text{-}at(x)} \\ \hline \end{array} \Rightarrow \begin{array}{|l|}\hline \mathrm{s}^{res}\ l \\ \hline e)(s^{res} \\ loc(l) \\ s^{res} : AT(x,l) \\ \hline \end{array}$

Figure 4: Accomplishment: call at

Lexical DRS: $\begin{array}{|l|}\hline \mathrm{e}\quad \mathrm{x}\quad \mathrm{l} \\ \hline \mathrm{e{:}\ sail\text{-}to(x,l)} \\ \hline \end{array}$

Meaning Postulate 1: $\begin{array}{|l|}\hline \mathrm{e}\quad \mathrm{x}\quad \mathrm{l} \\ \hline \mathrm{e{:}\ sail\text{-}to(x,l)} \\ \hline \end{array} \Rightarrow \begin{array}{|l|}\hline \mathrm{s}^{res} \\ \hline e)(s^{res} \\ loc(l) \\ s^{res} : AT(x,l) \\ \hline \end{array}$

Meaning Postulate 2: $\begin{array}{|l|}\hline \mathrm{e\,x}\quad \mathrm{l} \\ \hline \mathrm{e{:}\ sail\text{-}to(x,l)} \\ \hline \end{array} \Rightarrow \begin{array}{|l|}\hline \mathrm{s}^{prep} \\ \hline s^{prep} \subseteq e \\ s^{prep} \neq AT(x,l) \\ \hline \end{array}$

Figure 5: Achievement: sail to

events are and what general properties they have"(Kamp and Reyle, 1993, p. 505). First, we still miss the transparent information about the characteristic properties of eventualities beyond their temporal dimension. Second, we have not yet established an ontology which reflects the use of events and states as descriptions of explanations of action going on. If we take these challenges serious, then we must assume that the Vendler Classes do not form an arbitrary way of categorizing verbal constructions, but reveal a cognitive dimension of the use of natural language expressions involving descriptions of explanations. In other words: **the Vendler Classes reflect ways of explaining a complex, dynamic real world**. From such a viewpoint, one may give the linguistic properties of states and events in a tree structure as in figure 6.

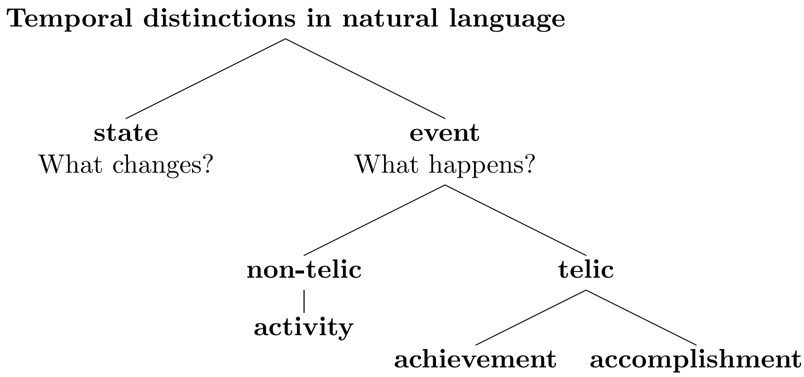

Figure 6: Instruments for the expression of temporal information

3 Eventualities and action

The idea which will be spelled out now is that the instruments available for the explanation of action match the instruments available for the expression of temporal information in natural language with respect to the involved additional non-temporal information and the treatment of change. With regard to change, this match can be stated as follows: in the theory of action things change while action does not change itself but changes a thing. A similar structure holds for the theory of eventualities: a state may change while an event does not change itself but changes a state. We may conclude from this that the relation between things and action on the one hand and states and events on the other hand reflects different conceptualizations of change with a similar structure. The explanation of a certain kind of action going on and the description of the corresponding eventuality with the use of Aktionsarten involves the same amount and type of additional information. This means that the culmination point of an achievement corresponds to the goal of a strategy and the supposed ramifications of an accomplishment correspond to the realization of an intention. A similar correspondence holds for stative Aktionsart and the explanation of things: the use of stative Aktionsart describes the instantiation of a thing's holding of a potential state, without further involvement of information about causes or goals. Activities correspond to the explanation of physical movement, involving no information about a goal or intention but about possible physical causes, which distinguish the use of activity-descriptions from stative descriptions.

Under such assumptions, states and events are elaborated forms of transforming the information gained by an explanation of action going on in the real world into natural language expressions. The relation between language and explanation can then be stated as follows: Temporal information about action going on is expressed in natural language by the use of event-expressions, depending on the instrument which has been chosen to explain the action going on. Properties of things are expressed in natural language by the use of state-expressions.

Aktionsarten then represent the natural-language pendants to the four types of action explanation explicated in chapter 2.1.[20]

- The explanation of an instantiation of a potential state of a thing maps to descriptions involving stative Aktionsart.[21]
- The class of non-stative verbs matches to the general concept of action[22], which can itself be decomposed in several subclasses:
  - The explanation of physical movement matches to the non-telic event descriptions, the Vendler-Class of activities, involving information about causal effects of the action.
  - Strategic behavior matches to descriptions involving achievements, involving additional information about the goal and the strategy itself.
  - Intentional acting matches to descriptions involving accomplishments, involving additional information about the goal, the strategy and the intention of the agent.

Figure 7 presents the correspondences spelled out above in a condensation of figure 1 and figure 6 into one structure. The figure is a structural analysis of the instruments used to conceptualize time when it is a) explained from action going on and b) expressed in natural language. The tree structure (7) folds up the ways in which action going on can be explained (with explanatory instruments (EI)) and expressed (with linguistic instruments LI)).

[20]The relation between action and explanation is not an unique one-to-one correspondence: the same action may be described under the viewpoint of different explanatory instruments, resulting in different descriptions of the same action going on. More in this in chapter 5.7

[21]This goes along with an idea by John Smart, who calls these stative verbs "thing-expressions" (Smart, 1949).

[22]Which are called "event-expressions" by John Smart (Smart, 1949)

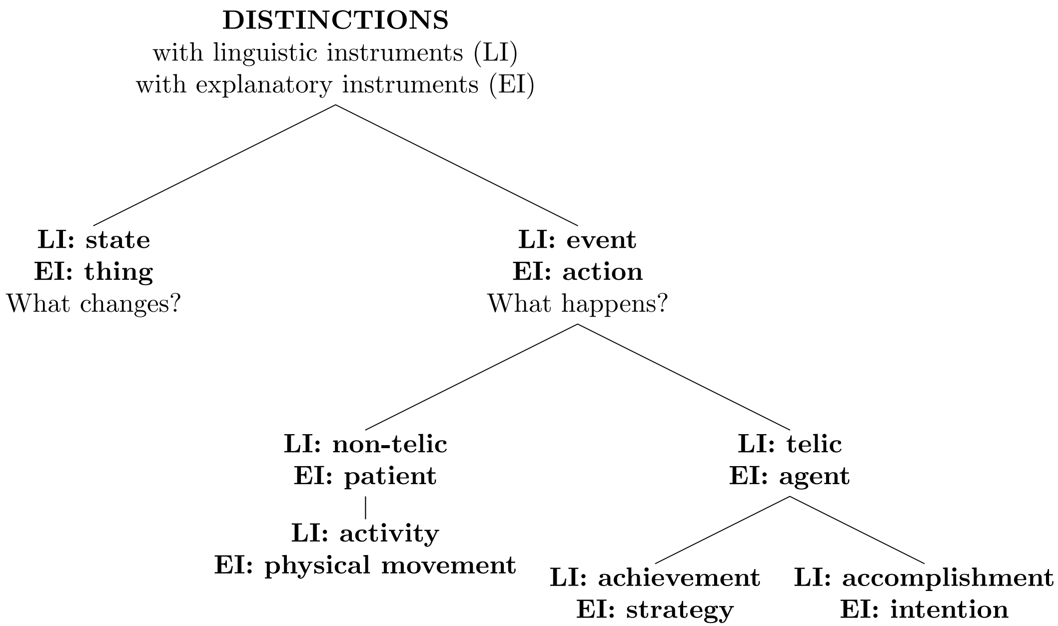

Figure 7: This figure shows the correspondence between the instruments of explanation and the instruments of natural language with regard to the treatment of non-temporal information and change. For more information, see chapter 3.

4 Formally defining action

Before we start formalizing the results of the preceding discussion, it will be useful to recapitulate the ingredients of the proposed analysis of verbal expressions referring to spatio-temporal entities identified so far and how the analysis will fit into the framework of Standard DRT. With "Standard DRT" I refer to the current state of the art, as it is presented in (Kamp et al., 2004).
With respect to figure 7, the components which are needed to properly represent the non-temporal properties of Aktionsarten are given in the following list:

(1) A Set Ind of agents, patients and things; and discourse referents $x_1, ..., x_n$ for them

(2) A set of possible times together with a partial ordering, the structure **TS** and discourse referents for possible times $t_1, ..., t_n$

(3) A set $\mathcal{B}$ of basic actions A; and a set *Action* of discourse referents $\mathsf{a}_1, ..., \mathsf{a}_n$ for them

(4) An adequate representation of action in the model and a possibility to cope with change

(5) A notion of states of affairs that hold in a model at a certain time and world

(6) A way to represent explanations of actions and expressions involving eventualities

We will proceed by working off the above list, giving further explanations on each item. A notational note: in the following, arbitrary DRSs will always be represented by the letter K.

4.1 Agents, patients, things

Agents, patients and things belong to the ontological class of individuals. More specific, they are individuals possessing an ontological status, depending on whether they are subject of action (agent), object of action (patient) or bear states (thing). This means that being an agent, a patient or a thing is a property ascribed to an individual which indicates her ontological status (not her ontological class). Thus, agents, patients and things can be represented in a DRS just as individuals are represented in the Standard DRT approach with the use of a set of individuals Ind introduced in the Discourse Universe U. As there is no uniquely specified mapping from individuals to their ontological status but only a context-dependent assignment specified by the occurrence of the respective individual in a specific term involving action, it can be assumed that the ontological status of an individual is merely a notational matter than a strict ontological classification. Consequently, we will not spell out such a function from individuals to their ontological status, as it is not necessary for the further argumentation. The context-dependence of the ontological status of an individual leads to somewhat obscure effects: e.g. humans which are preferably analyzed as intentional agents become thing-like patients if they are used in a context illustrated by the examples (9) and (10). The swimming of Peter in

(10) is not different from the swimming of a piece of wood in (9) in terms of the action both perform which is explained as the physical movement of swimming, without further explications on how Peter may actually perform the swimming. A change of the explanatory instrument used to explain an action going on results in a shift of the ontological status of an individual. More on this point can be found in chapter 5.7, where the general concept of explanatory shifts (or coercion in linguistic terms) is explicated.

(9) Peter is swimming.

(10) The piece of wood is swimming.

4.2 Time and action

We must decide now which concept of time provides an adequate basis for the modeling of actions. In order to justify the decision I have made, a short digression to the philosophical background of time with respect to action seems to be helpful. In the philosophy of time it is extensively discussed how measurement and movement of time interact with each other (a point which was already touched during the discussion in chapter 2.1). Since the beginning of philosophy, philosophers dispute about the nature of time. While some[23] focus on the movement of time and proclaim that time is constituted internally, that time is of *intrinsic* nature, other philosophers, especially physicians[24] focus on the measurement of time and assume that time is constituted externally, that time is of *extrinsic* nature. Both conceptions can be expressed in natural language by the use of the extrinsic order *earlier-later-coincident* (where at least two individuals are needed to set them in the ordering relation), and the intrinsic order of *past, present and future* (for which only one individual is needed to determine the present). Additionally, one may dispute about the structural properties of time. Intrinsic conceptions of time are commonly connected with a topological structure (such as in DRT[25]), extrinsic conceptions of time with a metrical order (such as in Newtonian Physics).[26] A representative of one of these approaches may try to reduce the other conception of time to the conception he takes as fundamental by asking questions such as "Does time has a metric structure by itself or must the metrical structure at first be established from a topological structure?". Among the most famous of such attempts is Bertrand Russell's proclamation of the superiority of extrinsic time (Russell, 1915) and Arthur Prior's effort to reduce extrinsic time to intrinsic time (Prior, 1967). John McTaggart in turn showed that none of the reductions is possible (which lead to the well-known postulate of the unreality of time (McTaggart, 1908)). The problem is now that both approaches to time stand in a reciprocal ontological dependency, which was already stated by Aristotle: "Not only do we measure the movement by the time, but also the time by the movement,

[23]Such as Aristotle, who states in his physics: "Time is not number with which we count, but the number of things which are counted" (Aristotle, 2005a, Book IV, Part 12)

[24]Such as Isaac Newton, who determined time as a *parameter* in a space-time quadruple (x, y, z, t)

[25]The points of the time structure of DRT are constructed from a set of intrinsic intervals with a topological structure (the so called Russell-Kamp construction, (Kamp, 1979)).

[26]Besides these two conceptions, there also exists the Leibniz-Einstein conception of time: time is intrinsic but has a metric structure.

because they define each other. The time marks the movement, since it is its number, and the movement the time.” (Aristotle, 2005a, Book IV, Part 12). Luckily DRT takes an ecumenic view, leaving the question open whether there are possible reductions.

After all we have said about the nature of actions, an *intrinsic conception of time with a topological structure* is the appropriate means to formally model time. This decision is justified by two reasons concerning the properties of actions discussed in chapter 2.1. First, actions are defined by their effects and not by their duration. Thus, assumptions about a metrical structure of time do not provide a useful basis for the analysis of actions. Second, action is explained by setting the subject of action in relation to the objects of action. Thus, assuming an extrinsic nature of time does not capture the nature of actions, as it is a relation between two objects.

Several other properties of actions have to be covered by the formal model of time devised in the following. We want the model to explicitly capture the uncertainty of actions and take into account that each action may change the actual world in a different way. Therefore, the model includes a set of possible times which represent the various possibilities the world may evolve by an association with the state of affairs which holds at that time, depending on the present action going on. The formal concept of time proposed here does not explicitly assume any equality of the theory of time to the theory of numbers. Actions are represented only with the use of a topological structure without further stipulations on the duration of each basic action, which would automatically be introduced by the use of a number-like time-structure.[27] Thus, we assume that time has a certain degree of granularity, which is defined by the granularity one can assume for the cognitive apparatus of humans. With regard to the granularity of time, the proposed model implies the assumption that some kind of cognitive conceptualization has already been performed resulting in a topological structure of the world’s evolution using the atomic interval of a *basic action*. ”Basic” in the sense proposed here means that inside a basic action, no further time exists, otherwise the basic action must be split up in two different basic actions. The interval structure of basic actions reflects the lower threshold of the conceptualization of the real world. How fine the granularity of this basic conceptualization of the real world actually is does not matter for the following formalism, as it only deals with the topological structure itself and not with the duration of actions. Another reason for the use of such a ”discrete” point-like structure of time is that it should be possible to fix times in order to deal with change. Change is always a change from some temporally fixed state of affairs time to some other temporally fixed state of affairs. In other words: the set of possible times in the model is determined by the conceptualization’s fixing of (possible and real) state of affairs with respect to the basic units of action going on. Under such assumptions, basic actions are equal to the basic units of change. Figure 8 points up what the proposed structure of action-time looks like.

[27] Nevertheless, it is possible to assume an underlying structure of the real numbers, where conceptualization singles out those times at which the intervals of basic actions take place.

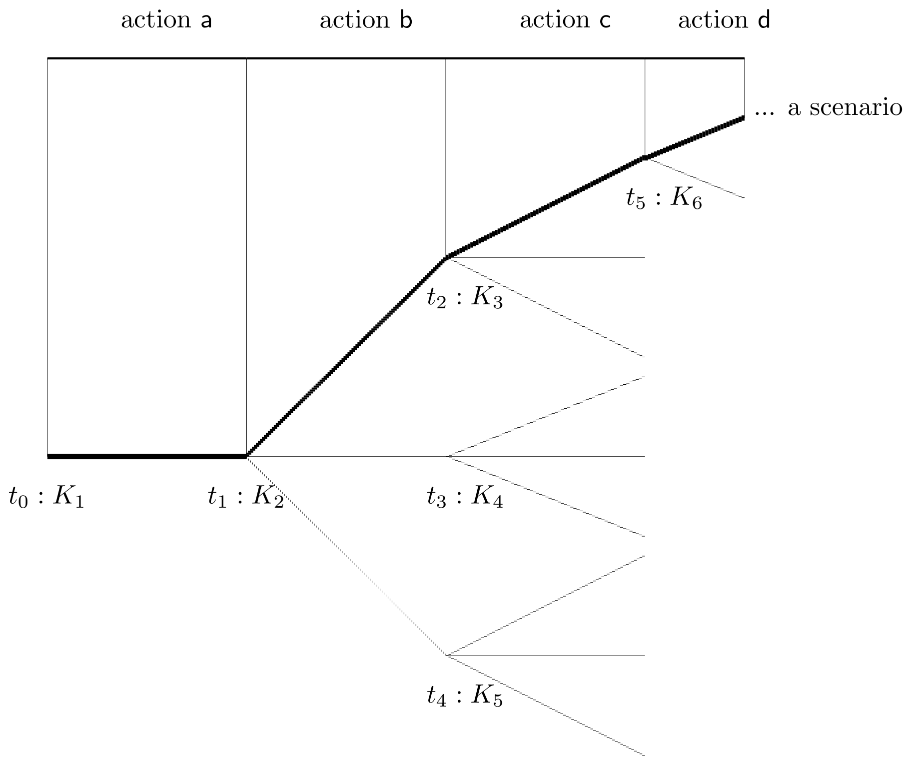

Figure 8: Action and time in a branching-time framework. An agent at t_1 has the options to choose either t_2, t_3 or t_4. Depending on the agent's choice, either a state of affairs represented by K_3, K_4 or K_5 comes to hold. The choice itself consists in the performance of some action. E.g. action b brings about a change from K_2 holding to the state of affairs represented by K_3.

With these assumptions about time, the following formal definitions (loosely based on (Singh, 1994)) can be given:

Definition 3 *The time structure* ***TS***

- ***T*** *is a set of possible times*[28] *ordered by* $<$ *.*
- *Each possible time is associated with the state of affairs holding at that time in the form of an ordered pair, where the DRS states the conditions*

[28]Possible times in the sense proposed here are to be understood in the sense of possible worlds in modal logic, which are part of the Standard DRT-Analysis. But there exists a formal difference, because the set of possible times has a linear ordering defined on it, while the set of possible worlds has no such order. This means that we have to deal with a kind of "double-modality", where we have the evaluation of formulas with respect to a possible world and a possible time in that world: each possible world has several possibilities to evolve, depending on what happens. For our purposes we do not need to consider all combinations of possible worlds and possible times, because actions are not about what could have been done in another world, but how one can change reality, the actual world. Thus, I omit worlds considering the evaluation of formulas containing actions and assume that **evaluation takes place in the real world**. The decision whether the different possibilities of future evolution are real or not is left to the reader, but I assume that the past of an agent is the real past and not a just possible past. In other words: up to the present, it is possible to determine reality, and for the future evolution we assume that there are different possibilities reality may evolve.

which hold in the world at time t : $\left\langle t, \begin{array}{|c|}\hline \\ \hline \textit{state of affairs that holds at } t \\ \hline \end{array} \right\rangle$.
Note that the DRSs representing the state of affairs holding at each possible time are trivially true because they represent all the true conditions of the model holding at a certain time. DRSs representing state of affairs do not involve temporal information.

- $< \subseteq \boldsymbol{T} \times \boldsymbol{T}$ *is a strong partial ordering. The following conditions hold for* $<$ *and we call* $\langle <, \boldsymbol{T} \rangle$ *the time structure* ***TS****:*

  (1) Transitivity: $(\forall t, t', t'' \in \boldsymbol{T} : (t < t' \wedge t' < t'') \Rightarrow t < t'')$
  (2) Asymmetry: $(\forall t, t' \in \boldsymbol{T} : t < t' \Rightarrow t' \not< t)$
  (3) Irreflexivity: $(\forall t \in \boldsymbol{T} : t \not< t)$

A *scenario* at a time t is a maximal set of times, which includes the given time and all future times on a given branch of time. In other words: a scenario formalizes a way in which the world could possibly evolve in the future by picking out a path through the various possibilities of evolution. Formally, a scenario is defined as in Definition 4:

Definition 4 *Scenarios*

- *A Scenario at time t is a set* $S \subseteq \boldsymbol{T}$ *that satisfies the following conditions:*
  - *Rootedness:* $t \in S$
  - *Linearity:* $(\forall t', t'' \in S : (t' = t'') \vee (t' < t'') \vee (t'' < t'))$
  - *Maximality:* $(\forall t' \in S, t'' \in \boldsymbol{T} : (t' < t'') \Rightarrow (\exists t''' \in S : (t' < t''') \wedge (t''' \not< t'')))$
- *The notation* $[S; t, t']$ *denotes an inclusive* ***interval*** *on a scenario* S *from* t *to* t' *with* $t, t' \in S$ *and* $t \leq t'$.
- $\boldsymbol{S}_t$ *denotes the set of all scenarios at moment t. Because every scenario is rooted at a time, the set of scenarios is disjoint at different times:* $t \neq t' \Rightarrow \boldsymbol{S}_t \cap \boldsymbol{S}'_t = \oslash$.
- *It is useful to define an assignment function for reality,* ***R****, which assigns the real scenario to every time.*

Definition 5 *Truth of a proper*[29] *DRS K in a model M (Kamp et al., 2004, p. 27):*

- *A proper DRS K is true in a model M iff there exists a verifying embedding g for K in M with respect to the empty assignment* Λ*. The model M will be specified in definition 28.*
- *We write* $\vDash_M K$ *iff there exists an g such that* $\langle \Lambda, g \rangle \vDash_M K$.
- *In most cases, truth will be determined with respect to a time and a model, which will be written as* $\vDash_{M,t} K$.

[29] A proper DRS is a DRS where all occurrences of Discourse Referents are properly bound.

Definition 6 *Quantification over scenarios, Verum and Falsum*

- $\models_{M,t} \mathsf{A}K$ *iff* $(\forall S : S \in \boldsymbol{S}_t \Rightarrow \exists g : \ g \models_{M,S,t} K)$
- $\models_{M,t} \mathsf{P}K$ *iff* $(\exists t' \in \boldsymbol{T} : t' < t$ *and* $\exists g : \ g \models_{M,t'} K)$
- $\mathsf{E}K \equiv \neg\mathsf{A}\neg K$
- $\mathsf{G}K \equiv \neg\mathsf{F}\neg K$
- $\models_{M,t} \mathsf{R}K$ *iff* $\exists g : \ g \models_{M,\boldsymbol{R}(t),t} K$
- true *denotes the verum (a condition which is true in every model),* false *the falsum.*

Additionally, we put some coherence constraints on the respective parts of the model (following (Singh, 1994)) in order to represent properly what we know about the behavior of the physical world. Among these are eternity, the atomicity of actions, the passage of time and others. A complete list can be found in Appendix A. For our analysis these constraints are only of marginal interest, for a more profound discussion I refer the reader to (Singh, 1994).
How is a basic action identified? In the last paragraph, we have identified three formal criteria: the period of time at which it happens, given by an interval $[t_0, t_1]$, the bearer of the action, and the effects the action brings about. Formally, we will model basic actions as a set $\mathcal{B}$ of tuples A consisting of an agent x, the action a which is performed, the time t_0 when the action starts and the time t_1 when it is finished. The effects of an action are included in the state of affairs holding at the time after the action has been performed and thus must not be explicitly stated in the entry of a basic action.[30] Additionally, we must assume that actions start and end on one branch of time. This is what is expressed by constraint 7 in appendix A. We can then define the set of basic actions $\mathcal{B}$ generated by a conceptualization of the real world as shown in definition 7. Conditions involving actions will be called action terms.

Definition 7 *The set of basic actions* $\mathcal{B}$ *is a set of tuples* A*, such that*

- $A = \langle x, \mathsf{a}, [t_0, t_1]\rangle$,
- *where* $x \in Ind$, $t_1, t_0 \in \boldsymbol{T}$ *and* $\mathsf{a} \in Action$ *where*
- *Action*$= \{\mathsf{a}_1, ..., \mathsf{a}_n\}$ *is a set of discourse referents denoting basic actions.*

Action terms will be evaluated with respect to the temporal intension of the involved discourse referents for actions. The intension operator introduced in definition 8 is similar to that which is known from classical modal logic and returns the set of times at which the argument of the operator is true.

Definition 8 *The temporal intension Operator* $\langle\!\!\lbrack\ \rbrack\!\!\rangle$

[30] I must confess that I cannot give a formal criteria for the identification of an action's effects from a snapshot, but I think that this a challenge for science in general. E.g. physics may be able to give such formal laws of effect identification with the use of the general principle of causality. In the following, I assume that the effects of an action can be singled out from the conditions expressing the state of affairs holding at the respective time.

- *The temporal intension of an action symbol* $\mathsf{a} \in$ *Action is for each Individual* x *the set of periods at which an instance of* a *is performed by* x*:* $\langle\!\langle \mathsf{a} \rangle\!\rangle^x := \{[t_0, t_1] | \, \langle x, a, [t_0, t_1] \rangle \in \mathcal{B}\}$
- *A notational note:* $[S; t, t'] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x$ *means that agent* x *is performing an action* a *in* S *from* t *to* t'*.*
- *We may also define the temporal intension of a DRS* K*, which is the set of times at which* K *is true:* $\langle\!\langle K \rangle\!\rangle := \{t | \vDash_{M,t} K\}$

5 The representation of eventualities

With the concept of basic actions at hand, we are now able to formalize the correlation between explanations of action and natural language expression involving Aktionsarten as it was discussed in chapters 2 and 3. While we go through the various Aktionsarten, we will introduce more complex concepts of action explanation, such as strategies and intentions.

5.1 The basic structure of representation

The conclusion of chapter 3 was that the temporal instruments which are available for explanation and natural language expressions correlate in a systematic way. In order to represent this correlation a notation is developed in the following combining both ways of dealing with time in one representation. By this, it is possible to express the temporal properties of an eventuality as well as those properties which go beyond the temporal (the additional information which is used for the explanation of some action going on). The explanation of *action* provides information about the way the action can be identified from a sequence of snapshots, the natural language description of the action locates an *eventuality* in discourse time and makes the eventuality available for further reference. The structure I adopt to represent this analysis of eventualities is that of an ordered pair, which consists of an event-expression (e:$R(x_1, ..., x_n)$) or state-expression (s:$R(x_1, ..., x_n)$) and the explanation of the action going on which is described by the eventuality. Definition 9 shows what the basic structure of lexical entries representing this dual approach to time looks like. This skeletal definition will be fleshed out as we proceed with the discussion of the formalization of the various types of action explanation.

Definition 9 *The basic structure for the representation of eventualities*
The representation of an eventuality E *is an ordered pair of the form*

- $\mathsf{E} : \langle \mathsf{e}{:}R(x_1, ..., x_n), \textsf{ACTION-TERM}\rangle$ *or*
- $\mathsf{E} : \langle \mathsf{s}{:}R(x_1, ..., x_n), \textsf{ACTION-TERM}\rangle$

Where $\mathsf{e} : R(x_1, ..., x_n)$ *is an event-expression,* $\mathsf{s} : R(x_1, ..., x_n)$ *is a state-expression of Standard-DRT*[31] *and* $\textsf{ACTION-TERM}$ *is an explanation of action, to be defined in the following.*

5.2 Thing/State

In accordance to the discussion in chapter 3, states will be analyzed as a thing's holding of an instantiated potential state. For the formal treatment states and their corresponding explanation type, this means that the explanation of things is analyzed as a thing holding an action which causes no change but it is rather some kind of "stand-by"-action.

Syntax and semantics of the ACTION-TERM "thing" is given in definitions 10 and 11, figure 9 shows the basic DRS-structure of a lexical entry for descriptions involving the explanation of things, definition presents information on how such DRSs are evaluated.

[31] For a specification of the syntax and semantics of such expressions, I refer the reader to the standard reference for DRT (Kamp et al., 2004, p. 105–120).

Definition 10 *Syntax of action terms involving a thing's holding of an instantiation*

- *If* $x \in Ind$ *and* $\mathsf{a} \in Action$*, then* $x \lfloor \mathsf{a} \rfloor$ *is a condition.*

Definition 11 *Semantics of a thing's holding of an instantiation*

- $\models_{M,t} x \lfloor \mathsf{a} \rfloor$ *iff* $\exists t_1 : [S; t, t_1] \in \langle [\mathsf{a}] \rangle^x$

x s
E: $\langle \mathsf{s} : R(x), x \lfloor \mathsf{a} \rfloor \rangle$

Figure 9: DRS structure representing the correlation between states and instantiated properties of things. The action a represents the instantiation of a potential x is holding.

Definition 12 *Verification of an eventuality* E *involving the description of instantiated potentials of things*

- E*:* $\langle \mathsf{s} : R(x), x \lfloor \mathsf{a} \rfloor \rangle$ *is true iff*
- $\mathsf{s} : R(x)$ *is satisfied, where* $R(x)$ *represents a stative verb, and*
- $x \lfloor \mathsf{a} \rfloor$ *is satisfied*
- *Where* $\langle [\mathsf{a}] \rangle^x = dur(\mathsf{s})$*, where dur is a 1-place functor from eventualities to times, returning the duration of state-expression and event-expressions.*

5.3 Movement/Activity

As discussed in chapter 3 the instrument of causality which is used for the explanation type of physical movement finds its correspondence in the instrument of activity-Aktionsart in natural language. Such explanations include additional information about the effects of the action, because even if the change an activity brings about is not mentioned in the natural language expression, there have to be some effects in order to identify the respective action. A spatio-temporal entity for which it is not possible to identify any effects of its progress through time is not an action but a thing (see above). This implies that there is a fundamental ambiguity between the explanation of things and activities, depending on the assignment of effects to entities, which will be spelled out in chapter 5.7 below. Information about the causal effects of a basic action can be gathered from the state of affairs which holds at the time when the basic action is finished.[32]
Syntax and semantics of the ACTION-TERM "movement" is given in definitions 13 and 14, figure 10 shows the basic DRS-structure of a lexical entry involving the ACTION-TERM "movement", definition 15 presents information on how such DRSs are evaluated.

[32]We already mentioned how difficult it is to single out the effects of an action, and assume in the following that this is contributed by some theory of causality.

Definition 13 *Syntax of action terms involving physical movement*

- *If* $\mathsf{a} \in$ *Action,* $x \in$ *Ind and* K *a DRS describing a state of affairs, then* $x\,\langle \mathsf{a} \rangle\, K$ *is a condition.*

Definition 14 *Semantics of action terms involving physical movement*

- $\models_{M,S,t}\ x\,\langle \mathsf{a} \rangle\, K$ *iff* $(\exists t' \in S : [S;t,t'] \in \langle\!\![\mathsf{a}]\!\!\rangle^{x})$ *and* $\models_{M,S,t'} K)$.

$x_1, ..., x_n$ e
E: $\langle \mathsf{e} : R(x_1, ..., x_n), x_1\,\langle \mathsf{a} \rangle\, K\ \rangle$

Figure 10: DRS structure representing the correlation between activities and explanations of physical movement. The DRS K represents the state of affairs which is caused to hold by x_1's doing of a

Definition 15 *Verification of an eventuality* E *involving the description of physical movement*

- $\langle \mathsf{e} : R(x_1, ..., x_n), x_1\,\langle \mathsf{a} \rangle\, K\ \rangle$ *is true iff*
- $\mathsf{e} : R(x_1, ..., x_n)$ *is satisfied, where* $R(x_1, ..., x_n)$ *represents an activity verb and*
- $x\,\langle \mathsf{a} \rangle\, K$ *is satisfied, where* K *is a DRS representing the state of affairs which comes to hold after the performance of* a *by* x.
- *Where* $\langle[\mathsf{a}]\rangle^{x} = dur(\mathsf{e})$.

5.4 Strategy/Achievement

With regard to the discussion in chapter 3, a strategy is a means to subsume a sequence of basic actions under the consideration of a goal. All actions belonging to the strategy are supposed to lead to the goal of the strategy by picking out a path through the tree-like time structure. A strategy does not add any new capabilities to an agent but simplifies the representation of sequences of basic actions as it is not needed to state all the actions included in the strategy. A strategy is an abbreviation, a "packed" representation for a sequence of basic actions under the consideration of a goal.
Syntax and semantics of the ACTION-TERM "strategy" is given in definitions 16 and 17, figure 11 shows the basic DRS-structure of a lexical entry involving the ACTION-TERM "strategy", definition 18 presents information on how such DRSs are evaluated.

Definition 16 *Syntax of a strategy*
An abstract strategy leading to the realization of the goal stated by a DRS K will be represented as ***do(K)***.
If K is a DRS representing a state of affairs, then

$x_1, ..., x_n$ e
E: $\langle$e:$R(x_1, ..., x_n), x_1 \mathbf{do}(K)$ $\rangle$

Figure 11: DRS structure representing the correlation between achievements and strategic explanations. The DRS K represents the state of affairs which is the goal of the strategy.

- $\boldsymbol{do}(K)$ *is a condition.*

Definition 17 *Semantics of a strategy*
The semantics for conditions involving strategies will be defined analogous to that of basic actions with the use of the temporal intension operator.

- $\langle\!\lbrack \boldsymbol{do}(K) \rbrack\!\rangle = \{[S; t, t'] |$ *such that* $\vDash_{M,t',S} K$ *and* $(\forall t'' : t \leq t'' < t' \Rightarrow \nvDash_{M,t'',S} K)$[33]

Definition 18 *Verification of an eventuality* E *involving the description of strategic behavior*

- *E:* $\langle$e:$R(x_1, ..., x_n), x_1 \boldsymbol{do}(K)\rangle$ *is satisfied iff*
- e:$R(x_1, ..., x_n)$ *is satisfied, where* R *represents an achievement verb and*
- $x_1 \boldsymbol{do}(K)$ *is satisfied*
- *where* $dur(\mathsf{e}) = \langle\!\lbrack \boldsymbol{do}(K) \rbrack\!\rangle$[34]

5.5 Intention/Accomplishment

The remaining instrument of action explanation which is integrated into the framework of DRT is the explanation of strategies with the help of intentional ascriptions. Explaining action with the use of intentions requires even more information than explanation with strategies. First of all, we need information about how to identify the intention. The only way to do so is to assume that a certain effect of the performance of a strategy is intended, in the sense that the performance of a certain strategy is directed to the realization of a mental goal. If we want to apply an intentional explanation to performances of a strategies, we need to assume that a) the agent can have intentions and b) that at least some of the necessary causes of his performing of the strategy are intended. (cp. chapter 3).
As intentions express several properties at once, it is useful to split up the complex concept of intention into several single operators, for which the syntactic definition is given in 19 and the semantic definition is given in 20. Syntax

[33]The temporal intension of the strategy $\mathbf{do}(K)$ is the set of all those intervals that begin at any time where K is achievable and that end at the first occurrence of K after their beginning.
[34]There is even more information available: in terms of the theory of event nucleus, achievements focus on the culmination point of an eventuality. This culmination point is defined by the time at which the goal conditions expressed by K come to hold. If needed, this time can be used for setting the culmination time.

$x_1, ..., x_n$ e
E: $\langle$e:$R(x_1, ..., x_n), x_1 \vert K\ \rangle$

Figure 12: DRS structure representing the correlation between accomplishments and intentional explanations. The DRS K represents the intended states of affairs, where the intentional attitude is represented as $|$.

and semantics of the ACTION-TERM "intention" itself is given in definitions 21 and 22, figure 12 shows the basic DRS-structure of a lexical entry involving the ACTION-TERM "intention", definition 23 presents information on how such DRSs are evaluated.

Definition 19 *Syntax of the operators for intentions*
If $x \in Ind$, $\boldsymbol{do}(K_1)$ a strategy and K_2 a DRS representing the intended state of affairs, then

- $x \left\langle \boldsymbol{do}(K_1) \right\rangle_i K_2$ *is a condition*
  (At the given time, x performs $\boldsymbol{do}(K_1)$ in order to realize K_2)
- $x \left\langle\left\langle \boldsymbol{do}(K_1) \right\rangle\right\rangle K_2$ *is a condition*
  (At the given time, K_2 will come to hold at a future time by performing $\boldsymbol{do}(K_1)$)

Definition 20 *Semantics of the operators for intentions*

- $\models_{M,S,t} x \left\langle \boldsymbol{do}(K_1) \right\rangle_i K_2$ *iff* $(\exists t' : [S; t, t'] \in \langle\!\langle \boldsymbol{do}(K_1) \rangle\!\rangle^x$ *and* $\models_{M,S,t'} K_2)$
- $\models_{M,t} x \left\langle\left\langle \boldsymbol{do}(K_1) \right\rangle\right\rangle K_2$ *iff* $\models_{M,t} \mathsf{A}(x \left\langle \boldsymbol{do}(K_1) \right\rangle_i \mathsf{true} \rightarrow \mathsf{F}K_2)$

Definition 21 *Syntax of Intentions*

- *If $x \in Ind$, K a DRS representing the intended state of affairs, then $x|K$ is a condition.*

Definition 22 *Semantics of Intentions*
The difference between the imagined goal of an intention and the realized goal of an intention discussed in chapter 2.1 is captured by the use of two DRSs, one representing the intended goal, the other representing the real state of affairs holding after the realization of the intention. In the ideal case, both are equal, but in most cases, some side-effects and unwanted causes of an action also hold after the realization of an intention.

- $\models_{M,t} x|K$ *iff* $(\exists \boldsymbol{do}(K_1) :\models_{M,t} x \left\langle\left\langle \boldsymbol{do}(K_1) \right\rangle\right\rangle K)$
- *Where K represents the intended state of affairs, K_1 represents the real state of affairs holding after the strategy realizing the intention has been performed.*

Definition 23 *Verification of an eventuality* E *involving the description of an intention*
A DRS structure E:$\langle \mathsf{e}{:}R(x_1, ..., x_n), x_1|K\rangle$ *is satisfied iff*

(1) $\mathsf{e}{:}R(x_1, ..., x_n)$ *is satisfied, where* R *represents an accomplishment verb and*

(2) $x_1|K$ *is satisfied.*

Besides these technical properties of intentions, there exist numerous constraints on the interaction of intentions with knowledge, believe and the actions which are available for choice. A list of such constraints can be found in Appendix B.

5.6 The construction of explanations

Constructing a representation of the type proposed above from a given natural language expression involving eventualities does not pose great problems if the standard-DRT construction algorithm is used (see (Kamp et al., 2004)). The conditions representing the explanation of the described action are invoked by the use of the lexical entry of the respective verb. The formalism which is available now can also be used to generate DRSs from a given conceptualization of the real world in terms of basic actions. If the raw sensual data is conceptualized in a way that has identified the basic units of action and the set of basic actions is defined by the component B of the model, then it is then possible to state rules which give the circumstances under which a certain explanation may be applied to a given set of basic actions. The following rules are conditionals: if all the conditions in the scope of the if-antecedent can be fulfilled, then the conditions in the scope of the then-consequent become available for the construction of representations.

5.6.1 Things

If no causal effects of an action can be identified from the state of affairs holding after the action has been performed, then the respective basic action is explained as a **thing**'s holding of an instantiation of a potential state and described by a stative expression.

Definition 24 *Conditions for the use of the explanation of instantiations of potentials of things*
If

- $\exists x \exists \mathsf{a} \exists t_0, t_1$ *such that*
- $[S; t_0, t_1] \in \langle[\mathsf{a}]\rangle^x$

then

- $[S; t_0, t_1]$ *can be explained by the use of a DRS as follows:*
- $$\begin{array}{|l|}\hline x\ \mathsf{s} \\ \hline \mathsf{E}{:}\langle \mathsf{s} : R(x), x\ \lfloor \mathsf{a} \rfloor\ \rangle \\ \hline \end{array}$$
- *Where* $R(x)$ *is the representation of a verb describing* a *with stative Aktionsart.*

5.6.2 Movement

If the causal effects of an action can be identified from the state of affairs holding after the action has been performed, then the respective basic action is explained as **physical movement** and described by an activity-expression.

Definition 25 *Conditions for the use of physical movement explanation*
If

- K *is the representation of the causes of the doing of* a *and*
- $\exists x \exists \mathsf{a} \exists t_0, t_1, t_2$ *such that*
- $t_0 < t_1$ *and*
- $[S; t_0, t_1] \in \langle [\mathsf{a}] \rangle^x$ *and*
- $\exists g : \ g \models_{M,S,t_1} K$,

then

- $[S; t_0, t_1]$ *can be explained by the use of a DRS as follows:*
- $$\begin{array}{|l|}\hline x_1, ..., x_n \ \mathsf{e} \\ \hline \mathsf{E}\text{:} \langle \mathsf{e} : R(x_1, ..., x_n), x_1 \langle \mathsf{a} \rangle \, K \ \rangle \\ \hline \end{array}$$
- *Where* $R(x_1, ..., x_n)$ *is the representation of a verb describing* a *with activity Aktionsart.*

5.6.3 Strategy

If the effects of a sequence of basic actions can be identified (from the state of affairs holding after the actions have been performed) as the goal of the performance of the respective sequence of basic actions, then the respective sequence of basic actions is explained as **strategy** and described by an achievement-expression.

Definition 26 *Conditions for the use of intentional explanation*
If

- K *is the representation of the goal of the strategy* x *is performing and*
- $\exists x \exists \boldsymbol{do}(K) \exists t_0, t_1$ *such that*
- $[S; t_0, t_1] \in \langle\!\langle \boldsymbol{do}(K) \rangle\!\rangle$ *and*
- $\exists g : \ g \models_{M,S,t_1} K$ *and*
- $\forall t_2 : t \leq t_2 < t_1 \Rightarrow \neg \exists g : \ g \models_{M,S,t_2} K$,

then

- $[S; t_0, t_1]$ *can be explained by the use of a DRS as follows:*
- $$\begin{array}{|l|}\hline x_1, ..., x_n \ \mathsf{e} \\ \hline \mathsf{E}\text{:} \langle \mathsf{e}\text{:}R(x_1, ..., x_n), x_1 \, \boldsymbol{do}(K) \ \rangle \\ \hline \end{array}$$
- *Where* $R(x_1, ..., x_n)$ *is the representation of a verb describing* $\boldsymbol{do}(K)$ *with achievement Aktionsart.*

5.6.4 Intention

If the effects of a strategy can be identified as the realization of an imaginary goal, then the effects of the performance of the strategy are explained as **intention** and described by an accomplishment-expression.

Definition 27 *Conditions for the use of intentional explanation*
If

- K_2 *is the representation of the intention of* x *and*
- K_1 *is the goal of the strategy performed by* x *in order to realize the intention and*
- $\exists x \exists \boldsymbol{do}(K_1)$ *such that*
- $\models_{M,t} x \langle\langle \boldsymbol{do}(K_1) \rangle\rangle K_2$

then

- $\boldsymbol{do}(K_1)$ *can be explained by the use of a DRS as follows:*
$x_1, ..., x_n$ e
E: $\langle$e:$R(x_1, ..., x_n), x_1 \vert K\ \rangle$
- *Where* $R(x_1, ..., x_n)$ *is the representation of a verb describing* $x|K$ *with accomplishment Aktionsart.*

5.7 Explanations and coercion

It must have become clear that quite a lot of knowledge is involved in the choice of the right description for a certain type of action going on. The interplay between knowledge and resulting description becomes especially apparent in the case of a change of the information involved to explain the action going on. It is possible to explain the same action going on with different Aktionsarten, depending on the information which is assumed to explain the respective change. Linguists are familiar with this phenomenon by the term *coercion.* Depending on whether information is added to or removed from the explanation, it is possible to distinguish the following types of coercion (van Lambalgen and Hamm, 2004, p. 171–177):

- adding information about a goal or intention: **additive coercion**
  - activity → accomplishment (+goal)
  - achievement → accomplishment (+intention)
- removing information about a goal: **subtractive coercion**
  - accomplishment → activity (-goal)
- adding/removing information about the identified causes/intentions: **cross-coercion**
  - state → activity (+causes)

- activity → state (-causes)
- accomplishment → state (-intention)

Coercion not only influences the form of description of action going on, but also changes the ontological status of the involved individuals. Examples (9) and (10) in chapter 4.1 illustrate such a change of the ontological status. A similar case arises, when a sailing ship is described as an intentional agent as in example (6), chapter 2.1. It is intuitively clear that ships cannot have intentions, but if one applies the instrument of intentional explanation to a sailing ship, it becomes an intentional agent. The same holds for example (5), chapter 2.1: the description of the ship's landing supposes that the ship has the same ontological status as a cat hunting a mouse: it is an animated strategic agent. This observation surely deserves more attention, but the transparent representation of such ontological subtleties is only a nice side-effect of the theory proposed, and we will not go into more details here. Of more interest is the question whether the large number of possible coercions has the status of a marginal phenomenon[35] or if coercion reflects a basic property of the commerce with time. It must have become clear during the last chapters that with regard to the ambiguity and flexibility of conceptualizations, coercion is a natural ingredient of every theory of temporal reference which is able to model the flexibility of human cognition of time. In the framework proposed here, coercion is handled by the representation of the additional information involved in the use of temporal expressions. Adding or removing information results in a different explanation and a different Aktionsart and thus it is possible to capture coercion in an intuitively appealing way.

5.8 Integration into the framework of Standard DRT

In order to integrate the proposed analysis of actions into the framework of Standard DRT, the set of basic actions $\mathcal{B}$ and the time structure **TS** has to be added to the model of Standard DRT (as given in (Kamp et al., 2004, p. 105–120)). This enables the evaluation of expressions of the extended DRS language involving explanations of action going on developed in the last chapter. The extended model M is given in definition 28.

Definition 28 *The extended model M*

- *A model M for the extended DRS language presented in the last chapter is a tuple*
- $\langle W, U, \mathcal{EV}, \mathcal{T}, \mathcal{LOC}, \Im, \mathcal{B}, \boldsymbol{TS}\rangle$,
- *where*
  - W *is a non-empty set of worlds,*
  - U *is a non-empty set of individuals,*
  - $\mathcal{EV}$ *is an eventuality structure,*

[35]Which seems plausible if the position of coercion in the linguistic literature is taken as an indicator for its prominence: in most cases, coercion is treated at the end, where it often destroys the cumbersome achieved formal system of eventualities by adding a large number of exceptions.

– *$\mathcal{T}$ is a non-empty set of (real) times,*
– *LOC is a 1-place function assigning each eventuality* $\mathsf{eors} \in \mathcal{EV}$ *an interval in the time structure built from T,*
– *Imp is a function interpreting the formulas of standard DRT with respect to a time of the set* $\mathcal{T}$[36]*,*
– *$\mathcal{B}$ is a non-empty set of basic actions as defined in definition 7,*
– ***TS** is a non-empty set of possible times together with the structural properties given in definition 3.*

The set of real times $\mathcal{T}$ of the model of Standard DRT can be related to the set of possible times $\mathbf{T}$ of the extended model with the use of the operator for real times R (Definition 6) by applying R to $\mathbf{T}$, which returns the set of real times $\mathcal{T}$.
Some more words need to be spent on the process of DRS evaluation involving action terms. It may be helpful to commemorate the treatment of presuppositions in DRT, where the presuppositions of a DRS have to be satisfied before the evaluation of the main DRS takes place (see (Kamp et al., 2004, p.131–192) for details). The evaluation of DRSs involving action terms follows a quite similar procedure, as the additional constraints posed by the explanation of an eventuality (the ACTION-TERM) have to be checked for satisfiability before the representation of the complex eventuality E can be evaluated. The evaluation of an ACTION-TERM and respectively explanations takes place in two steps:

- First, the semantics of the respective ACTION-TERM requires that a certain sequence of actions is performed by the involved individual. This is evaluated with the help of the temporal intension operator and the set $\mathcal{B}$ where the basic actions are stored.
- Second, the effects of the respective action going on have to be evaluated. A set of conditions (the causes, goals or intentions of an action going on) must come to hold at a certain time (when the action or strategy is finished or the intention is realized) in order to verify the ACTION-TERM. Such effect-conditions are evaluated with respect to the state of affairs connected to the respective time. The conditions representing the state of affairs themselves are evaluated against the model and as already mentioned they should trivially be true.

Along the way, we have widened the scope of DRT. The model of the extended DRS language is no longer just a discourse model but consists of a discourse model and a real world model. This in turn explains the twofold structure of the extended representation of eventualities E: event- or state-expressions deal with the integration of spatio-temporal entities into the structure of natural language discourse, explanations relate spatio-temporal entities to the real world, a common ground accessible to all participants of the discourse.

[36]This means that the interpretation function incorporates both times and possible worlds.

6 Examples revisited

The reader's stamina to pass a lot of difficult discussions in the last chapters will now be rewarded with a demonstration of the formal power which was gained by extending the DRT-formalism to the treatment of actions. In the following, we will examine the example sentences from the very beginning of this paper (with minor modifications) in detail and show how representations for each sentence can be constructed. Recall the following examples:

(1') The sail is white.

(2') The engine is vibrating.

(5) The ship is calling at Monkey Island.

(6) The ship is sailing to Monkey Island.

6.1 The dummy model and simplifying assumptions

In the following, assumptions about the prototypical meaning of strategies and intentions are made in the way that the conceptualization of the action going on represented by the set $\mathcal{B}$ is a simple prototypical conceptualization of the basic actions involved in the meaning of the verbs "call at" and "sail to". A well-crafted theory of prototypes may decide whether the prototypical sequences of basic actions are attached to the lexical entry of the respective verb or if a function is constructed assigning verbs their prototypical meaning with the use of members of the set $\mathcal{B}$. For our purposes, we will assume that it is possible to assign a prototypical conceptualization to strategies and go not into the details of how this is actually done, as we only deal with the structural properties of strategies. Thus it is assumed in the following that the actions required for the evaluation and construction of DRSs can be singled out from the set $\mathcal{B}$. In order to show how the example representations are evaluated and constructed, we will define the parts of the model of interest to us (the sets $\mathcal{B}$ and $\mathbf{T}$) as shown in figures 13 and 14. For the purpose of simplicity, we omit the ordering structure of $\mathbf{T}$ by assuming that the order of times is given by the indices of the time points in $\mathbf{T}$ and assume that we work on just one scenario. In the following, we focus on the evaluation of the respective ACTION-TERMs and will therefore ignore the evaluation of the state- and event-expressions of Standard-DRT, which is anyway done with the help of other parts of the model. The same applies to the treatment of tense, which is not covered in the following examples, as it is concerned with the relation of the state- and event-expressions to discourse time.

$$\mathbf{T} = \left\{ \begin{array}{l}
\left\langle t_0, \begin{array}{|l|}\hline \mathrm{x,y,z,l} \\ \hline sail(y) \\ white(y) \\ monkey-island(l) \\ ship(z) \\ \neg AT(z,l) \\ \hline \end{array} \right\rangle, \\
\left\langle t_1, \begin{array}{|l|}\hline \mathrm{x,y,z,l} \\ \hline sail(y) \\ white(y) \\ monkey-island(l) \\ ship(z) \\ \neg AT(z,l) \\ \hline \end{array} \right\rangle, \\
\left\langle t_2, \begin{array}{|l|}\hline \mathrm{x,y,z,l} \\ \hline machine(x) \\ sail(y) \\ hot(x) \\ no-gas(x) \\ reefed(y) \\ ship(z) \\ monkey-island(l) \\ \neg AT(z,l) \\ \hline \end{array} \right\rangle, \\
\left\langle t_3, \begin{array}{|l|}\hline \mathrm{w,z,l} \\ \hline anchor(w) \\ set(w) \\ ship(z) \\ monkey-island(l) \\ \neg AT(z,l) \\ \hline \end{array} \right\rangle, \\
\left\langle t_4, \begin{array}{|l|}\hline \mathrm{z,l,v} \\ \hline ship(z) \\ gateway(v) \\ monkey-island(l) \\ ship(z) \\ monkey-island(l) \\ AT(z,l) \\ installed(v) \\ \hline \end{array} \right\rangle, \\
\left\langle t_5, \begin{array}{|l|}\hline \mathrm{z,l,v} \\ \hline ship(z) \\ lie-off(z) \\ monkey-island(l) \\ AT(z,l) \\ \hline \end{array} \right\rangle
\end{array} \right\}.$$

Figure 13: The set of possible times **T** for the dummy model. The DRSs representing the state of affairs holding at each time are trivially true.

$$\mathcal{B}= \left\{ \begin{array}{l} \langle x, \textsf{strike-sail}, [t_1, t_2]\rangle\,, \\ \langle x, \textsf{throw-anchor}, [t_2, t_3]\rangle\,, \\ \langle x, \textsf{install-gangway}, [t_3, t_4]\rangle\,, \\ \langle x, \textsf{lie-off}, [t_4, t_5]\rangle\,, \\ \langle x, \textsf{white}, [t_0, t_1]\rangle\,, \\ \langle x, \textsf{vibrate}, [t_0, t_1]\rangle\,, \\ \langle x, \textsf{sail}, [t_0, t_1]\rangle \end{array} \right\}.$$

Figure 14: The set of basic actions $\mathcal{B}$ for the dummy model.

6.2 The sail is white

First a lexical DRS must be stated representing "be white" according to chapter 5.2, which is given in figure 15. With this lexical entry, Sentence (1') gets an analysis as in figure 16[37] and the obtained DRS is satisfied at time t according to definition 11 iff there exists a time t' such that the interval $[S; t, t'] \in \langle[\textsf{white}]\rangle^x$.[38] The only interval in the model for which this condition can be fulfilled is $t = t_0$ and $t' = t_1$, because $\langle[\textsf{white}]\rangle^x = [t_0, t_1]$. The state of affairs holding at t_0 supplies the information that x is specified as $sail(x)$.

x s
E $\langle$s : $white(x), x \lfloor \textsf{white} \rfloor\rangle$

Figure 15: Lexical DRS representing the verb "be white"

x s
$sail(x)$ E $\langle$s : $white(x), x \lfloor \textsf{white} \rfloor\rangle$

Figure 16: The sail is white.

It is also possible to construct the DRS given in figure 16 by using the procedure stated in definition 24. If we do so, we first need to find an individual x, an action a and an interval $[t, t']$ such that this interval is member of the set returned by the temporal intension of a with regard to x and no causes of the doing of a can be identified at t'. Then we can explain the action going on in this interval as a thing's holding of an instantiation of a potential state and describe it with an expression involving stative Aktionsart. An instantiation of the conditions mentioned above, using the lexical structure for the explanation of things as stated in definition 9 is shown in figure 16, where a=white, $t = t_0$, $t' = t_1$ and x is specified by $sail(x)$.

6.3 The machine is vibrating

Again we first need to specify a lexical DRS representing the the verb "vibrate" which is given in figure 17. With the use of this lexical entry, sentence (2')

[37] For details on the construction algorithm of DRT, see (Kamp et al., 2004)

[38] Remember that we focus on the evaluation of the action terms and thus ignore the evaluation of the state-expression.

obtains a representation as in figure 18. The evaluation of figure 18 says that the representation of the explanation is satisfied for the interval $[t_0, t_1]$. As in the previous example, the same DRS as in figure 18 could have been constructed with the use of the procedure specified in definition 25. As this differs from the previous example only with respect to the causes of the vibration, we will not spell out this construction in detail.

$$\begin{array}{|l|}\hline x \ \mathsf{e} \\ \hline \ \mathsf{E}\,\langle \mathsf{e} : vibrate(x), x \,\langle \mathsf{vibrate} \rangle\, K \rangle \\ \hline \end{array}$$

Figure 17: Lexical DRS representing the verb "vibrate"

$$\begin{array}{|l|}\hline x \ \mathsf{e} \\ \hline \ machine(x) \\ \ \mathsf{E} \left\langle \mathsf{e} : vibrate(x), x \,\langle \mathsf{vibrate} \rangle \begin{array}{|c|}\hline \\ \hline \text{hot(x) no-gas(x)} \\ \hline \end{array} \right\rangle \\ \hline \end{array}$$

Figure 18: The machine is vibrating. The causes of the vibration have been identified from the state of affairs holding at the time the vibration is completed.

6.4 The ship is calling at Monkey Island

Example (5) will be explained with the use of strategies. A lexical DRS representing the entry for the verb "call at" is given in figure 19. In chapter 5.4 it was stated that strategies are abstractions and respectively subsumptions in the way that they do not explicitly state the involved basic actions leading to the goal of the strategy. Thus, an action $\mathsf{call\text{-}at}$ does not exist, but the abstract strategy $\mathbf{do}(K)$, where K represents the goal of the strategy. Nevertheless the basic actions constituting the performance of the strategy come into play when the respective DRS involving the strategy is evaluated. For the evaluation of the DRS presented in figure 20, a sequence of basic actions needs to be identified from $\mathcal{B}$ leading to a time where the goal $\begin{array}{|c|}\hline \text{x,l} \\ \hline \text{AT(x,l)} \\ \hline \end{array}$ comes to hold. In our case, this is the sequence of basic actions $\langle x, \mathsf{strike\text{-}sail}, [t_1, t_2] \rangle$, $\langle x, \mathsf{throw\text{-}anchor}, [t_2, t_3] \rangle$, $\langle x, \mathsf{install\text{-}gangway}, [t_3, t_4] \rangle$, $\langle x, \mathsf{lie\text{-}off}, [t_4, t_5] \rangle$ and consequently the interval $[t_1, t_5]$.[39] The performance of these basic actions starting at the evaluation time t_0 brings about a change from $\begin{array}{|c|}\hline \text{x,l} \\ \hline \neg AT(x,l) \\ \hline \end{array}$ to $\begin{array}{|c|}\hline \text{x,l} \\ \hline \text{AT(x,l)} \\ \hline \end{array}$ at time t_5, which is a realization of the goal $\begin{array}{|c|}\hline \text{x,l} \\ \hline \text{AT(x,l)} \\ \hline \end{array}$. One may think of the realization of the goal as being caused by the installment of the gangway, as the goal condition comes to hold at the DRS representing the state of affairs at the time after $\mathsf{install\text{-}gangway}$ has been performed. Again, it has to be said that this is not the only way one may conceptualize the landing of a ship, but we assume

[39] Note that we rely on a conceptualization which singles out the basic actions belonging to a certain strategy.

$$\begin{array}{|l|}\hline x \ \mathsf{e} \ l \\ \hline \mathsf{E}\left\langle \mathsf{e} : call - at(x,l), x \ \mathbf{do}\left(\begin{array}{|c|}\hline \\ \hline \text{AT(x,l)} \\ \hline\end{array}\right)\right\rangle \\ \hline\end{array}$$

Figure 19: Lexical DRS representing the verb "call at"

$$\begin{array}{|l|}\hline x \ \mathsf{e} \ l \\ \hline ship(x) \\ Monkey - Island(l) \\ \mathsf{E}\left\langle \mathsf{e} : call - at(x,l), x \ \mathbf{do}\left(\begin{array}{|c|}\hline \\ \hline \text{AT(x,l)} \\ \hline\end{array}\right)\right\rangle \\ \hline\end{array}$$

Figure 20: The ship is calling at Monkey Island

that a "dummy conceptualization" delivers a prototypical meaning in terms of basic actions "calling at" involves. The representation in figure 20 is satisfied for the interval $[t_1, t_5]$. We can also construct the DRS stated in 20 with the use of the procedure stated in definition 26, as the interval $[t_1, t_5]$ satisfies the conditions for strategic explanation.

6.5 The ship is sailing to Monkey Island

For the treatment of example (6), the lexical DRS representing the entry for the verb "sail to" is shown in figure 21. For the basic concept behind the analysis of intentions proposed in this paper the reader is referred to chapter 5.5, where intentions appear as ascriptions to strategies, assuming the incidence of a goal which is not ensured at the time of evaluation and not explicitly mentioned in the natural language expression describing the strategy. The goal is nevertheless implied by the use of an intentional ascription to explain an agent's strategic behavior. Following definition 22 the evaluation of figure 22 requires that there exists a strategy $\mathbf{do}(K_1)$ such that the realization of the goal of the strategy brings about the intended states of affairs K_2. The strategy bringing about K_2 is the strategy of landing explicated in the previous example. This means that $\mathbf{do}\left(\begin{array}{|c|}\hline \text{x,l} \\ \hline \text{AT(x,l)} \\ \hline\end{array}\right)$ is a strategy, performed by the ship at the interval $[t_0, t_5]$ where the strategy consists of the basic actions $\langle x, \textsf{sail}, [t_0, t_1]\rangle$, $\langle x, \textsf{strike-sail}, [t_1, t_2]\rangle$, $\langle x, \textsf{throw-anchor}, [t_2, t_3]\rangle$, $\langle x, \textsf{install-gangway}, [t_3, t_4]\rangle$, $\langle x, \textsf{lie-off}, [t_4, t_5]\rangle$. Performing this strategy brings about the intended state of affairs at time t_4, which is in this case is equal to the goal of the strategy. It is also possible to construct a DRS as shown in figure 22 by applying the procedure stated in definition 27 to the interval $[t_0, t_5]$, which satisfies the conditions of executing an intentional explanation. Intuitively, choosing the right strategy, goal and intention is no trivial task for such a complex way of explanation but this illustrates the acuteness of a well-elaborated theory of prototypes in terms of basic actions, as mentioned several times above. Additionally, a theory of ability and know-how is required to model the structure of such complex tasks (which is given in e.g. (Singh, 1994)).

$$\begin{array}{|l|}\hline x\ \mathsf{e}\ l \\ \hline \mathsf{E}\left\langle \mathsf{e} : sail - to(x,l), x \,|\, \begin{array}{|c|}\hline \\ \hline \text{AT(x,l)} \\ \hline \end{array} \right\rangle \\ \hline \end{array}$$

Figure 21: Lexical DRS representing the explanation of the verb "sail to"

$$\begin{array}{|l|}\hline x\ \mathsf{e}\ l \\ \hline ship(x) \\ monkey - island(l) \\ \mathsf{E}\left\langle \mathsf{e} : sail - to(x), x \,|\, \begin{array}{|c|}\hline \\ \hline \text{AT(x,l)} \\ \hline \end{array} \right\rangle \\ \hline \end{array}$$

Figure 22: The ship is sailing to Monkey Island

7 Conclusion and Outlook

This paper has outlined a formal treatment of the pragmatic implications of Aktionsarten. Besides the points mentioned in this paper, this sketch can be fleshed out with respect to several directions of further research, for each of which a formal treatment of actions can bring about substantial efforts.

- A formal theory of pragmatics which is not concentrated on the analysis of speech acts but covers all aspects of pragmatics in the sense of a theory of action has not yet been developed. Especially the notions of know-how and ability need a formal treatment in order to capture the complex structure of an agent's performances.

- The same considerations hold for a formal theory of conceptualization which is needed for the proper understanding of the meaning of natural language expressions. First steps into this direction have been made in the framework of Lexical DRT (Kamp and Rossdeutscher, 1994).

- The analysis of the interaction of time, tense, action and the ascription of propositional attitudes such as intentions has not been addressed in this paper, but it is the topic of actual research in the framework of DRT (Kamp, 2005).

I hope that this paper has shown that action semantics and discourse semantics are natural companions depending on each other and that the analysis of the interplay between the cognitive instruments of explanation and natural language is a fruitful field of research.

A List of Coherence Constraints

For our model to capture the real physical world in an adequate way, we need to put some constraints on the model excluding unintuitive constellations. For further discussion, see (Singh, 1994, p. 28–37).

(1) **Unique ending of actions**
$\forall \mathsf{a} \in \mathcal{B}$, $\forall S$ and times $t_0, t_1, t_2, t_3 \in S$:
$[S; t_0, t_2] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x$ and $[S; t_1, t_3] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x$ implies that $t_2 = t_3$, if $t_0 \leq t_1 < t_2$.

(2) **Eternity**
The model provides a future time for every time:
$\forall t \in \mathbf{T} : \exists t' \in \mathbf{T} : t < t'$
Together with the maximality of scenarios, this is equivalent to the constraint that there is always some scenario along which the world can evolve:
$\forall t \in \mathbf{T} : \exists S \in \mathbf{S}_t : \exists t' \in S$ and $t < t'$.

(3) **Actions in progress**
We may speak of an agent performing an action at every time at which the action happens:
$[S; t, t'] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x \Rightarrow (\forall t'' \in \mathbf{T} : t \leq t'' < t' \Rightarrow [S; t'', t'] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x)$.

(4) **Passage of time**
Every individual is performing an action at every time:
$\forall t \in \mathbf{T}, \forall x \in Ind, \forall S \in \mathbf{S}_t : \exists t' \in S : \exists \mathsf{a} \in \mathcal{B} : [S; t, t'] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x$.

(5) **Reachability of times**
There are no models which include times that are only reachable by an infinite number of actions:
$\forall x \in Ind, \forall S, \forall t, t' \in S : t < t' \Rightarrow (\exists t_0, t_1 : t_0 \leq t < t' \leq t_1$ and $(\exists \mathsf{a}_1, ..., \mathsf{a}_n$ and $[S; t_0, t_1] \in \langle\!\langle \mathsf{a}_1 \cdot ... \cdot \mathsf{a}_n \rangle\!\rangle^x$ [40])).

(6) **Reality does not change**
The real scenario is the suffix for the actual scenario:
$(\forall t, t' \in \mathbf{T} : t' \in \mathbf{R}(t) \Rightarrow \mathbf{R}(t') \subseteq \mathbf{R}(t))$.

(7) **Atomicity of basic action**
The actions in the model are atomic, consequently we should split up an action that consists of several subparts:
$(\forall \mathsf{a} \in \mathcal{B}, x \in Ind, t, t', t_1 \in \mathbf{T} : t < t' < t_1 \Rightarrow (\forall S_0, S_1 \in \mathbf{S}_t : [S_1; t, t'] \subseteq S_0$ and $[S_1; t, t_1] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x \Rightarrow (\exists t_0 : [S_0; t, t_0] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x)))$

(8) **Weak determinism**
If two times satisfy the same DRS K describing the state of affairs, then the fragments of the model which is rooted in these moments have to be isomorph with respect to the temporal precedence relation and K: [41]

[40] Where $\cdot$ denotes a sequence of actions.
[41] The isomorphism is modeled by an order-isomorphism:

(a) Let L and L' be sets with an ordering relation $<$, then the mapping f from L to L' is an order-isomorphism iff
- f is surjective
- $(t \in L$ gdw. $f(t) \in L')$ and

$(\forall x \in Ind, \mathsf{a} \in \mathcal{B}, t, t', t_0 \in \mathbf{T}, S_0 \in \mathbf{S}_t : (t \sim t' \text{ and } ([S_0; t, t_0] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x) \Rightarrow (\exists S_1 \in \mathbf{S}_{t'}, t_1 : [S_1; t', t_1] \in \langle\!\langle \mathsf{a} \rangle\!\rangle^x \text{ and } [S_0; t, t_0] \approx [S_1; t', t_1]))).$

See (Singh, 1994, p. 33), (Emerson, 1990, p. 1014) for further information.

- $(\forall t, t_0 \in L : t < t_0 \text{ iff } f(t) < f(t_0))$

(b) $t \sim t'$ iff $\{\psi \in \phi | t \in \langle\!\langle \psi \rangle\!\rangle\} = \{\psi \in \phi | t' \in \langle\!\langle \psi \rangle\!\rangle\}$

(c) $L \sim L'$ iff $(\exists f : f$ is a order-isomorphism and $(\forall t \in L \Rightarrow t \sim f(t)))$

B Formal properties of intentions

This appendix is concerned with the interaction of intentions and concepts such as believe. To formally model believe, we identify the possibilities an agent may believe in with the set of possible alternative times (associated with a state of affairs) at a given time. Thus at first a function is defined to assign each individual alternative times. Syntax and Semantics of the believe-operator is given in definition 30 and 31.

Definition 29 *Assignment function for alternative times*

- ***B*** *assigns each individual at a certain real time alternative times.*

With **B**, it is possible to formalize the believes of an agent with the help of an operator:

Definition 30 *Syntax of the believe-operator*

- *If $x \in Ind$ and K is a DRS, then $x\mathsf{B}K$ is a condition.*

Definition 31 *Semantics of the believe-operator*

- $\models_{M,t} x\mathsf{B}K$ *iff* $(\forall t' : (t, t') \in \boldsymbol{B}(x)$ *implies* $\exists g : \ g \models_{M,t'} K)$

The formalization of the properties of intentions follows (Singh, 1994).

(1) **Satisfiability**
$x|K \rightarrow \mathsf{EF}K$
The intention K is satisfiable on some future time.

(2) **Temporal consistency**
$(x|K_1 \wedge x|K_2) \rightarrow x|(\mathsf{F}K_1 \wedge \mathsf{F}K_2)$
If an agent intends both K_1 and K_2, then he intends achieving them in some temporal order.

(3) **Persistence does not entail success**
$\mathsf{EG}(x|K) \wedge \neg K)$ is satisfiable.
Just because an agent persists with an intention does not mean that he will succeed.

(4) **Absence of closure under beliefs**
$x|K_1 \wedge x\mathsf{BAG}(K_1 \rightarrow K_2) \wedge \neg x|K_2$ is satisfiable.
Intentions are independent from believes.

(5) **Consistency with beliefs about reality**
$\neg(x|K \wedge x\mathsf{B}\neg\mathsf{RF}K)$
This constraint holds in the present of the following property:
$\models_{M,t} x|K$ implies $(\exists t' : (t, t') \in \mathbf{B}(x)$ and $\models_{M,w,t'} \mathsf{RF}K)$
An agent with an intention considers at least on alternative in which that intention is realized.

(6) **Entailment of belief in possible success**
$x|K \rightarrow x\mathsf{BEF}K$
Even though an agent may not believe that his intention will succeed, he should believe that it may succeed. This holds in presence of the following constraint:
$\models_{M,t} x|K$ implies that $(\forall t' : (t,t') \in \mathbf{B}(x) \wedge \models_{M,t'} \mathsf{EF}K)$

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