Situoid theory

An ontological approach to situation theory

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Abstract

Situations are entities that have been discussed in philosophy, ontology and computer science for applications in the field of knowledge representation, conceptual modelling and natural language semantic. On the basis of an extensive literature review, situations and entities we call situoids, which are more basic than situations, will be discussed and their ontological features investigated. As far as possible, the results of this investigation are formulated as axioms. This is done with respect to a background top-level ontology, the ontology of GOL. The belief that situoids are "parts of reality that can be comprehended as a whole" is central to this research, and will be investigated thoroughly. Situations as derived entities are not given as much attention, but some of their features will be discussed as well. While attempting to describe situoids, other categories have to be mentioned, such as states of affairs and infons. The theory is built up systematically from states of affairs over infons, situoids to situations. Some applications known from situation theory are revisited in the framework of situoids. Finally, it is shown how the theory if situoids can be used to introduce modality in GOL.

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[1] See `http://www.doaj.org`.

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1 Preface

Let me remark on some issues I found important before I start with the essence of this thesis.

This is essentially my first scientific writing. Five years of studying did not prepare me all too well for this task, but I still hope this work is worth reading.

I used English language, which is not my native language. I used it to practice writing in English, as I am willing to continue working in an English-speaking environment. Although this is not my first writing in English, it is the first of this size. Please accept occasional mistakes I made in the use of English language. Most sentences are short and trivial, compared to a scientific text or some other text of an English writer. Maybe you can see this as an advantage, and find it easier to read.

I will be using a plural form throughout this thesis, except in this chapter. So when I formulate some result, I will use “we”. I could have written this thesis using strictly passive phrases, but I find this hard to read. I did not want to use “I”, because this thesis is not about me, but about the ontology of situations and situoids.

Another remark: This thesis involved a lot of reading, and most of the articles I read were published in journals which did not offer their articles online for free. I would have loved to ignore these articles, but it was impossible, because this decision would have had a severly negative impact on my thesis. I was lucky, because I finally found a solution to access tons of articles online for free, but this was an exceptional case. Students who were not so lucky would have had less information for their thesis, or they would have paid lots of money to buy all those articles. And still, scientists all over the world continue to publish their research in journals which charge a fee for accessing their content. With hundreds of journals available today, any library, any institution, any person would have to spend unreasonable amounts of money to access all the information in these journals. This brings about a barrier to scientific knowledge. “Poor” institutions (for example in Third World countries, but also in countries like Germany) will not have the same possibilities as richer ones. Private people will find it almost impossible to access scientific information.

The solution to this is easy. Classical journals are obsolete anyway, in the meantime, since most journals offer their articles online. Because most of the time reviewers and members of the editorial board are working for free, it is just a simple step to creating an online, “Open Access” journal. Thousands are already available, with the same scientific standards (peer review, et cetera) as classical journals. The Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities[1], signed by representatives of most major scientific institutions in Germany and Europe, requests all scientists to support the use of Open Access journals. And still there are many scientists who refuse. The reasons vary. It may be found necessary to publish in more famous journals for the own scientific career, for own pride, because it is the usual way, or for the sake of more funding. The reasons may vary, but they are all flawed. The most important goal of all science is to gain knowledge for the sake of all of humanity. With the creation of a barrier to access of information for large groups of people, modern science becomes a hobby for a highly privileged guild of persons from First World countries. And more, scientific progress is slowed down by this kind of behaviour. Knowledge actually grows faster the more people share it. Please

[1] `http://www.mpg.de/pdf/openaccess/BerlinDeclaration_en.pdf`

consider using Open Access journals[2].

If you are a scientist publishing in classic journals, please do not feel insulted by my statements above, but read them critically. This is my own, private opinion, that arose out of the writing of this thesis and the discussions I had with other students facing the same problems as I did. This is the only relation this chapter has with this thesis, but I found it so important, I did not want to leave it out. This is also the only reason I wrote a preface.

[2] `http://www.doaj.org`

2 Introduction

Ontology has experienced a renaissance recently. In the past, it has been used as a term for probably the most fundamental branch of metaphysics, the study of being or existence, the most fundamental study of reality, the science of "being qua[1] being". In computer science it refers to the formalization of all the relevant entities, relationships and rules of a domain, usually in a hierarchical data structure. Ontologies are used in branches of artificial intelligence and knowledge representation. They can be used for inductive reasoning or classification, or the communication and sharing of information between different systems. Most ontologies in use today are limited to a single domain, like the Gene Ontology, that is limited to the domain of genes. Ontologies, that are not limited to specific domains are called Top-Level-Ontologies, Upper Ontologies or Foundation Ontologies. They try do define general entities in a general sense. This can be highly valuable for common sense reasoning or as a foundational background for domain specific ontologies. Some claim, that this leads to "semantic and ontological warfare due to competing standards", mostly due to different philosophical views on what exists. There are several projects that develop an Upper Ontology, one of them is the GOL[2] group in Leipzig with their GFO, General Formal Ontologies[3]. This work is a contribution to the General Formal Ontologies. Due to different fundamental, philosophical views, probably no Top-

[1] Qua means here "respectively" or "with regard to the aspect of".

[2] General Ontological Language

[3] We use plural, here, because the GOL group develops a set of ontologies with branch points, so that different philosophical views can be accommodated.

Level-Ontology will ever become a single, widely accepted standard, and even in this work there will be decisions made that contradict some of the decisions already made by the designers of the General Formal Ontologies. Some of them will be minor, and could or could not be integrated in GFO. Some may be more important, and as we will try to defend our decisions thoroughly, we encourage the GOL researchers to use our argumentation to improve their ontology framework. This is to say, that this thesis will not be limited by the decisions already made by the GOL group. If there is enough evidence to justify this step, we will argue in favor of philosophical views different to those expressed in the General Formal Ontologies.

2.1 Motivation

Consider the following statements.

1. "The situation at the beginning of the 100 meter race was the following: Alan is in start position one, wearing red clothes. Ben is in position two, wearing blue clothes. He is the favorite. Carlo and Denis are in position three and four."
2. "This is an embarrassing situation."
3. "The situation in Europe during 1914 and 1918 was critical."
4. "The situation in Europe in the year 1914 lead to the First World War."
5. "I would not have acted differently in the same situation."
6. "The situation on this x-ray shows, that the person that x-ray has been taken of had a broken leg."
7. "In the situation of a terrorist bombing, oil prices rise rapidly."

All those statements claim to be about situations. In the first, a situation is characterized by certain statements, facts, that are the case in this situation. The second statement assigns an attribute, being embarrassing, to a situation. The third does the same, but clearly extends the situation over an interval of time, 4 years, and a certain region, Europe. The fourth refers to a certain situation as the cause of an event. One can refer to this event also as a situation, as the previous example shows. The fifth example connects a situation with some action, that has been performed in it. The sixth example describes a situation, that somehow seems to involve another situation, the situation where some person broke a leg. The seventh example refers to a situation as an instance of some concept, some general idea of a situation, the terrorist bombing, and also asserts a fact to it.

These examples show, that the term "situation" is used in several different meanings. Just what are the similarities, that lead us to the usage of this term? What do all of the above mentioned references to situations have in common? These question have to be answered in order to characterize an ontological category of situations. As important as the similarities are the differences of the references to situations above. The main distinction will be between those, that have a temporal extension, and those without. We will call the first "situoids", the latter "situations".

The examples show another aspect. Obviously, situations can be used to describe parts of the real world. But there are other ontological categories that can be described using situations. We mentioned some of them, events and actions. Both have been discussed before, and are frequently used together with, sometimes synonymously to situations. An intense study of situations should help us in the investigation of both, events and actions.

The fourth example refers to a situation as a cause of some event, possibly another situation. The study of cause and effect has been going on for centuries. The relationship between cause and effect is called causality. A study of situations, that may be causes, or effects, may lead to better understanding of the concept of causality.

The first example somehow characterizes a situation, by stating facts, that is, relations between certain objects in the situation. What a fact is, how it behaves and how and in what way it can occur in a situation is another issue, that may be solved by a study of situations. Facts are closely related to states of affairs, and the nature of existence, the ontology of states of affairs has been debated for decades amongst philosophers, and in the process of an ontological investigation of situations, the ontology of states of affairs has to be reviewed, too.

The seventh example refers to some concept, a certain situation may be an instance of. These concepts are called "universals" in philosophy. They are general ideas of concrete existing or abstract entities, that are its instances, and they usually determine certain properties of its instances, for example the fact, that oil prices rise rapidly in a situation of a certain type. Universals have an impact on situations, and have to be investigated when situations are.

Example six has some interesting properties. Obviously, there is a described situation, an x-ray of some persons leg, but due to certain properties of this situation, information about some other situation is revealed, the situation where a person broke a leg. Situations appear to be able to carry the information of other situations.

Situations can be described in natural language. All the examples above show this as a fact. We could ask the question, whether there are situations that are not describable in natural language. And another question can be asked, too, whether or not we describe anything other than situations, whenever we express our thoughts in words. Also, all of the above examples have to be uttered. This utterance-situation may be viewed as a situation, that defines the context of the uttered statement. Can this be used to give meaning to consecutive sections of text, like a novel? The answer to these questions and therefore a theory of situations may give valuable insight in the semantic of natural language.

Finally, all the examples above may indeed have something in common; we refer to situations as to special parts of reality, parts, that can be comprehended as a whole. What this means, will have to be investigated first.

2.2 Objectives

The main objective of this thesis is an in depth analysis of situations as an ontological category. The category *situation* as well as all other categories needed to understand it, states of affairs, infons, actions or events, shall be investigated and the findings should be put in axioms as far as possible. These axioms should extend the axioms of the ontologies of GOL, or replace them if necessary. In the end, a theory of situations has to be developed within GOL or some modified version of GOL, which has at least the same expressive power as Situation Theory, a formalism developed by Jon Barwise and John Perry, for example in [Barwise, 1989]. To achieve this, Situation Theory and its axioms can be used as a background, but should be extended, altered or in parts rejected when necessary, in order to obtain a philosophically well founded description of the category *situation*. If parts of Situation Theory are copied into GOL, it has to be shown that these parts are appropriate.

Before situations can be analyzed, the more basic categories of *facts* or *states of affairs* have to be analyzed. It is believed that states of affairs can be viewed as basic information units, or infons, that are used to communicate information, or express information present in a situation. A category of facts does exist in GOL, but the instances of this category are not information units. Another objective of this thesis is to reexamine the GOL category of *facts* and analyze whether it is suited to be used together with the category of situations. If not, it has to be modified or extended accordingly.

In the analysis of situations, the concept of “being comprehensible as a whole” will be central. It has to be analyzed thoroughly, and, as far as possible, axioms have to be formalized for it, so it can be applied to different entities as well.

Other entities that may be related to situations, like universals, sets, processes, changes, etc. can be more thoroughly understood, and if adequate, some of their properties can be deduced from the properties of situations.

There are still some ontological categories or relations in GOL, that require clarification. Some are clearly understood and axiomatized, but GOL does not provide the means to specify an instance of this category. If adequate, this thesis will provide hints or solutions to some of these questions.

2.3 Structure of this thesis

First we will summarize the state of the art in the ontology and theory of situations in chapter 3. In section 3.1 we will introduce shortly situation calculus as it has been developed by McCarthy and Hayes. In 3.2 we will introduce situation theory as it has been developed by Barwise and Perry.

Chapter 4 gives an overview over ontology in philosophy and in computer science. Our reference ontology GOL will be introduced in this chapter.

Chapter 5 is the central part of this thesis. There we will develop our own theory of situoids and situations within the ontology of GOL. Section 5.1 will introduce infons, 5.2 situoids. Central to 5.2 is the discussion of comprehension, the relationship between parts and wholes and the relation of situoids to reality and worlds, but other properties of situoids will be discussed, too. The rest of chapter 5 discusses situations and their models, but some derived categories like processes and changes as well.

Chapter 6 discusses the theory that has been developed in 5. Two important applications are shown: How the theory can be used to give a semantic for natural language, and how it can be used to introduce modality into GOL. Later, some remarks are made concerning the similarities and differences to situation theory as developed by Barwise and Perry.

Chapter 7 is a review on the thesis. The contributions made are listed, and ideas for future research are given.

3 Situation Theories

The concept of "situation" has been known in computer science for several years. A simple approach is known as situation calculus, and although it is useful for several applications, it is quite weak in an ontological sense, and we will discuss situation calculus only short. Later, in the 1980s, situation theory or situation semantics has been developed, and it is a rich theory, and the basis of our work, so we will discuss it in length.

3.1 Situation Calculus

A simple approach to capture information about situations is situation calculus. It is due to John McCarthy and Pat Hayes[McCarthy and Hayes, 1969]. In situation calculus, the world consists of a series of snapshots, situations. Every situation is created from the previous by a series of actions. Relations and properties are noted with a separate situation argument.

$$R(x_1, ..., x_n, S_0)$$

Properties subject to change are called **fluents**.

Changes from one situation to another are modeled using a function, $Result : Action \times Situation \mapsto Situation$. The atomic predicate $Holds(f, S)$ is true, if the fluent f is true in the situation S.

Actions are described by stating their effects. Therefore **effect axioms** have to be stated, describing the properties of a situation that results from doing some action. However, this is not enough. One also has to state axioms describing a situation after *not* performing an action. Those are called **frame axioms**. Frame axioms have to be stated for every fluent and action. Another solution is to use a **successor-state axiom**. This axioms states, that a fluent is true after some action, if an action made it true or it has been true and no action made it false.

This is a very weak theory of situations. The world consists of a series of snapshots, that are complete on its own. There is no development within a situation, since they do not have a duration. We shall therefore turn our attention to a more complex theory of situations.

But first, let us consider an example. We want to open a bottle of beer, smell the beer and after that we drink the beer. So the fluents we have to consider are $closed(x)$ and $empty(x)$, the actions will be $Open$ and $Drink$.

We start off with the beer closed and not empty.

$$Holds(closed(beer), S_0)$$

$$\neg Holds(empty(beer), S_0)$$

Now we want to perform the action of opening the beer, ending up in a new situation.

$$S_1 = Result(Open(beer), S_0)$$

However, this does not do anything yet. We have to put some knowledge about our $Open$ action in our theory, our first effect axiom.

$$\forall x, S\,(Holds(closed(x), S) \rightarrow \neg Holds(closed(x), Result(Open(x), S)))$$

Now

$$\neg Holds(closed(beer), S_1)$$

is true and our beer is no longer closed. But before consuming the beer we would like to smell it first, because we are in another country and do not trust their ability to brew beer after German purity law[1].

$$S_2 = Result(Smell, S_1)$$

There is no fluent changed here, because the smelling is rather a symbolic act, we cannot smell the ingredients anyway.

After we finished this ritual, we finally want to drink the beer, ending up in a new situation.

$$S_3 = Result(Drink(beer), S_2)$$

We need some effect axioms too. We can only drink an open, not empty beer. And after we finished drinking, the beer is empty.

$$\forall x, S\,(\neg Holds(closed(x), S) \land \neg Holds(empty(x), S) \rightarrow Holds(empty(x), Result(Drink(x), S)))$$

Now the question is, if

$$Holds(empty(beer), S_3)$$

is true. Oddly, it is not. Since there is no axiom saying otherwise, the beer could have closed itself while we were smelling the beer. The beer could have been closed already in S_2. Even worse, the beer could have emptied itself at any time! We have to add some frame axioms about things, that do not change, if some

[1] In fact, before this law has been put in place 1516, some fatal accidents with beer brewed using daturia plants have occurred, and we do not want to take this risk.

action is done. If the beer is empty or open, then there is no way to undo this.

$$\forall a, x, S\ (Holds(empty(x), S) \rightarrow Holds(empty(x), Result(a, S)))$$

$$\forall a, x, S\ (\neg Holds(closed(x), S) \rightarrow \neg Holds(closed(x), Result(a, S)))$$

Now we have to state, that the bottle only open when we open it, and, more important, that the only way it will get empty is, when we consume it.

$$\forall a, x, S\ (Holds(closed(x), S) \wedge a \neq Open \rightarrow Holds(closed(x), Result(a, S)))$$

$$\forall a, x, S\ (\neg Holds(empty(x), S) \wedge a \neq Drink \rightarrow \neg Holds(empty(x), Result(a, S)))$$

Now our beer will be empty in S_3, but not before that.

3.2 Situation Theory

Jon Barwise and John Perry developed in [Barwise, 1981] and [Barwise and Perry, 1981] a theory of situations, which we will call "Barwisean situation theory". The goal of this section is to outline the major properties and results of the Barwisean situation theory.

Situation theory is a mathematical theory of meaning, supposed to be a semantic for natural language. In it, the world consists of individuals, properties, relations, spatio-temporal entities, and situations.

A basic assumption in Barwises situation theory is that everything used in the theory can be objectified and treated as an object of the theory, especially situations, relations, operations, conditions, parameters.

3.2.1 Relations

Relations in situation theory can be treated as objects. In [Barwise, 1989], Jon Barwise states:

> Relations are the glue that holds things together, the primary constituents of the facts that go to make up reality. Any relation we use in the theory can also be objectified and treated as an object of the theory.

As in first order logic, every relation R has arguments. Since situation theory is designed to capture information about reality, restrictions on the kind of arguments certain relations can take have to be imposed. Barwise takes a notion of appropriateness between relations and the objects, that can serve as their arguments, as given. In later versions of situation theory, roles take this place.

There is no reason to assume, that the arguments are in a predefined order. Therefore an *assignment* is a function a assigning objects to some arguments of the function. It is not necessary to fill all argument places with objects. Although it is convenient for us to assume, that all argument places are filled by appropriate objects, there is no reason to justify such a step. Consider the relation of **eating**. This relation takes at least three arguments: the eater E, the food eaten, F, and a space-time-location t where the eating takes place. Let $eating(E,F,t)$ be this relation. However, even if we do not know the food eaten, F, it still makes sense to issue a statement, that E is eating at t. The classic approach to this statement in logic would be the proposition $\exists x(eating(E,x,t))$. If we want to model information expressed in natural language, there is no reason to state $\exists x(eating(E,x,t))$ from the sentence "E is eating at t". We take an assignment a filling only the role of the eater and the space-time-location, and leaving the food unassigned: $eating(E,x,t)$, or sometimes $eating(E,t)$.

3.2.2 Infons

Let us now consider information. Information is built up from basic information units, states of affairs or infon.

Definition 3.1 (Infon, Polarity, Major Constituent, Minor Constituent). A relation R and an appropriate assignment a of objects determine two basic infons. The notion of these infons is $\langle\langle R, a; 1\rangle\rangle$ and $\langle\langle R, a; 0\rangle\rangle$ or, in case the arguments have been ordered, $\langle\langle R, a_1, ..., a_n; 1\rangle\rangle$ and $\langle\langle R, a_1, ..., a_n; 0\rangle\rangle$. Let $\phi = \langle\langle R, a; i\rangle\rangle$, then R is called major constituent of ϕ, each $a_{arg} \in Arg(R)$ is called a minor constituent of ϕ and the value $i \in \{0, 1\}$ is called the polarity of ϕ. Basic infons with polarity 1 are called positive, with polarity 0 negative.

A basic infon that obtains is called a fact. Given a relation R and an appropriate assignment a, at most one of the defined basic infons obtains. We write $\models \phi$ for a basic infon that obtains.

3.2.3 Axioms of situation theory

We will give a brief summary of the axioms of one of the later versions of Barwisean situation theory, without much motivation and explanation, mainly to refer to them later. For a complete discussion, see [Barwise, 1989].

Axiom 3.1. Every relation is the major constituent of some basic infon, and everything is a minor constituent of some basic infon.

Axiom 3.2. If $\phi = \langle\langle R, a; i\rangle\rangle$ and $\phi' = \langle\langle R', a'; i'\rangle\rangle$ are basic infons, then $\phi = \phi'$ iff $R = R'$, $i = i'$ and $a_{arg} = a'_{arg}$ for each argument arg of R.

Axiom 3.3. Given an n-ary relation R and an appropriate sequence a of arguments for R, either $R(a)$ or $\neg R(a)$, but not both. $R(a)$ iff $\models \langle\langle R, a; 1\rangle\rangle$; $\neg R(a)$ iff $\models \langle\langle R, a; 0\rangle\rangle$.

So far we can only talk about basic infons. Axiom 2 states under which circumstances we will consider basic infons identical, namely when they are identical item by item. However, infons are supposed to capture information, so they may be informational equivalent, although they are not identical item by item. Furthermore, given two basic infons, one might be stronger than the other, so that one infon is entailed by the other.

Axiom 3.4. Let ϕ, ϕ', ϕ'' be infons. Then $\phi \Rightarrow_l \phi$ and if $\phi \Rightarrow_l \phi'$ and $\phi' \Rightarrow_l \phi''$ then $\phi \Rightarrow_l \phi''$. If $\phi \Rightarrow_l \phi'$ and ϕ is a fact, then so is ϕ'.

Axiom 3.5. Let a and a' be appropriate assignments for R, and a is a subassignment of a'. For $i \in \{0,1\}$, let $\phi_i = \langle\langle R, a; i\rangle\rangle$ and let $\phi'_i = \langle\langle R, a'; i\rangle\rangle$. Then $\phi'_1 \Rightarrow_l \phi_1$ and $\phi_0 \Rightarrow_l \phi'_0$.

Axiom 3.6. Every set of infons Σ has a least upper bound (concerning $\Rightarrow_l$) $\bigwedge \Sigma$ and a greatest lower bound $\bigvee \Sigma$. $\bigwedge \Sigma$ is a fact iff each infon in Σ is a fact, $\bigvee \Sigma$ is a fact, iff some infon in Σ is a fact.

Axiom 3.7. The basic infons $\phi = \langle\langle R, a; i\rangle\rangle$ and $\phi' = \langle\langle R, a'; i\rangle\rangle$ are compatible iff a and a' are compatible as functions. Then $\phi \oplus \phi' = \langle\langle R, a \cup a'; i\rangle\rangle$.

Now, for the first time, we will consider situations. A situation is "a part of reality that can be comprehended as a whole in its own right – one that interacts with other things."[Barwise, 1989] They relate to other things of the world in the sense, that they stand in relation to other things, or have properties.

$\models$ is a binary relation, holding between situations and infons. $s \models \phi$ means "ϕ holds in the situation s".

Axiom 3.8. An infon ϕ is a fact iff there is a situation s such that $s \models \phi$.

Axiom 3.9. A situation s_1 is a part of a situation s_2, $s_1 \triangleleft s_2$, if $\{\phi | s_1 \models \phi$ and ϕ is a basic infon$\} \subseteq \{\phi' | s_2 \models \phi'$ and ϕ' is a basic infon$\}$. If $s_1 \triangleleft s_2$ and $s_2 \triangleleft s_1$, then $s_1 = s_2$.

Therefore the part-of relation between situation is a partial ordering.

Barwise takes the axioms now a step further and defined some kind of interpretation for situations by stating the relation between sets and situations.

Axiom 3.10. Every set F of facts determines a smallest situation s such that for every $f \in F : s \models f$.

Axiom 3.11. Every set is the set of constituents of at least one situation.

The last axiom brings in models of situations.

Axiom 3.12. There is a unique operation M taking values in the sets satisfying the following equations:

- if b is not a situation or infon, then $M(b) = b$.
- if $\phi = \langle\langle R, a; i \rangle\rangle$, then $M(\phi) =< R, b, i >$ (a state model), where b is the function on $dom(a)$ satisfying $b(x) = M(a(x))$.
- if s is a situation, then $M(s) = \{M(\phi) : s \models \phi\}$.

3.2.4 Situation theory and set theory

Barwise and others do not believe that standard set theory (ZFC[2] or others) is sufficient for modeling situations. Instead, the use of an anti-foundation-axiom set theory is recommended. Aczel has developed a set theory based on ZFC, but replacing the foundation axiom. In set theory, every set can be pictured by a graph. A graph is well-founded if it has no cycles or infinite paths, non-well-founded otherwise. Aczels anti-foundation-axiom states, that every graph, well-founded or not, pictures a unique set. For a complete discussion, see [Aczel, 1988], [Pakkan and Akman, 1994-1995].

[2]The axiom system of Zermelo-Frankel with the axiom of choice.

Reasons for choosing ZFC-AFA to model situations are some inherently circular situations, especially while modeling common knowledge. Considering the situation s, where John is kissing Mary, $s \models \langle\langle kiss, John, Mary; 1\rangle\rangle$ and $s \models \langle\langle kiss, Mary, John; 1\rangle\rangle$ holds. If you could ask John whether he knows, if he is kissing Mary, he would certainly agree, so

$$s \models \langle\langle knows, John, \langle\langle kiss, John, Mary; 1\rangle\rangle; 1\rangle\rangle$$

and the same for Mary. If you ask Mary, whether she knows that John knows that he is kissing her, she would agree too, and so on. A finite infon cannot capture all the information in this situation. The fact that John is kissing Mary is known to both, John and Mary, it is common knowledge amongst them and it is also common knowledge that it is common knowledge, and so on. We call the above approach of capturing common knowledge the *iterate approach*. It can be understood and modeled without the use of hypersets.

Another way to capture common knowledge is the *fixed-point approach*. Let ϕ be the fact that John is kissing Mary. Then the fact $\tau = \langle\langle know, \{John, Mary\}, \phi \wedge \tau\rangle\rangle$ captures the information that both know ϕ and both know this is common knowledge between them. Note that τ is a constituent of itself.

The third approach to common knowledge is the *shared situation approach*. The situation s where John is kissing Mary is modeled by

- $s \models \langle\langle kiss, John, Mary; 1\rangle\rangle$
- $s \models \langle\langle kiss, Mary, John; 1\rangle\rangle$
- $s \models \langle\langle know, John, s; 1\rangle\rangle$
- $s \models \langle\langle know, Mary, s; 1\rangle\rangle$

In this approach the situation s is a constituent of itself. If we take sets as models for situations, the set s_S should be a member of itself.

3.2.5 Discussion of Barwisean situation theory

Let us review some of the decisions made by Barwise in his development of situation theory.

First we note, that there is some kind of appropriateness between relations and the arguments of those relations, that make up infons. Barwise did not give a formal definition of what is meant by *appropriateness*. Intuitively, while formalizing knowledge about a given situation, a human designer has an understanding of what is meant by it. However, an intelligent agent in general does not see the difference between $\models \langle\langle eat, Alice, meat; 1\rangle\rangle$ and $\models \langle\langle eat, Alice, 23; 1\rangle\rangle$ without further knowledge. What certainly is needed is some kind of representation of what categories of objects exist in our world, and what categories a certain relation can take as its arguments. Understandingly, this goes far beyond the scope of situation theory, and we will discuss this in chapter 4.

Also, it is not enough that $\langle\langle eat, Alice, 23; 0\rangle\rangle$ should hold, but that $\langle\langle eat, Alice, 23\rangle\rangle$ can never be true, it should not be considered an infon at all. A state of affair or infon of this kind should be considered nonsensical (in the spirit of Wittgenstein).

On the other hand, if we consider an algebra of infons permitting conjunction or disjunction of it, we have to decide whether we want to consider infons of the kind $\langle\langle R, x_1, ..., x_n; 1\rangle\rangle \wedge \langle\langle R, x_1, ..., x_n; 0\rangle\rangle$ infons. Our intuition behind calling infons *infons* was that they capture information. Infons of this kind, contradictions or tautologies, do not contain any information at all. Of course they are false (or true) in every situation, but they are not about situations at all. We do not want to consider these as infons either. Infons, in our approach, contain information about situations or the world, they are *meaningful*. There must be a possible situation for any infon to hold, and another possible situation for an infon to not hold. Otherwise we will not consider them infons at all.

Barwise refers to spatio-temporal entities in his approach, but never clarifies what he means by it. It is not obvious whether he understands situations as having a duration no matter how short, or if he allows them to exist only at an instant, a point in time, or both. He states that they exist in time and space, therefore they occupy space, but whether the space (or the time) have to be connected, is unclear. After all, even the most basic structure of space and time is unclear. Is time and space unlimited? Are they dense? Or linear?

Perhaps he did not want to commit himself to such fundamental decisions, and leave it for further work, or for any applicant of situation theory to decide. However, we argue that the structure of situations cannot be understood without a theory of time and space. One way to complete situation theory with a theory of space and time is to use some existing theory of it and add its axioms to the ones of situation theory, and state an appropriate relation between both, situation theory and the preferred theory of time and space. This appears to be promising, because one could alter the axioms of time and space and compare their expressive powers.

We will argue later, that there is an ontological difference between situations that have a durations and those, that exist at a point in time. Therefore, we will consider only one theory of time and space, the theory used in the GOL ontology, sometimes called *glass model*.

Probably the most difficult task in amending situation theory is to define some conditions for a situation to be called "situation". Barwise refers to some closure conditions occasionally, but never states one of them.

Let us consider an example. John is kissing Mary, while laying on a bank in a park. This situation is taking place at a certain time t, and a certain place s. We certainly want to consider this a situation. Let us imagine now the same situation, but with the bank gone. Both of them are still laying, but the bank is outside our situation. So it seems as if they were floating in the air, about 75 cm above the ground. One might argue that this is impossible, and therefore should not be considered a situation at all. On the other hand, it is a part of reality, and maybe we only need to consider the information that John is kissing Mary while laying, at a certain spatio-temporal location, and they are about 50 centimeter above the ground. If we know about gravity and the mass of John and Mary, we could argue that there has to be some force keeping them above the ground, but do not know what this force is.

Also, more abstract, we could ask if a set can be viewed as a situation. The elements of a set may stand to each other in certain relations, and the set is some whole entity. What if the set is infinite? Or undecidable?

So we could try to find some kind of closure conditions situations have to fulfill. We will attempt this later when we introduce our ontology based situation theory.

4 Ontology

4.1 Ontology in Philosophy

Aristotle was a Greek philosopher, living from 384BC-322BC. He wrote a number of books that were called the *Physics*. His works were organized in such a way, that there was another set of books right after the *Physics*. The content of those books was a basic, fundamental area of philosophical inquiry, and did not have a name at this time. Some of Aristotle's scholars gave those books the name "ta meta ta physika", meaning "the (books) after the physics". Therefore the name "metaphysics" has been created.

Nowadays, metaphysics is the name of a branch of philosophy, concerned with the study of the most fundamental concepts, like being, relation, space, time, causation or existence. Ontology is *the most fundamental* branch of metaphysics. It is concerned with the study of being and existence, and the basic categories of them. Aristotle described ontology as "the science of being *qua* being", the science of being respectively being. It determines the categories of "beings", and decides whether and in what sense the elements of those categories can be said to "be".

Some examples of ontological questions are: What is existence? What are physical objects? Is existence a property? When does an object go out of existence, as opposed to merely changing?

Some of the basic problems of ontology is the problem of substance and the problem of universals.

4.1.1 Universals

Let us observe the sun, an orange, a lemon, a banana, and a yellow car. We could ask, whether all of those things have some thing in common, something we would call “yellowness”. Is there an individual being such as “yellowness”? There are two beliefs among philosophers, and the problem of universals is deciding, which is right. Platonic realists believe, that there is some nonphysical being called “yellowness”, that stands in some relation to all yellow objects. This being is a “universal”. The opposing view is the one of nominalists, which believe, that there is no such thing and that all yellow objects have nothing in common except being called “yellow”. Therefore they get the name “nominalists”.

It is agreed that universals have to satisfy at least the following conditions:

- Universals can be multiply instantiated.
- Universals are abstract.
- Universals are the referents of general terms.

Platonic realism

In Platonic realism, universals exist “in a realm”, that is separate from space and time. According to this belief, universals are not ideas in someones mind, they are not mental entities at all. One way to see Plato’s universals is as “archetypes”, as original models, and particular objects are copies of those models. A specific banana is a copy of bananeness, the specific yellow of a yellow car is a copy of yellowness. Another way objects and universals might be related is that objects "participate" in the universals, or the universals are "inhered" in the objects.

In Platonic realism, some universals are not instantiated at all, although they *could* be instantiated. Exactly how particular objects instantiate a universal is a basic problem of Plates theory.

If we think of yellowness in general, we think of the universal "yellowness", not of a particular yellowness of some object. But how the concept of "yellowness", an entity that exists neither in space nor in time, came to our mind, is another problem that has to be solved in the theory of Platonic realism. Plato's answer was quite simple: We were all born with "a priori" knowledge of a wide variety of concepts.

Despite a lot of criticism, Platonic universals seem to capture the meaning of general term, like "yellowness" or "bananáness", well. When we speak of something yellow, it is convenient to think of it as something outside of space and time, but which has a lot of instances.

Aristotle's universals

Aristotle had a similar, but in several points distinct view on universals. He believed, that universals are simply types, properties or relations that are common to their various instances. Universals exist *in* their instances, they exist only when they are instantiated. They exist only *in re*, in things, never apart from them. Therefore, an universal is something identical in each instance. All yellow things have something in common, namely their "yellowness". There is no universal "yellow" apart from any yellow thing. On the contrary, in all yellow things there is the same universal, "yellowness". Thus universals do exist in space and time.

Aristotle's universals can be multiply instantiated. The same universal appears in each of its instances. This may seem confusing at first, saying that exactly the same thing exists *in* multiple objects all over the world. We have to keep in mind that universals are non-physical objects, and there is no reason to believe, that universals behave like physical objects.

How do we form concepts according to Aristotle? We *abstract* from a lot of instances. Thereby we pay attention to a quality all instances have in common. So by focusing on the common quality a bunch of bananas and some yellow cars and a lemon have in common, namely the same universal, "yellowness", we form the concept of "yellowness".

When we refer to "yellowness", we do not simply refer to "all yellow things", but rather to some quality, all yellow things have in common.

Nominalism

Nominalism is the believe, that no universals exists, no abstract properties, relations or types, but only particular things. Everything that does exist exists in space and time.

Some nominalists belief, that only general terms or names exists – but no qualities they refer to. A general term refers to a specific object or a collection of objects. So if we talk about "yellowness", this might refer to a specific banana, a collection of some bananas and lemons and cars or the collection of all yellow things on the world.

If we consider 20 beer, then all they have in common is that they are "called" beer, but no quality of just being "beer". However, there must be a reason for calling a certain beer "beer". It is the ingredients, hop, malt, water, the taste, the aroma, the color, the look, that lets us identify a beer. The question nominalists have to answer is, why beers appear to have certain qualities in common, although they do not.

If we refer to the yellowness of a banana, we certainly do not refer to the banana itself, but to the property of being yellow. Nominalists deny the existence of instances of properties or relations. However, even if we cannot experience an abstract thing like "yellowness", at least we can experience an instance of it. How this is possible is another question that has to be answered by nominalists.

There are some weaker forms of nominalism, namely imaginism and conceptualism. Both still deny that universals exists. Imaginism is the believe, that "universals" are pictures in mind. One can picture a banana in mind, the look, the smell, but it does not mean, that it is a concept of what a banana really is. Conceptualism is the view that universals are concepts and individual objects are instances of concepts in mind.

Another and the last here mentioned approach to nominalism is called "ostrich nominalism". In sentences as **a** is F, ostrich nominalism takes **a** alone to be the truth-maker for these sentences. Asked why two bananas are both called banana, an ostrich nominalist would answer that they both do not have any entity in common, but however are both bananas, one cannot analyze further.

4.1.2 Substances

Another question in ontology is what we call objects, or object-hood. There are two main theories: objects are either *substances*, which are in some way distinct from their properties and relations, or they are nothing more than a *bundle* of their properties. This problem is called the *problem of substance*.

Bundle theory

Bundle theory is based on the believe, that objects are nothing more than their properties and relations. Taking away the properties or relations means taking away the object itself. In particular, there is no substance, that these properties inhere in.

Followers of this theory argue, that whenever we describe an object or imagine an object, we image or describe a property or relation. There is nothing we can imagine about any object that is not property or relation. In particular is it impossible to imagine some substance without any properties or relations.

However, since objects are nothing more than bundles of properties and relations, the question comes to mind, what ties those properties together. Since there is no substance they inhere in, some thing has to keep them together, bound to one object. They may just be conceived as a collection, a set, a bundle, but what puts them in this collection, is a question that has to be answered by followers of this theory.

Substance theory

Substance theory is the view, that objects are something over and above their properties. In substance theory, substance can exist or be distinguished from their properties and relations. Even if it is impossible for the substance not to inhere anything, we can speak of it as a separate being.

If we attribute a property to an object, like “a banana is yellow”, there is a subject, the banana, and we say of it that it has a property, being yellow. It makes no sense to speak of yellowness alone, without any subject. We therefore refer to a substance, and attribute it with a property. Whatever a property is of is the substance.

Another problem of substance theory is the inherence relation. For an object to have a property is definitely different than the property being a part of the object. So the question is, what this inherence relation between substances and properties actually is. A common answer to this is that inherence is a primitive concept: it cannot be explained any further, but it does not have to be explained further, too. One can understand inherence a priori.

Substance theory refers to some things without properties, bare objects. But whenever something comes to our mind, we think of some property or relation of it. It is absolutely impossible to find a bare object somewhere in the world. And we do not have any notion at all for such objects.

4.2 Ontology in computer science

Ontology in computer science is distinct from, but similar to ontology in philosophy. While ontology in philosophy is the study of existence in general, in computer science, “an ontology is the attempt to formulate an exhaustive and rigorous conceptual schema within a given domain, a typically hierarchical data structure containing all the relevant entities and their relationships and rules within that domain.”[The Internet Community]

Usually, while constructing a knowledge base for a certain domain, the designer has to restrict herself to a fixed vocabulary, some basic concepts, on which all other terms are based. This terminology is called an (domain specific) ontology. In this ontology, the relationship between those concepts will have to be specified. Important relations are $is-a$ and $part-of$.

After the concepts for one domain have been specified, the used concepts can be abstracted. Considering a domain for medical research, one concept could be *disease*. But a disease can also be considered some kind of *process*. A *blood* *sample* with a certain *blood type* could be viewed as simple *matter* or some *substance* with a *property*.

Every domain specific ontology can be abstracted, until no further abstraction seems possible. The result will be a terminology of the most fundamental categories of being, and a description of the relations thereof. This is called a top-level ontology. The question arises, if all domain specific ontologies converge to the same top-level ontology.

Before considering the main top-level ontology for this work, “General Formal Ontology”, let us review some existing ontologies.

4.2.1 KR Ontology

The KR[1] Ontology has been developed by John F. Sowa in [Sowa, 2000]. A graphical representation of the top-level categories and their connection can be seen in figure 4.1. Sowa established seven primitive categories: Independent, Relative, Mediating; Physical and Abstract; Continuant and Occurrent. The twelve categories in the center of figure 4.1 are each generated by three of the basic categories, one of each group.

Additionally, there are two general types, $\top$ and $\bot$. $\top$ is the super-type of all types, and all individuals are instances of $\top$. $\bot$ is a subtype of all types and no individual is an instance of $\bot$.

Abstract is information without any carrying entity. It exists outside of time and space. No matter the physical encoding of information, whether paper or bits or a verbal report, the same entity, the same information exists in all of them, and it is an **abstract**. **Physical** is an entity that exists in space and time. **Independent** is an entity that exists independent of any relationships to other

[1] KR stands for Knowledge Representation.

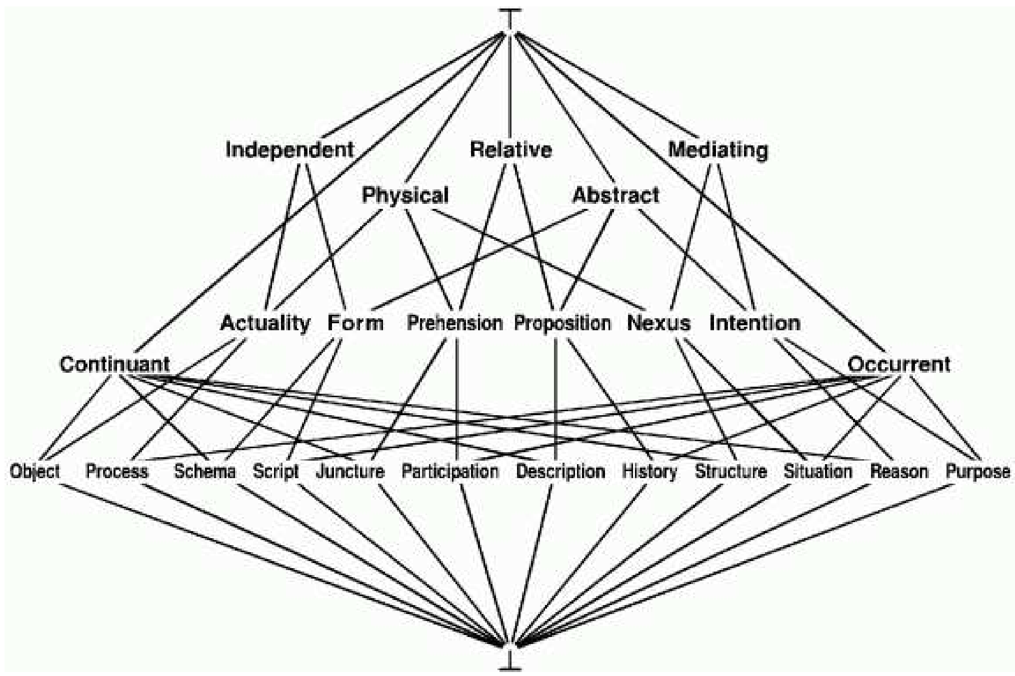

Figure 4.1: Hierarchy of Top-Level categories in KR Ontology

entities. Therefore the characteristic feature is some kind of firstness. **Relative** is an entity that has to be in relationship to some other entity to exist. **Mediating** is an entity, that brings other entities into relationship. An example is “John is kissing Mary.” Then there exists an individual kiss, bringing John and Mary into relationship. Mediating is therefore characterized by some kind of thirdness. A **Continuant** or **Endurant** is an entity that exists over some period of time. It exists in space, but has no temporal parts of its own. At any point of time where the entity exists, it exists as a whole. A **Occurrent** has temporal parts, that are called stages. It may exists on different places during different stages. A lifetime may be considered an occurrent.

We do not want to describe all of KR Ontology, so let us now consider the relevant concepts needed to gain an insight on situations in the KR Ontology.

An **Actuality** is an independent physical entity. The term is due to Whitehead, and is the same as Aristotle’s ousia or Descartes’ res vera. Instances are objects and **processes**.

Processes

Processes are occurrents, physical entities and they are independent of any other entity. They can be described by two points in time, the starting and end point of the process, and the changes that occur in this time interval. Figure 4.2 shows a further distinction of processes. In a continuous process changes take place continuously. An example is again an electron moving through space. In a discrete process changes occur only after some time. The time interval between two changes is called a **state**. The change is called an **event**.

Continuous process are distinguished in three different kinds, **Initiations**, **Continuations** and **Cessations**. In the first kind, an explicit starting point can be given. An example is a marathon. In the latter an ending point can be explicitly

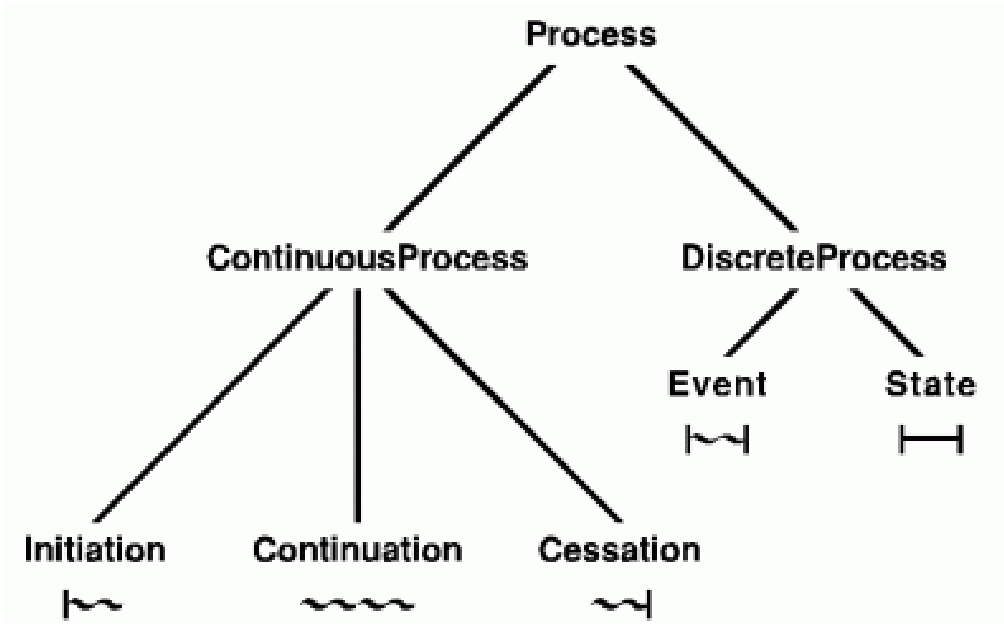

Figure 4.2: Hierarchy of Processes in KR Ontology

stated. An example might be an execution. In Continuations neither a starting nor an end point is relevant. An example is an electron moving through space.

A **Nexus** is a physical entity, mediating some other entities. It consist of a bundle of prehensions, like the participants of a process.

In the KR Ontology, a **Situation** is a Nexus considered as an occurrents. It mediates the participants of a process[2]. It is therefore similar to a **Structure**, which is a Nexus considered as an endurant. A Structure mediates multiple objects, whose joint constitutes the Structure. To imagine a Situation better, consider a marathon. A marathon is a process, and there are some kind of participants, a route, a landscape, weather. Then a situation is some kind of entity that holds all those things together, the time, the space, the process and all entities involved.

[2]Remember that a process can have different participants in its different stages.

This view on situations does not lead to a theory of situations as in [Barwise, 1989], and we will take another position later in this thesis.

4.3 General Formal Ontology

The General Formal Ontology (GFO) has been first introduced in [Degen, Heller, Herre, and Smith, 2001]. A lot of work is going on and several modification and amendments have been made since the first version of the General Formal Ontology appeared. The most recent version and the one used in this work will be [Heller, Herre, Burek, Loebe, and Michalek, 2004a], although some parts of this thesis are based on [Heller, Herre, Burek, Loebe, and Michalek, 2004b], an older and unofficial version of GOL.

GFO is the ontology of GOL, the General Ontological Language from the same research group in Leipzig. The purpose of the ongoing effort is to create a formal framework that can be used to create domain-specific ontologies. The foundation of this will be a set of top-level ontologies, that can be used in this framework.

Since this work is supposed to be more theoretical in nature, we will focus on the set of top-level ontologies used in GOL, the General Formal Ontology. GFO defines a set of categories, that remain unaltered in every ontology of GFO. However, one can choose between different axiom-systems.

4.3.1 Categories of GOL

Figure 4.3 shows the categories that are used in the GFO. Categories are collections of entities with a certain intension. If an entity is an instance of a certain category, then it has certain properties due to membership in that category. Let a be an entity, and X a category. We will write $a :: X$ if a is an instance of X.

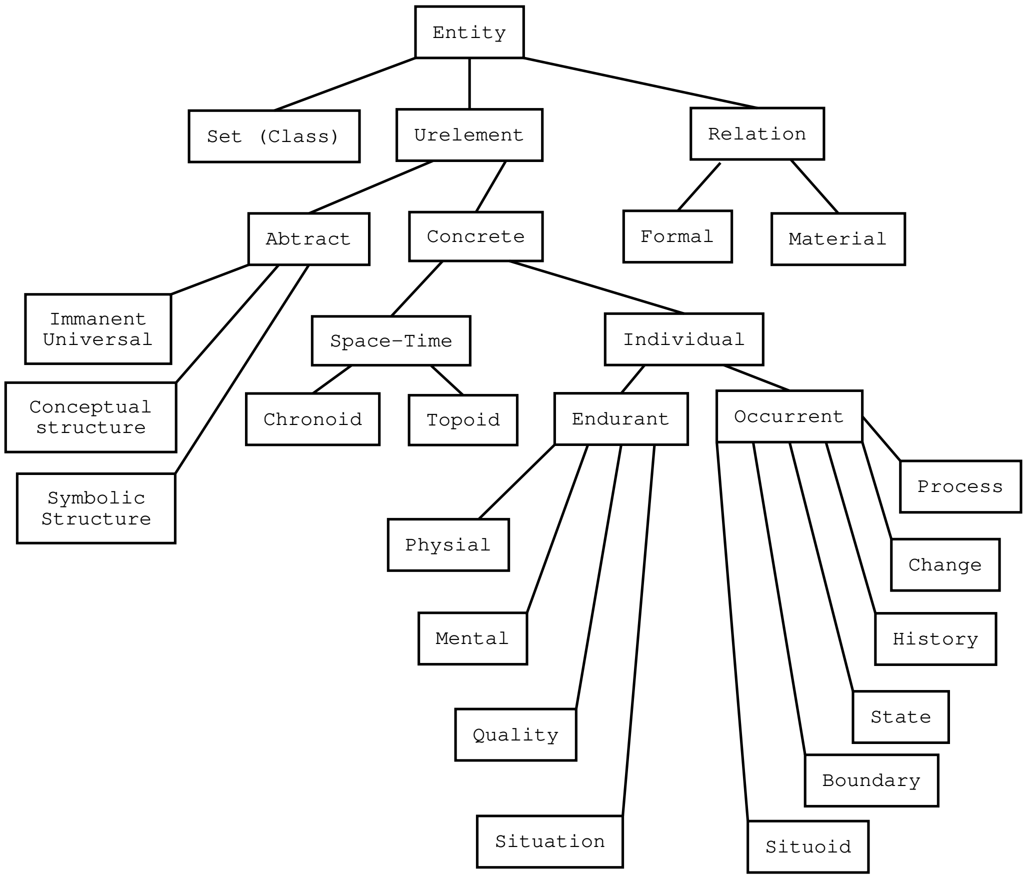

Figure 4.3: Hierarchy of Categories in GOL

As usual, we can also write $a \in X$ if we mean, that a is a member of the set X. However, intensionality is lost in the use of sets. Still, there is some relation between sets and categories:

Definition 4.1 (Extension of a category). The extension of a category C is the set $X = Ex(C) = \{x | x :: C\}$.

A category is any of the broadest classes of "things", where "thing" here means anything that can be discussed and cannot be reduced to any other class. For example taking "physical object" as a category implies that physical object-hood cannot be reduced or expressed in any other terms, such as a bundle of properties as in section 4.1.2.

The GOL-categories that are of concern to this thesis are the categories of situation, situoid, and relations to some degree, as they are needed to build up facts. We also need to understand the concept of time and space in GOL, as well as the concept of a universal.

Universals

Universals are sometimes used synonym to categories in [Heller et al., 2004a]. Three kinds of universals are used in GOL: immanent universals, conceptual structures and symbolic structures. Immanent universals exist in the individuals (in re) and not independent from them. Conceptual structures are how universals are conceived in an agents mind, represented as symbolic structures. There is still some research going on in the GOL-group concerning universals. We will write more about universals in section 5.3.6.

Time

In GOL, time is divided in two basic entities: time boundaries and chronoids. Chronoids are time intervals, and they always have a duration. Time boundaries depend on chronoids: A chronoid has exactly two time boundaries, a left and a right time boundary. We denote chronoids with $chr(i)$, meaning i is a chronoid, and time-boundaries with $tb(b)$, meaning b is a time boundary.

We use the relations:

1. $bl(x,y) =_{def}$ x is left boundary of the chronoid y
2. $br(x,y) =_{def}$ x is right boundary of the chronoid y
3. $coinc(x,y) =_{def}$ the time boundaries x and y coincide

Defined is $b(x,y) =_{def} br(x,y) \vee bl(x,y)$.

Let us view the axioms of this theory as in [Stenzel and Hoehndorf, 2003].

The first axiom asserts the existence of a chronoid.

Axiom 4.1.

$$\forall i(tb(i) \rightarrow \exists!!x(int(x) \wedge b(x,i)))$$

The second axiom asserts the uniqueness of the left and right boundary of a chronoid.

Axiom 4.2.

$$\forall x(int(x) \rightarrow \exists!!u(bl(u,x) \wedge \exists!!v(br(v,x))))$$

The next axiom states that time boundaries and chronoids are disjunct.

Axiom 4.3.

$$\neg\exists x(int(x) \wedge tb(x))$$

The next axiom asserts that time is infinite: Every left boundary of a chronoid coincides with the right boundary of another chronoid, and vice versa.

Axiom 4.4.

$$\forall x,u\,(bl(x,u) \rightarrow \exists y,v\,(br(y,v) \wedge coinc(x,y)))$$

Axiom 4.5.

$$\forall x,u\,(br(x,u) \rightarrow \exists y,v\,(bl(y,v) \wedge coinc(x,y)))$$

Chronoids may have internal structure.

Axiom 4.6.

$$\begin{aligned}\forall x,y,a,b,c,d\,(br(b,x) \wedge bl(c,y) \wedge coinc(b,c) \wedge bl(a,x) \wedge br(d,y)\\ \rightarrow \exists e,f,z\,(bl(e,z) \wedge br(f,z) \wedge (coinc(a,e) \wedge coinc(d,f)))\end{aligned}$$

The last axiom asserts the linearity of time.

Axiom 4.7.

$$\begin{aligned}\forall x,y\,(tb(x) \wedge tb(y) \wedge \neg coinc(x,y) \rightarrow \exists!!i\exists a,b\,(int(i) \wedge b(a,i) \wedge b(b,i) \wedge\\ coinc(a,x) \wedge coinc(b,x)\end{aligned}$$

This theory of time and the theory introduced by [Allen and Hayes, 1990], using only one relation, the relation *meets*, are equivalent[3], as shown in [Stenzel and Hoehndorf, 2003]. Sometimes this model of time is called the "glass continuum".

Space

The theory of space in GOL is based on works of Brentano and Chrisholm [Brentano, 1976, Chrisholm, 1983]. Space is three dimensional, and a connected

[3] They are equivalent in the sense that in each theory the other is interpretable.

region of space is called a topoid. Regions of space are mereological sums of topoids, sums in the sense of a relation $\leq_{st}$, spatial part-of[4]. As for chronoids, regions of space have boundaries, and the boundaries of different regions of space may coincide. However, a three-dimensional region of space has a two-dimensional boundary, which may have one-dimension boundaries which again has zero-dimensional boundaries or spatial points as boundaries.

Spatial regions have size and shape. Two different regions of space are congruent if they have the same size and shape.

Endurants and Occurrents

While some philosophers as described in [Rescher, Summer 2002] believe, that all individuals, all entities of the world have temporal parts, GOL distinguishes between endurants and occurrants, or more recently between presentials, persistants and processes. We will use both notions in this thesis.

Endurant are individuals that are wholly existent at a time boundary. Endurants have no temporal parts. An example may be a physical object, like a ball. A ball is wholly present at a point in time, a time boundary. It persists through time as a universal with instances at time boundaries. Those universals are called persistants.

Processes, or occurrents, are individuals that have temporal parts.

Situations and Situoids

Many features of situations and situoids in the most recent version of GOL in [Heller et al., 2004a] have been introduced due to the research in this thesis, and will be explained in detail during this thesis.

[4]More on this relation can be found in section 5.2.9.

We will only mention that situations are endurants, and situoids are occurrents.

Relations, Roles and Relators

Relations in GOL are special universals with relators as its instances. Relations have a finite number of arguments. Relations are not extensional. There are concrete existing entities called relators with the power of mediating other entities. Relators have an internal structure defining the role each argument plays, as in [Loebe, 2003].

In GOL, material and formal relations are distinguished. Material relations (and material relators respectively) are founded in other entities than only their arguments, they are inherently more. An example may be a contract, relating two individual agents. Then the contract is viewed as a material relator, mediating between the two agents. Formal relations hold between their arguments directly. Examples include $part-of$ and $greater-than$.

The mode of being of relators is still unclear. Their existence as abstract of concrete individuals, their relation to time and space is still discussed and open for further research.

Relations, relators and roles can be described much more thorough and more features can be outlined, but as this is not relevant to our work[5], please be referred to [Heller et al., 2004a]. Facts and infons are also closely related to relations and relators, and they will be discussed in depth in section 5.1.

[5] If we need more features of relations, we will introduce them when we need them. Some of our views on relations will differ from the views in GOL as expressed in [Heller et al., 2004a], but we will only mention this difference explicitly when we believe that it is of severe impact.

4.3.2 Levels

In GOL it is assumed that the world is organized into strata, which are again organized into layers. This is based on [Poli, 1998]. Level are strata or layers. There are at least three strata: a material stratum, a mental or psychological stratum and a social stratum. Levels are characterized by the categories they use, and those categories imply a certain granularity, so that granularity is a derived concept.

The mental and the social strata are founded in the material stratum. This basically means that the categories and entities of the mental and the social strata can be reduced to categories of the material stratum, but only with a loss of information, so the reverse is not possible. The relation between the mental and the social stratum is still unclear. Granularity and levels are discussed in section 5.2.11.

5 Ontological situation theory

In this chapter we will introduce our situation theory, which we call “situoid theory”. It will be mainly an extension of Barwisean situation semantics, put into an ontological background.

5.1 Infons and states of affairs

There has been a lot of discussion of what a state of affairs is. The major consensus is, that states of affairs are an ontological category, a fundamental kind of entity. States of affairs have been mostly ignored in the past, so they are explicitly mentioned only recently. In the beginning of the 20th century, two people have to be mentioned, who made efforts explaining the nature of states of affairs, Bertrand Russel and Ludwig Wittgenstein, mostly in the study of facts, which are states of affairs that are the case, or obtain.

In [Russel, 1985], Russel writes about facts:

> The first truism to which I wish to draw your attention[...]is that the world contains facts, which are what they are whatever we may choose to think about them, and that there are also beliefs, which have reference to facts, and by reference to facts are either true or false[...]. If I say “It is raining”, what I say is true in a certain condition of weather and is false in other conditions. The condition of

> weather that makes my statement true (or false as the case may be), is what I should call a "fact".

Russel already contrasts two different things. First there are things in the world, real, existing entities, which are called facts by Russel. Then there are other entities, existing in an agents mind, that may or may not be true in reference to a certain fact and in a certain environment. Here, we will call Russel's "facts" states of affairs, and will refer to those entities about states of affairs, which may or may not be true or false as infons.

An example of a state of affairs may be "John's drinking of 500 ml beer"[1]. The appropriate infon is then something like "John drinks 500 ml beer." Note, that the first sentence is not true or false, nor could ever be, but is describing an event, while the second states a belief, and could well be wrong in a certain situation, and true in another.

The most important question that arises out of the notion of states of affairs, and the most hotly debated one, is whether there are states of affairs, that are not the case. Is there a state of affairs "Robert's drinking of 500 ml beer", when Robert never drinks beer[2]?

Other questions that will have to be answered in an ontological investigation of states of affairs are whether there are only basic states of affairs, or if we will acknowledge a full algebra of states of affairs, using conjunction, disjunction, quantifiers or negation. Another problem is about the completeness of states of affairs. Consider again the state of affairs "Robert's drinking of beer". What about the state of affairs "Robert's drinking"? A closely related question is how states of affairs are individuated, namely what the identity conditions on states of affairs are. A lot of the discussion is closely related to the acknowledgement

[1] Obviously, the state of affairs is not this sentence, but a real event. As it is very hard to include real events in a thesis of this kind, we denote events like this with phrases of the above kind.

[2] Please regard this possible state of affairs as purely hypothetical. Robert is indeed drinking beer on a more or less regular basis.

of possible worlds, and the theory of what possible worlds are. As we are developing a theory of situations and situoids in this thesis, we have to wait until we introduced situoids, before we can start an in depth analysis of the relation of states of affairs and possible worlds, or possible situoids. Therefore, the part of this section concerning possible worlds will be incomplete, and we will refer to other sections like 5.2.7 and 5.2.6 at some times.

The question we will discuss here are:

- What are states of affairs?
- Do non-obtaining states of affairs exist?
- How complex are states of affairs? Is there an algebra of states of affairs?
- What are the identity conditions for states of affairs?
- What are infons and what is their relation to states of affairs?
- Is there an algebra of infons?

5.1.1 How states of affairs are constituted

Since Wittgenstein has been one of the most influential philosophers researching states of affairs, let us examine, what he wrote about states of affairs:

> A state of affairs (a state of things) is a combination of objects (things). [...] The configuration of objects produces states of affairs. In a state of affairs objects fit into one another like the links of a chain. In a state of affairs objects stand in a determinate relation to one another.

This is close to Barwise, who defined a state of affairs as being constituted by a relation *R* holding amongst objects, the arguments of *R*. However, in [Barwise, 1989], states of affairs do not contain only a relation and objects, but also a polarity, distinguishing between positive and negative states of affairs. We are not prepared to commit ourselves to negative states of affairs yet. However, we will commit ourselves to the belief, that a state of affairs is a configuration of things. Therefore, a state of affairs is made up of at least a characteristic relation *R* and a number of objects, the arguments of *R*.

The question still is, what those objects are, that make up a state of affairs. There are two separate ways of how to conceive states of affairs, described in [Wetzel, Fall 2003]:

> - Contingently existing, structured chunks of reality, embedded in the causal net of nature, and composed of concrete particulars, the features they exhibit, and relations among them. Call this *concrete compositionalism*.
> - Necessarily existing abstract entities, existing outside spacetime, without concrete particulars or other contingent entities as constituents. Call this *situational abstractionism*.

For an in-depth discussion of those two views, see [Wetzel, Fall 2003]. Here we will only state the fundamental differences in both theories, and how we will apply their results in this thesis.

Adopting the viewpoint of concrete compositionalism, we would state the following axiom:

Axiom 5.1.

- If *a* is any concrete particular and *F* is a property *a* has, then *a* and *F* are constituents of the state of affairs consisting in *a* having *F*.
- If an *n*-place relation *R* holds among concrete particulars $a_1, ..., a_n$ then $a_1, ..., a_n$ and *R* are all constituents of the state of affairs consisting in *R*'s

holding among those relata.

Also, in the compositionalist view, a state of affairs S would not exist, if one of its constituents does not exist.

Situational abstractionism views states of affairs as necessarily existing, abstract entities, which are necessarily not dependant on contingently existing entities. Even if there were no things, there would be infinitely many states of affairs. An abstract entity is an entity that necessarily exists, and is not dependant on concrete things. A possible motivation behind this view is the need for accepting possible, but non-obtaining relations among things, therefore possible, but non-actual states of affairs, and simultaneously rejecting the view on possible, but non-actual worlds with possible, but non-actual existing objects. If rejecting the existence of non-actual, possible worlds, this view solves several problems, as discussed in length in [Wetzel, Fall 2003].

In this thesis, we will adopt another view about states of affairs. We believe, that states of affairs exist in reality and are constituted by any existing entity, concrete or abstract. In the terms of GOL, states of affairs are constituted by the relation between sets, urelements or relations themselves. We will acknowledge the existence of abstract, non-actual worlds in reality. Those worlds will contain situoids, and situoids are the entities that make states of affairs factual. Therefore, states of affairs are made up of existing entities, which may exist in an abstract, possible world.

Using GOL-terms, we can formulate the following axiom:

Axiom 5.2.

- If an n-ary relation R holds among entities $a_1, ..., a_n$ then $a_1, ..., a_n$ and the relator $r :: R$ are all constituents of the state of affairs consisting in R's holding among its relata and we will write $\langle\langle r :: R, a_1, ..., a_n \rangle\rangle$.

For simplicity reasons, we will from now on simply write $\langle\langle R, a_1, ..., a_n \rangle\rangle$ for such a state of affairs, and ignore the relator, except when we need it. We did not limit the arguments of the relator of a state of affairs in any way, and thereby allowing states of affairs such as $\langle\langle r :: R, a_1, \ldots, r, \ldots, a_n \rangle\rangle$. However, whenever the relator of a state of affairs occurs as an argument, too, we will never use the short notion for writing states of affairs.

We can, of cause, classify states of affairs further, by the entities that are its constituents. Then we end up with a class of states of affairs that is made up by concrete individuals, a class that is made up of abstract entities and a class of mixed entities. However, a detailed classification is left open in this thesis.

5.1.2 The problem on negative and non-basic states of affairs

The question remains whether there are states of affairs that do not obtain. Are there states of affairs, configurations of things, that do not exist? Exist non-existant states of affairs?[3] This is closely related to the question, whether there are things, concrete entities, that do not exist.

Imagine the state of affairs "Bugs Bunny's being a rabbit". Now there are several problems with this state of affairs (if we could call it that). The main problem appears to be, that Bugs Bunny is a cartoon character, and does not exist in real in our world, except perhaps as some concept of a cartoon rabbit. This concept, however, is something different than a rabbit. Therefore, Bugs Bunny is not a rabbit, but something else.

Some philosopher suggest, that there is another state of affairs, namely the negation of "Bugs Bunny's being a rabbit", that obtains. Barwise would denote "Bugs Bunny's being a rabbit" with $\langle\langle Rabbit, BugsBunny; 1 \rangle\rangle$ and the negative state of affairs $\langle\langle Rabbit, BugsBunny; 0 \rangle\rangle$. But what does the latter mean? There are two

[3] We have to acknowledge here, that our choice of words is highly prejudiced.

ways of looking at this. Either it is the absence of a configuration of things, the non-existence of a state of affairs, or it denotes "Bugs Bunny's being a non-rabbit". We reject the first view as it contradicts our belief that states of affairs are real, existing configurations of entities, and not the absence of such a configuration. The second view seems more plausible on the first, but the question arises, what a "non-rabbit" would be. Are there any non-rabbits in our world? We will deny this question, too, until someone can show us a non-rabbit[4].

There may be occasions, when negative relations occur, as in *having* and $non-having$ or *lacking*, and they may perfectly make sense. Is this then some kind of negative state of affairs, that is formed by negating the relation? We take the standpoint, that those are fundamentally different relations, and they are not related[5].

If there were negative states of affairs, then there would be an imbalance between the number of positive and negative states of affairs, as for every positive state of affairs exists a possibly infinite number of negative states of affairs. Image the state of affairs $\langle\langle Rabbit, BugsBunny; 1\rangle\rangle$, saying Bugs Bunny's being a rabbit. Now there is only one positive state of affairs, but we could state a number of negative ones: $\langle\langle Dog, BugsBunny; 0\rangle\rangle$, $\langle\langle Snake, BugsBunny; 0\rangle\rangle$, $\langle\langle Tree, BugsBunny; 0\rangle\rangle$, et cetera.

In this thesis, we will deny the existence of non-obtaining states of affairs. States

[4]It may be possible to say, that a non-rabbit is anything, that is not a rabbit. Therefore, it is the *set* containing all entities except rabbits. A non-rabbit would then be an entity, that is contained in this set. However, at the moment we are concerned with an investigation of ontological categories, and not abstract, set-theoretical models for rabbits, non-rabbits or entities in general. The set *NonRabbit* does have an extension in reality, but we do not believe it to be a category of existence. States of affairs are not extensional entities. To illustrate this, imagine being asked by a child "What is this thing?", while the child is pointing towards some strange building. Then, usually, your answer will not be "This is a non-rabbit." or "This is not a rabbit." but rather a remark about what this building really is (perhaps in terms of a concept).

[5]This does not mean, that there may be no axioms relating these relations. We could state that whenever some entity is $non-having$ some property, it is *lacking* this property.

of affairs exist in the configuration of entities. They are the configuration (or relation) of real, existing objects. It is nonsensical to speak of the existence of non-existent configurations of things. Therefore, states of affairs are made up of exactly one relator $r :: R$ and a number of entities $a_1, ..., a_n$.

We believe, this also answers the question whether there are non-basic states of affairs, like disjunctive or conjunctive states of affairs. Because states of affairs consist of exactly one relator (and therefore one relation) and a number of object which this relator mediates, there are no non-basic states of affairs.

The relation may be composed of several relations. For example, consider the location of three red dots, d_1, d_2, d_3, on a white sheet of paper. Then each two of those dots stand in a relation R_1, R_2 or R_3 to each other, designating their spacial location to each other. There is also another relation, maybe D, stating that those three dots stand in a different, spatial relation to each other. The holding of relation D is a consequence of the holding of R_1, R_2, and R_3, but only with regard to a background theory. If we had an ontology of relations and a theory of the relations R_i and D, we could deduce the holding of D. But even then, D is a relation in its own right.

States of affairs, that are constituted by only one relator holding amongst a number of objects are called *basic*.

We take on the viewpoint of logical atomism in this thesis, and therefore state, that there are only basic states of affairs. We will also consider states of affairs of the form $\langle\langle R, a_1, \ldots, \langle\langle P, b_1, \ldots, b_m \rangle\rangle, \ldots, a_n \rangle\rangle$, which have other states of affairs as constituents, as basic.

5.1.3 The problem of beliefs

A problem raised (for example in [Wetzel, Fall 2003]) is how basic states of affairs can be used to account for beliefs. Let us consider the state of affairs "Kay's believing of the coffee cup's being on the table". First imagine that the coffee cup is on the table. Then the state of affairs would simply be $\langle\langle Believes, Kay, \langle\langle Is-on-table, CoffeeCup\rangle\rangle\rangle\rangle$. But now, what happens, if Kay is mistaken, and the coffee cup is not on the table? As we stated that there are only states of affairs that obtain, what is Kay believing?

Obviously it is possible that the coffee cup is on the table, it just happens not to be the case, and therefore is not a state of affairs. But the belief is something existing, we can even give it a meaning. We can say that it may refer to a state of affairs, as we can create a picture in our mind of a part of the world, where "The coffee cup's being on the table" is a state of affairs.

At this point, with our commitment to obtaining, basic states of affairs, we have no way of accounting for the existence of "Kay's believing of the coffee cup's being on the table", even if it was true that the coffee cup is on the table[6]. So either we change our mind, and permit, at least to a certain degree, non-obtaining states of affairs, or we create a new kind of ontological category, which can account for beliefs.

We are not willing to reject our view on states of affairs so soon, due to the reasons mentioned above. We will rather take the approach and try to investigate some other kind of entity, closely related to states of affairs.

[6] The reason we cannot account for any beliefs is the following: In the example, Kay is believing something, let us call it x. This entity x is a creation of Kay's mind, and this is where x exists. Let us call the state of affairs "the coffee cup's being on the table" y. Constituent parts of y are some relator $r :: R$, where R is the relation "being-on", the coffee cup and the table. These entities are not present in Kay's mind, and therefore $x \neq y$.

There is another category of existence, or some fundamentally different kind of entity, which exists as abstract entity outside of space and time, and which "refers" to states of affairs. We call these entities "infons". They are closely related to special states of affairs, which we will call "pictural".

5.1.4 Infons

Infons are necessarily existing, abstract entities. They contain information about states of affairs, and therefore about how the world is. They are used to communicate knowledge about states of affairs. They are pictures of states of affairs plus information about its existence, and therefore pictures of parts of reality. They are the entities that exist in an agents mind, when she perceives a state of affairs and assigns it to some part of reality.

Infons are *about* states of affairs. They are close to set-theoretical constructions, and therefore to a certain degree extensional, as they are founded upon a pictural state of affairs, which is a part of reality, and a function, which is a set-theoretical construct.

A *basic infon* consists of a relation R, a number of objects, $a_1, ..., a_n$ and a polarity p, where $p \in \{0, 1\}$. We will denote basic infons as $\langle\langle R, a_1, ..., a_n; p\rangle\rangle$[7].

Until now, they look quite similar to states of affairs, and in order to avoid confusion about whether we just introduced infons because we did not want to commit ourselves to non-obtaining states of affairs, we will say some things about their ontological relationship to states of affairs.

Infons carry information about states of affairs in the world. They are supposed to describe the states of affairs that are the case in the world or a part of it. The

[7] We will soon become more concrete.

knowledge or information about the absence of a state of affairs is the kind of information carried by a negative basic infon.

A positive infon does not say more about states of affairs in some part of the world than a negative infon. Infons are chunks of information about models of parts of the world in an agent's mind. If in such a model the agent asserts a positive infon, she believes the corresponding state of affairs to exist in the part of the world she constructed a model for. If she asserts a negative infon, she believes the corresponding state of affairs not to exist in this part of the world.

What does it mean, that a state of affairs "corresponds" to an infon? We could just say, that an infon $\phi = \langle\langle R, a_1, ..., a_n; p\rangle\rangle$ and a state of affairs $s = \langle\langle P, b_1, ..., b_n\rangle\rangle$ correspond, if $R = P$ and for $i = 1..n$: $a_i = b_i$. But could we justify this? We said that states of affairs exist in the world, in a configuration of objects, while infons exist in an agents mind, as a model for some part of the world. Therefore it would be highly implausible, if we said that R is identical to P and all the objects of the real world are identical to objects in the agents mind. While R and P may be identical, as we will see later, $a_1, ..., a_n$ and $b_1, ..., b_n$ are certainly not.

The start of the solution to the question of correspondence between states of affairs and infons can be found in [Wittgenstein, 1959]. Wittgenstein distinguishes between states of affairs and pictures of states of affairs. He wrote:

> We make to ourselves pictures of facts.
>
> The picture presents the facts in logical space, the existence and non-existence of atomic facts.
>
> The picture is a model of reality.
>
> To the objects correspond in the picture the elements of the picture.
>
> The elements of the picture stand, in the picture, for the objects.
>
> The picture consists in the fact that its elements are combined with one another in a definite way.

This may answer our question. There are entities in pictures of states of affairs[8], entities corresponding to objects. Those are the elements of the picture. We could, therefore, say, that the objects in infons correspond to real objects. The problem is again with negative infons. Consider the infon $\langle\langle Sees, Kay, unicorn; 0\rangle\rangle$. Then there are two possibilities, that could account for this infons not obtaining. Kay and the unicorn exist, but they just do not happen to stand in the relation $Sees$. Or Kay or the unicorn do not exist, and therefore they cannot stand in this relation. It just so happens that unicorns are not part of our world, and the term "unicorn" does not stand for an object in our world.

We could turn for infons to "soft actualism", and state that all entities that occur in a picture of a state of affairs do exist in the world. But we are not willing to do this, as it would limit us too far in our further discussion about situoids and worlds. We will instead follow another path, again laid out by Wittgenstein in [Wittgenstein, 1959]:

> That the elements of the picture are combined with one another in a definite way, represents that the things are so combined with one another.
>
> This connexion of the elements of the picture is called its structure, and the possibility of this structure is called the form of representation of the picture.
>
> The form of representation is the possibility that the things are combined with one another as are the elements of the picture.

We will say, that infons are about possibilities of how things could be or not be. We will say, that an infon ϕ corresponds to a state of affairs s, if there is a possible world[9] w, such that s is a fact of w, and ϕ has the same structure (the

[8] Here "state of affairs" is translated as "fact".

[9] We have to mention possible worlds here, but do so only briefly. We will argue in favor of their existence later in this thesis, and will introduce them more formally and based on an investigation of situoids. For details, see section 5.2.10.

same characteristic relation) as *s* and the objects of *s* correspond to the elements of ϕ. Before we investigate correspondence of the relations and objects to the elements of the picture of the state of affairs, we state, that for every infon, positive or negative, there has to exist a state of affairs which is a fact in some (possible) world, and the infon "corresponds" to this state of affairs. A negative infon therefore contains the information, that the state of affairs is not present in the part of reality in concern. However, an infon has to be *possible* in the sense, that there has to exist a world, in which the infon corresponds to a state of affairs.

Now again back to infons and objects. We said that the objects correspond to the elements of the infon. This suggests, that there is a function, or a functional relation, between objects and the entities present in infons. The elements of the picture are abstract entities, representing objects. For the last time now, let us see, what Wittgenstein has to say about this relation:

> According to this view the representing relation which makes it a picture, also belongs to the picture.
>
> The representing relation consists of the co-ordinations of the elements of the picture and the things.

Therefore we state, that there is an assignment function *a*, assigning objects to picture elements, elements of the infon, and therefore filling the arguments of the constituting relation *R* of the infon. The assignment function is a part of the infon. The assignment function does not necessarily have to assign an object to every possible argument of the relation *R* (it may be a partial function). The same function has been used by Barwise in [Barwise, 1989] in situation theory as "assignment" for, what he called, states of affairs.

The elements of the picture, the parameters, are related to one another as the objects in the state of affairs are related to one another. States of affairs consist of a relator and its arguments are filled by objects. Pictures of states of affairs consist of a relator, and its arguments are filled by picture elements, parameters, and the assignment function a.

The picture consists of its elements being in relation to one another in a determinate way. Therefore, pictures of states of affairs are special states of affairs.

Something has to be identical, for the picture to be a picture of a state of affairs. Wittgenstein called this the form of the picture: The possibility, that things are related to one another as are the elements of the picture. Therefore, for a picture to be a picture, the following condition has to be met: "The elements of the picture must be related to one another as the elements of reality could be related to one another. This means: pictorial representation is possible at all only if the possibilities of combination of the elements of the picture are the same as the possibilities of combination of the elements of reality."[Morris, 2004] This will become clearer in the next section.

Definition 5.1 (pictural state of affairs). A picture of a states of affairs or pictural state of affairs is a state of affairs. It consists of a relation R with a set of arguments $Arg(R)$ and an assignment function $a : Arg(R) \mapsto Entity$. The pictural state of affairs is called complete, if a assigns every $arg \in Arg(R)$ an object, otherwise it is called incomplete. Pictural states of affairs are noted $\langle\langle R, a\rangle\rangle$, or $\langle\langle R, a_1, ..., a_n\rangle\rangle$ if it is clear from the context, that a pictural state of affairs is denoted and that $a_1, ..., a_n$ are assignments. The class of all pictural states of affairs is called $picSOA$.

The infon, as a piece of information in an agent's mind, describes the presence or absence of a state of affairs. Because infons exist in mind, pictures of states of affairs have to be used, to refer to the state of affairs. An infon consists of a function $f : picSOA \mapsto \{0, 1\}$ and the picture of a state of affairs.

Definition 5.2 (Infon). An infon consists of a pictural state of affairs ϕ and a function $f : picSOA \mapsto \{0, 1\}$. Let $\phi = \langle\langle R, a\rangle\rangle$ be a pictural state of affairs. Then we note an appropriate infon $\langle\langle R, a; p\rangle\rangle$, where $p \in \{0, 1\}$.

To obtain a complete description of infons and their relation to pictures of states of affairs and states of affairs, we have to formalize the correspondence relation.

5.1.5 Correspondence of infons and states of affairs

Let us first consider what is meant by the correspondence of states of affairs and pictures of states of affairs. The problem that is still open is, how we account for relations or relators. Given two states of affairs, $\phi = \langle\langle r :: R, a_1, \ldots, a_n \rangle\rangle$ and a picture of ϕ, say $\rho = \langle\langle p :: P, b \rangle\rangle$, and $Arg(\rho) = \{x_1, \ldots, x_n\}$. If ρ is a picture of ϕ, then $\forall i(0 \leq i \wedge i \leq n \rightarrow b(x_i) = a_i \vee b(x_i) = nil)$[10]. This is to say, that all arguments of the picture ρ have to be either unassigned or assigned to the appropriate objects of ϕ.

But what are we to do with the relations R and P, and the relators r and p for this sake? We could just extend the assignement function to include the relators as well, but this does not appear to be right. The picture is a logical representation of the state of affairs, and its elements behave in logical space as the elements of the state of affairs in reality. This suggests that there is some similarity in the relation of the state of affairs and the picture. We will take the point of view that the relations are identical, and the relators of the state of affairs and its picture are different (but still instances of the same relation).

This may not be satisfying for all philosophers. But we are dealing with a dilemma, GOL still has to face in the future. Relations and relators in GOL are entities, relations universals, relators its instances. GOL appears to be using entities from reality, but it is not. Even GOL cannot state "what" some entity is, but only "how" it is. Therefore, relations, relators and all other entities in

[10]We use *nil* here as a keyword designating that the function is not assigned for this argument.

GOL are symbolic structures, names, or pictures of entities in reality. These entities are "denoted" by names. GOL takes objects from reality, denotes them by names and describes "how" they are in logic. When GOL is talking about relations, then it is a logical description of how certain relations behave. The picture that an intelligent agents forms of a state of affairs is similar, as it is always a specification of the state of affairs in the domain of logic. A picture is a logical representation of its corresponding state of affairs. When GOL talks about some relation R (that does exist in reality, not as a symbolic structure), and uses the name P (which is a symbolic structure) to characterize R, then R is characterized by only logical means. Hereby, the symbolic structure P "corresponds" to relation R, or R is "denoted" by P. P is therefore the translation of R into logic. This is the reason we are stating that the relations in a state of affairs and its picture are identical: the state of affairs can be described in logic, and therefore its constituting relation-universal, too, and this is what creates the picture. These are the preliminaries of a denotation relation, which is still missing in GOL.

Definition 5.3 (Strong correspondence (SOA and $picSOA$)). Let $s = \langle\langle r :: R, x_1, ..., x_n\rangle\rangle$ be a state of affairs, $\phi = \langle p :: P, arg_1, ..., arg_n\rangle$ be a picture of a state of affairs and let a be the assignment function of ϕ. Then $corr(s, \phi) \iff R = P \wedge a(arg_1) = x_1 \wedge ... \wedge a(arg_n) = x_n$. We will then say, that s and ϕ correspond strongly.

This is a strong form of correspondence, because all argument places of ϕ are assigned an object. But the possibility exists, that only some argument places are filled by appropriate objects, so the picture is incomplete, but still a picture of a state of affairs. We will define what we will call "weak correspondence" for this case.

Definition 5.4 (Weak correspondence (SOA and picSOA)). Let $s = \langle\langle r :: R, x_1, ..., x_n\rangle\rangle$ be a state of affairs, $\phi = \langle p :: P, arg_1, ..., arg_n\rangle$ be a picture of a state of affairs and let a be the assignment function of ϕ. Then $wcorr(s, \phi)$, if and only if $R = P$

and there is a non-empty subset $X \subseteq \{arg_1, \ldots, arg_n\}$ such that $a(arg_i) = x_i$ for all $arg_i \in X$ and for all $b \in \{arg_1, \ldots, arg_n\}$
X holds $a(b) = nil$.

We will then say, that s and ϕ correspond weakly.

A picture of a state of affairs corresponds to a state of affairs, if they have the same structure and the picture elements are assigned to the appropriate objects present in the state of affairs. They correspond weakly, if they have the same structure, and at least one picture element is assigned an appropriate object present in the state of affairs. When we speak about correspondence between pictures and states of affairs, we usually mean weak correspondence, unless stated otherwise.

With this formalism, we can say what is meant by an infon corresponding to a state of affairs. An infon corresponds to a state of affairs, if its pictural state of affairs corresponds to the state of affairs. Of cause, it always corresponds to its picture of a state of affairs itself. Correspondence is our means of accessing the state of affairs in a picture or an infon, and therefore polarity of an infon is of no concern.

Definition 5.5 (Correspondence ($Infon$ and SOA)). Let $s = \langle\langle R, x_1, ..., x_n \rangle\rangle$ be a state of affairs and $i = \langle\langle P, a; p \rangle\rangle$ be an infon. Then $corr(i, s) \iff corr(s, \langle\langle P, a \rangle\rangle) \vee \langle\langle P, a \rangle\rangle = s$ and $wcorr(i, s) \iff corr(i, s) \vee wcorr(s, \langle\langle P, a \rangle\rangle)$.

Note, that this form of correspondance is not transitive. However, it will be useful to define a transitive relation based on correspondance. We will introduce the relation $corr^+$ as the transitive correspondance relation.

Axiom 5.3.

$$\forall x \forall y \forall z (corr(x, y) \wedge corr(y, z) \rightarrow corr^+(x, z))$$

We can only form pictures of possible states of affairs, states of affairs that exist in some possible world. This is asserted in the following axiom.

Axiom 5.4.

$$\forall x(picSOA(x) \rightarrow \exists y(SOA(y) \wedge corr(x,y)))$$

$$\forall x(Infon(x) \rightarrow \exists y(SOA(y) \wedge corr(x,y)))$$

Whether the reverse is true or not is an open question. It may be possible that there are states of affairs of which we cannot form a picture in our mind, and no infon either. We will leave it open as an alternative.

Axiom 5.5 (Alternative 1).

$$\forall x(SOA(x) \rightarrow \exists y(picSOA(y) \wedge corr(y,x)))$$

Axiom 5.6 (Alternative 2).

$$\exists x(SOA(x) \wedge \neg\exists y(picSOA(y) \wedge corr(y,x)))$$

Some other issue is, whether the correspondance relation is well-founded. Can we construct an unlimited series of pictures of pictures, without ever ending up with a corresponding state of affairs that is not a picture? We will deny this. We will, however, always end up with a state of affairs that is not a picture.

Axiom 5.7. Let SOA be the set of all states of affairs. Every non-empty subset $X \subseteq SOA$ has a $corr^+$-minimal element in SOA. No $corr^+$-minimal element in the set SOA is a pictural state of affairs.

5.1.6 An example on infons, states of affairs and pictures

To make things more clear, we will investigate a longer example using states of affairs, infons and pictural states of affairs. We will use some sketches to make

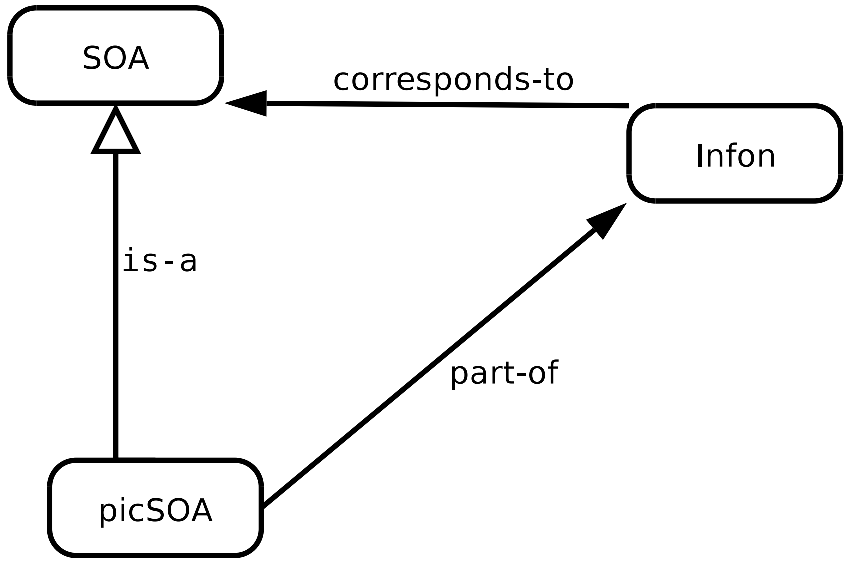

Figure 5.1: Relations between Infons, states of affairs and pictural states of affairs

things more clear.

First, what are the relations between the categories $Infon$, SOA and $picSOA$? Figure 5.1 shows their relations. Pictural states of affairs are specialized states of affairs. They are a part of infons. The $partof$ relation is not specified more closely, but we defined infons above, and believe this to be sufficient. It may have been better to use "constituent part-of" in out sketch, but it does not suffice either, so we refer to the previous definition and discussion. The correspondence between states of affairs and their pictures is missing. This is shown in more detail in figure 5.2.

Figure 5.2 shows the pictural representation of a state of affairs. To create a picture of a state of affairs, an agent is needed. The box on the left represents the agent's mind. The circle on the right represents some part of the world[11].

[11]It could just as well represent the world, with the only difference, that the agent has to be a part the world in this case.

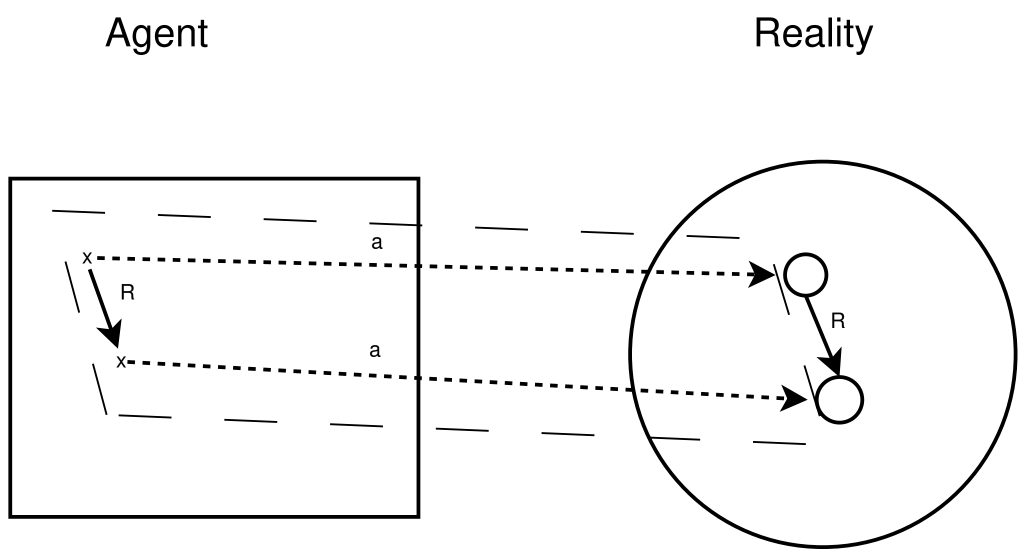

Figure 5.2: Correspondence between pictural states of affairs and states of affairs

In reality, two objects, represented as small circles, stand in relation *R*. The two objects standing in relation *R* are a state of affairs. In the agent's mind, two representations of these two objects, noted as small crossed, are created, and the assignment function *a* (dotted line) assigns them the objects in reality. The structure of the picture in the agent's mind and the structure of the state of affairs is isomorphic, so the relation *R* exists in the state of affairs and in the picture. The dashed polygon designates the picture of the state of affairs in reality: The picture elements, small crosses in the agent's mind, the structure of the picture as the relation *R*, and the assignment function *a*, but not the objects in reality. As can be seen, in the agents mind are also objects standing in some relation to each other, and therefore the picture is a state of affairs on its own.

We have mentioned, that pictural states of affairs may be about possible, but non-actual worlds. How do they enter the actual world, or the human mind, and what are their relations to states of affairs in the actual world? This is shown in figure 5.3. The box represents the agent, or more specifically the agent's mind. The small crosses are pictures of states of affairs, while the larger crosses represent states of affairs. Dotted lines designate the correspondence relation.

The circles are worlds, and only one of them is the actual world. The agent is a part of the actual world. Again, we do not like to define what "part of" means in this specific case, because here it is unnecessary. It suffices to know that the agent exists in the actual world. The other worlds are possible worlds. We do not want to say anything about the mode of being of possible worlds, as it is still a controversial issue in philosophy nowadays. For more information on possible worlds, see [Barwise, 1989], [Lewis, 1986], [Lycan, 1979].

It suffices for us to know, that there are alternative possibilities, possible worlds, that are accessible to a rational agent's mind. Those worlds contain states of affairs[12], and the agents mind has access to those states of affairs. The agent can create pictures of states of affairs in possible but non-actual worlds. Because the agent exists in one world, the actual world, the pictural states of affairs corresponding to states of affairs in possible worlds are facts of the actual world. This is how possibilities enter the actual world: The world is as it is, without any possibilities or alternatives, complete in itself. An agent has access to alternative, possible worlds, and can create pictures of their states of affairs. While the states of affairs present in possible but non-actual worlds are absent in the actual world, pictures of them exist, if an agent able to access other worlds with its mind exists.

Now the only missing category we need are infons. Infons contain a pictural state of affairs plus a function assigning it to 0 or 1. But how are they related to worlds? How do they enter reality? Figure 5.4 demonstrates some of these aspects. Again is the box an agent's mind and the big circles are possible worlds. There is a state of affairs, noted as a big cross in one world. This state of affairs

[12]Again, we do not want to state, that a world is the totality of their states of affairs, but only that there are states of affairs existent in a worlds.

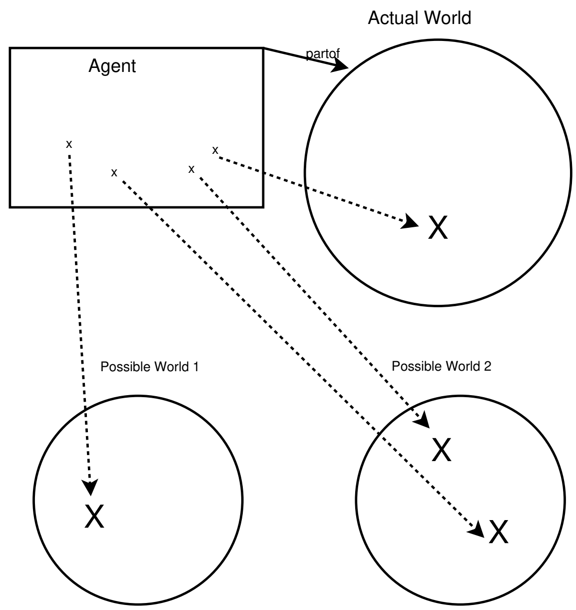

Figure 5.3: Pictures of states of affairs and their relation to possible worlds

is called *s*. The agent created a pictural state of affairs corresponding to *s*. This picture is called *p*. When focusing on a part of a world or a world, the agent perceives information present in this part. The smaller circles inside the world-circles represent parts of the world. Some of them will later be called situoids.

Information present in the world or its parts is information about the presence or absence of states of affairs. This information is expressed through infons. Those are sketched in the dotted boxes. The agent then recognizes the presence of this information in some parts of reality. There are two parts of which the agent believes the positive infon to obtain, the small circle around the state of affairs *s* and the world *s* is a part of, while the agents believes the negative infon to obtain in the entire other world with its parts and some part of the world *s* is a part of.

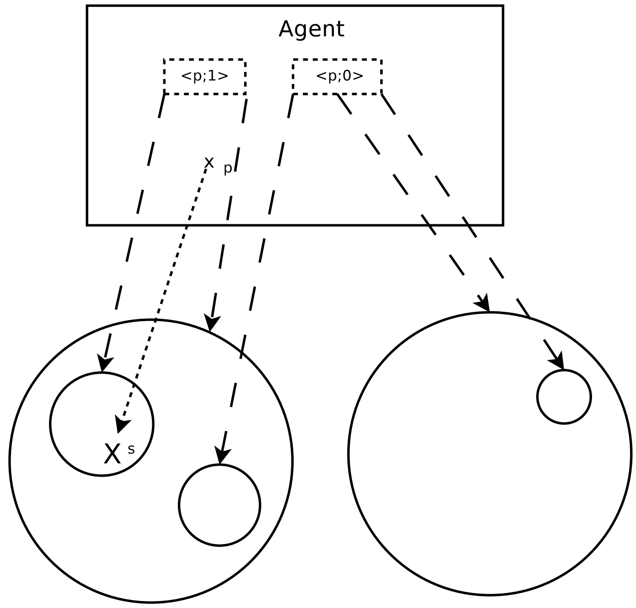

Figure 5.4: How infons enter reality

5.1.7 States of affairs and their relation to time

Let us consider a number of states of affairs:

1. *t*'s being green
2. Mary's walking uphill
3. Mary's climbing the hill
4. Mary's reaching the top of the mountain
5. Robert's knowing Kay

Are those states of affairs different and in what way? How do they behave in time?

The first expresses the property of an object, t. This is a fact at a point in time or during some time interval. This state of affairs may persist over several time-points, or exist at only one point in time. Or it may be viewed as existing through some time-interval, and cease to exist in the following.

The second expresses a property of an object, too. It states that Mary is walking uphill. A detailed analysis, using the ontology of GOL as a reference, reveales the following: There is an individual process p, the movement of an object in upward direction (towards the top of the hill). Mary is participating on this process p through her act of walking, z. Now this participation-relation is a universal in GOL, say R. The state of affairs is formed by a relator r with $r :: R$, the process p and the activity that relates Mary to p, z. So the state of affairs would be $\langle\langle r :: R, p, Mary, z \rangle\rangle$. This state of affairs may exist in a time-interval, but not at a point in time At sub-intervals of this time, Mary is still walking uphill, so the state of affairs exists at any given sub-interval. Also, there is no natural end-point of this activity, there is no culmination.

The third state of affairs is different from the second. There may be sub-intervals, where Mary is not climbing the hill. Also, there is an end-point, a culmination. But again, this state of affairs exists at a time-interval.

The fourth state of affairs is instantaneous, it can only exist at a point in time. It is inherently culminating, because the underlying process is.

The fifth state of affairs expresses a state. It exists during some time interval, but it makes no sense to ask, how long it lasted or whether it culminated.

There may be even more distinctions between states of affairs. We wanted to show, that states of affairs may be related in a variety of different ways to time. Also, they are neither only occurrents nor only endurants, they may be both. We may classify states of affairs by this distinction.

Some philosophers would disagree with us and deny, that states of affairs have a temporal extension. They would rather call those entities *events*, while states of affairs are the combination of objects at a point in time. Some philosophers like Ingarden would prefer to call some of the above relations between objects *processes* in a general sense, and only states of affairs of the fourth type "events". Others, like [Lombard, 1995] or [Kim, 1973] refer to events as special states of affairs. All discussion about events is mainly done under the question of causality. Events may be causes or effects of others. But then, the problem arises: "Sometimes an event is described as the cause of some quality in an object [...], or as the cause of a state of affairs [...]. Sometimes, again, an object or state of affairs is described as the cause of a quality in an object, or as the cause of a state of affairs, or as the cause of some event; and there are perhaps other sorts of causally related pairs."[Harris, 1981] Some of these problems are avoided when events are regarded as states of affairs, or at least constituted by states of affairs. As we do not wish to discuss causality further, please be referred to [Riker, 1957] for a good account of causality, that is close to our approach.

We subsume "events" (and "processes", in another terminology) under states of affairs. "Complex events" involving multiple states of affairs like "the Second World War" or a "marathon" do not exist in states of affairs, but rather in the domain of situoids and situations. "Primitive events", like the movement of an object a from the spatial point p_1 to p_2 (or, to use the proper GOL-terminology, the participation of the object a in the process consisting in the movement of an object from the points p_1 to p_2) or the states of affairs in the beginning of this section exist in the domain of states of affairs [Casati and Varzi, Fall 2002].

This leaves us with the problem of distinguishing different kinds of states of affairs; there are *instantaneous* and *enduring* states of affairs, some, that exist at a single point in time, some that exist during some time interval. States of affairs have a temporal extension. Their temporal extension is the set of time points (or time boundaries) or time intervals at which they exist.

Definition 5.6 (Temporal Extension of States of Affairs). The temporal extension of a state of affairs s is the set S of time boundaries and time intervals, at which s exists. The temporal extension of the state of affairs s is denoted by $TExt(s)$.

Now we can say, what instantaneous and enduring states of affairs are.

Definition 5.7 (Instantaneous, enduring and ambiguous states of affairs). A state of affairs s is called instantaneous, $InstSOA(s)$, if every element of the temporal extension of s is a time boundary: $\forall x(x \in TExt(s) \rightarrow tb(x))$. s is called enduring, $EndSOA(s)$, if every element of the temporal extension of s is a chronoid (time interval): $\forall x(x \in TExt(s) \rightarrow chr(x))$. s is called ambiguous, $AmbSOA(s)$, if it is neither instantaneous nor enduring.

There may be two kinds of ambiguous states of affairs, without a temporal extension and with time boundaries as well as time intervals as a temporal extension. States of affairs without a temporal extension may be viewed as abstract entities, or somewhere existing outside of time, like, maybe, $\langle\langle <, 1, 2\rangle\rangle$. We believe that a better interpretation is that this state of affairs exists throughout all time. States of affairs, like $\langle\langle Green, t\rangle\rangle$ may be viewed as existing at time points and time intervals. We rather believe, that there are two different states of affairs with different relations, one relating some property to an object at a point in time, another relating this property over some time interval. We take on the point of view that there are no ambiguous states of affairs in reality.

Axiom 5.8. All states of affairs are either instantaneous or enduring:

$$\forall x(SOA(x) \rightarrow (InstSOA(x) \vee EndSOA(x)) \wedge \neg AmbSOA(x))$$

Another distinction may be between *static* and *dynamic* states of affairs; consider the states of affairs $\langle\langle Rest, Kay\rangle\rangle$ and $\langle\langle Walk, Kay\rangle\rangle$, Kay's resting and Kay's walking. The first involves a state, and no property is changed by it, while the second inheres a change. Changes are ordered pairs of instantaneous states of affairs. For a detailed discussion of processes and how they can be used to classify infons, please be refered to [Heller et al., 2004a].

We assume that pictural states of affairs are always wholly present at a point in time, at a time boundary[13]. Therefore, infons are also always wholly present at a point in time.

Infons, taking pictural states of affairs as constituting parts, may have another argument, specifying a time boundary or a time interval. This infon describes the information about presence or absence of a state of affairs at some time entity (boundary or interval).

Definition 5.8 (Timed infon). A timed infon consists of a pictural state of affairs ϕ, a function $f : picSOA \mapsto \{0,1\}$ and a time entity t. Let $\phi = \langle\langle R, a\rangle\rangle$ be a pictural state of affairs. Than we note an appropriate timed infon $\langle\langle R, a; p; t\rangle\rangle$, where $p \in \{0,1\}$ and $tb(t) \vee chr(t)$.

Now we can extend the correspondence relation between infons and states of affairs to a timed correspondence.

Definition 5.9 (Timed Correspondence of infon and state of affairs). Let s be a state of affairs and $i = \langle\langle P, a; p; t\rangle\rangle$ be a timed infon. Then s and i stand in the relation of timed correspondence, $tcorr(i, s)$, if for the infon $i' = \langle\langle P, a; p\rangle\rangle$ $corr(i', s)$ obtains and $t \in TExt(s)$.

Now we have a rich enough formalism to start our discussion of situoids and situations. But before we start this, we will have to make some remarks about features we omitted here, because they can only be fully understood in the domain of situations and situoids.

[13] This is due to the nature of how concepts are kept in mind. For more detail, see the discussion of the mental stratum in [Heller et al., 2004a].

5.1.8 Conclusive remarks on infons

Pictural states of affairs and infons as well use the notion of an assignment function. This function does not have to be necessarily complete, some, or perhaps even all the arguments may be unassigned. We did not note the arguments as a function here, because for a huge part of this thesis it is irrelevant and less intuitive to read. However, keep in mind that the arguments are in fact a single, perhaps partial, function mapping parameters, or arguments, to entities. Sometimes this function is called an anchor for an infon. However, this will not become relevant until section 5.3.4. Parametric infons are also called situation types, because their arguments can be filled by several different entities, at different times. So there may be an infon $\langle\langle Eating, x, Karen; 1\rangle\rangle$, which is the type of all situations (or situoids) where Karen is eating. We also ignored the distinction between relations and relators when we felt this distinction is not necessary.

Also, we did not answer the question whether we admit an algebra of infons, because we cannot give it a semantic at this point. However, we will admit conjunction, negation and even existential quantification of infons later in section 5.3.5.

Please keep in mind for the rest of this thesis, that infons are not truth-bearers. They are information carrying entities. They are never true or false, but can be asserted to be either present or absent in some part of reality. The assertion of their presence or absence will be a proposition, and only propositions may be true or false.

5.2 Situoids

Let us now consider Situoids and Situations. Our intention is, that situoids and situations are entities, that do exist in the real world. They are entities, that stand in relation to other entities, they have qualities and properties. Situations and situoids are made up of states of affairs. Infons can be asserted to obtain in situations and situoids. Situations and situoids are parts of the world, in the sense that they are temporal, spatial or granular fragments of the world. If we limit our view of the world to a spatially or temporally finite region, we will eventually end up with a situoid or situation.

Barwise and others argued, that a situation is some part of the world that can be comprehended as a whole. So they are not just a part of the world, but a special, closed part of it. Just what those closure conditions are is not mentioned. There are some ideas mentioned in [Menzel and Sowa, 1993]. One should consider a situation (or situoid, in our vocabulary) as confined to a finite space and time. Since we believe it impossible to comprehend entities, that are separated in time or space, as a whole, we will restrict situoids and situations to connected space and time locations. Now one is tempted to think of situations as finite in a sense, that there is only a finite number of objects or states of affairs in a situation. This is not the case. There is still the possibility for an infinite number of objects that are contained in situations and situoids.

After all we noted about our understanding of situations and situoids until now, the reader familiar with modal logics is reminded of possible worlds. Possible worlds, too, can be comprehended as a whole, they can be infinite, and they may even be bounded in time and space, although they are usually not. There is a major difference between worlds and situations and situoids. In a world, all states of affairs are settled. Worlds are complete, total. In a situation or situoid there may be open issues, infons that are unsettled. It is possible, that neither an infon nor its complement[14] obtains in a situation, while in a world one of them has to obtain. This is the main difference between worlds and situations (or situoids): Totality versus partiality. We may even permit spatially and temporally unbounded situations. Then the question arises, whether the world as a whole is

[14]The complement of an infon is a change of polarity.

a situation, fulfilling one extra condition, namely completeness. Or if, at least, every proper part of the world is a situation. We will attempt to answer this question later in this work.

The main issue of concern to us will be the concept of being a comprehensive, whole part or reality. The last paragraph does not help us at all in answering the question how, in what sense, we can comprehend a situation or a situoid as a whole. Their partiality suggests the contrary. Let us examine some of the structure of situations and situoids closer before we come back to this question.

5.2.1 The difference between situations and situoids

Situoids are basic entities, while situations depend on situoids. According to [Heller and Herre, 2002], situoids "are the most complex integrated wholes of the world, and they have the highest degree of independence." Situoids do not need other entities in order to exist. Situoids exist in time and space. Every situoid is framed by a chronoid and a topoid. Therefore, situoids extend in time. Two other properties of situoids are mentioned. Situoids have to be coherent, and, again, comprehensible as a whole. An association relation between situoids and certain universals is supposed to assure this notion.

Definition 5.10 (Situoid). A situoid is an entity that does not need other entities in order to exist. Situoids are coherent and spatially and temporally connected. They have a temporal and spatial extent. $Situoid$ is the class of all situoids.

This is a very preliminary definition, and still needs some refinement. The main purpose for this definition is that we can refer to the class $Situoid$ later.

We can postulate the first axiom about situoids.

Axiom 5.9. Every situoid is framed by a chronoid and a topoid. The relation $top(s,y)$ has the meaning "the situoid s occupies the topoid y" and $prt(s,y)$ has the meaning "the situoid s is framed by the chronoid y". Then

$$\forall x(Situoid(x) \rightarrow \exists t \exists s(Topoid(s) \land Chronoid(t) \land top(x,s) \land prt(x,t)))$$

Situations are endurants. They are projections of situoids on time-boundaries of their framing chronoid. [Heller and Herre, 2002] states that situations have to fulfill certain principles of unity and must be comprehensible as a whole, which is again assured using a relation between situations and universals. We will not pose this restriction, but merely state, that every projection of a situoid on a time-boundary of its framing chronoid is a situation.

Definition 5.11 (Situation). A situation is the projection of a situoid on a boundary of its framing chronoid. $Situation$ is the class of all situations.

Again, this is a preliminary definition, that needs refinement. But, contrary to our definition of situoids, this definition is much closer to our final version. Because situations depend existentially on situoids, some of their features and properties can be deduced from the properties of situoids.

5.2.2 The "Supports" relation

We introduce a binary relation between states of affairs and situoids, $\models \subseteq Situoid \times Infon$. If s is a situoid and ϕ an infon, $\models (s,\phi)$ reads "ϕ obtains in the situoid s. We will use infix notation for this relation: $s \models \phi$, and write $s \not\models \phi$ for $\neg s \models (s,\phi)$.

With the help of this relation, we can say what we mean by a fact of a situoid.

Definition 5.12 (Fact). An infon ϕ is a fact, $\models \phi$, if and only if there is a situoid s, such that $s \models \phi$. If $s \models \phi$, ϕ is called a fact of s.

The first part of this definition may be ambiguous. Infons contain a pictural state of affairs and a function, mapping this picture to 0 or 1. Because there has to be a state of affairs, that corresponds to the picture, the infon has to correspond to a state of affairs in some world. One could argue, that this state of affairs would have to be part of some situoid. Since situoids have to fulfill more conditions than merely being a part of reality, it is unclear at this stage of this thesis, if there are states of affairs that are not part of any situoid, and we will not give an answer here[15].

The second part of the definition is apparently more clear, and we will constantly use it. Situoids, as special parts of the world, are comprehended, and then infons are asserted to obtain in situoids. If an infon ϕ with polarity p is a fact of the situoid s, then the state of affairs x with $corr(\phi, x)$ is present[16] in s if $p = 1$, and it is not present in s if $p = 0$.

5.2.3 Parts of situoids

Now we can introduce formally what we mean by one situoid being part of another.

To capture formally what is meant by a situoid being a part of the world, we introduce the binary relation $\leq \subseteq Situoid \times Situoid$. $s_1 \leq s_2$ if and only if all infons that are facts of s_1 are facts of s_2. By using the operator $S : Situoid \mapsto$

[15]Since this is a controversial issue, we will not give an answer at all, but rather leave it open. We will, however, give two alternative axioms, and leave it to the user of our theory to decide which one suits his needs and beliefs.

[16]We could use "is part of" here, but since we have not said what we mean by a part of a situoid yet, we will use this informal notion of "presence" in some situoid.

Set satisfying $S(s) = \{\phi | Infon(\phi) \wedge s \models \phi\}$ we can define this particular part-of relation as $s_1 \leq s_2 \iff S(s_1) \subseteq S(s_2)$.

This is the most basic part-of-relation for situoids. We will mention two other cases of a part-of relation. Let s be a situoid, and $c = chron(s)$ with $prt(s,c)$ its framing chronoid. The projection s_1 of s on $c_1 \leq c$, $s_1 = prt_f(s,c_1)$[17] is called a temporal part of s. $s_1 \leq_t s$ if and only if $s_1 = prt_f(s,c_1)$ and $c_1 \leq c$.

The spatial part-of-relation is similar. Let t be the topoid framing the situoid s with $top(s,t)$. $s_1 \leq_s s$ if and only if $s_1 = prs_f(s,t_1)$ and $t_1 \leq t$.

A question that arises is, if $s_1 \leq_t s \rightarrow s_1 \leq s$ and $s_1 \leq_s s \rightarrow s_1 \leq s$, this is to say, if one situoid being a temporal or spatial part of another situoid implies it being a part-of in the sense of the infons being a fact in it.

While this may seem plausible at first, there are some severe problems involved. Consider the following example: A railroad track over some fixed period of time viewed as a situoid s. Imagine, there is no train present in the fixed part of the world. Then $s \models \langle\langle Present, Train; 0\rangle\rangle$. But at times, there are trains traveling through this part of the world, and if we extend our spatial region, there may also be trains present. Let $s \leq_t s'$, then $s' \models \langle\langle Present, Train; 1\rangle\rangle$ may be true.

But not only negative infons will be reverted in extensions of situoids. Consider the above example again. Then $s \models \langle\langle \text{Number-of}, Train, 0; 1\rangle\rangle$ is true, but the extension s' does not support this information, but rather the inverse.

Generally we will deny a relationship between the different part-of relations.

Other variants of part-of relations are discussed in more detail in section 5.2.9.

[17] We use the suffix f to show that we use an already introduced relation of GOL as a function.

5.2.4 Axioms of situoid theory

Before we can advance any further and show some of the results and further properties of this situoid theory, we will have to formalize our work done so far. The best way to do this is to write down axioms. Our theory will be far from complete at this stage, but to proceed we will need some axioms.

Our first axioms state that there is a state of affairs and there is a situoid and there is an infon.

Axiom 5.10.

$$\exists x(SOA(x))$$

$$\exists x(Situoid(x))$$

$$\exists x(Infon(x))$$

The next axiom concern the $\models$-relation and asserts that situoids are not incoherent.

Axiom 5.11. For all situoids s and infons $\phi = \langle\langle R, a; p\rangle\rangle$, the following is true: If $s \models \phi$, then $s \not\models \bar{\phi}$, where $\bar{\phi} = \langle\langle R, a; 1-p\rangle\rangle$.

Now we can define an ordering relation on situoids. All infons that obtain in a situoid s_1 that is part of another situoid s_2 also obtain in s_2.

Axiom 5.12.

$$\forall s_1 \forall s_2 (s_1 \leq s_2 \rightarrow (\forall \phi (s_1 \models \phi \rightarrow s_2 \models \phi)))$$

Now we can state that two situoids are identical, if and only if they are part of each other, and their framing chronoid and topoids are identical. The reason we have to assert the identity of the framing chronoid and topoid are ontological in nature: It will be possible to descibe two different situoids, say, two different marathons, with exactly the same information. So both situoids are informationally equivalent, but present at different space-time coordinates.

Axiom 5.13.

$$s_1 = s_2 \iff s_1 \leq s_2 \wedge s_2 \leq s_1 \wedge \forall c_1, c_2, t_1, t_2 (top(s_1, t_1) \wedge top(s_2, t_2) \wedge t_1 = t_2 \\ \wedge prt(s_1, c_1) \wedge prt(s_2, c_2) \wedge c_1 = c_2)$$

Let us emphasize at this point, that the identity of the situoids framing chronoid and topoid may not be a sufficient criterion for identity. This is due to granularity considerations. We may descibe some scene from a birds-eye view, with only the basic information present, but we could descibe the same scene very detailed, adding waste amounts of information. As an example, consider a marathon. From a birds-eye view, the duration of the marathon, the position of the runners and maybe the names of the runners are the facts of this situoid. On the other hand, there is another situoid framed by the same topoid and the same chronoid, but with much more information available: The mood of the runners, the scenery, the altitude of the track, the weather, et cetera. We will consider this indeed a different situoid, and although both situoids are framed by the same chronoid and topoid, they are not identical. Therefore, situoids are not only spatio-temporal parts of the world, but also granular parts.

This is only the very beginning of a theory of situoids, but before we proceed, we will turn back out attention to infons.

5.2.5 More relations for infons

Now, that we understand what a state of affairs, an infon and what a situoid is, we will mention how an infon behaves, how it can enter into relations. There are relations between situoids or situation and infons, and relations between infons.

We will consider a relation $\Rightarrow_l \subseteq Infon \times Infon$. We want to understand $\phi \Rightarrow_l \phi'$ as "ϕ is as strong as ϕ'". This relation is reflexive and transitive, and if $\phi \Rightarrow_l \phi'$ and ϕ are facts of a situoid, so is ϕ'. We can capture this in the following axioms.

Axiom 5.14.

$$\forall \phi (\phi \Rightarrow_l \phi)$$

$$\forall \phi \phi' \phi'' (\phi \Rightarrow_l \phi' \wedge \phi' \Rightarrow_l \phi'' \rightarrow \phi \Rightarrow_l \phi'')$$

$$\forall s \forall \phi \forall \phi' (s \models \langle\langle \Rightarrow_l, \phi, \phi' \rangle\rangle \wedge s \models \phi \rightarrow s \models \phi')$$

This axiom will be needed when we write more about parameters of infons and the anchor function.

Barwise introduced another operation on infons, allowing us to merge or unify compatible infons. What does it mean for two infons to be compatible?

Definition 5.13 (Compatibility of infons). Two infons $\phi = \langle\langle R, f; i \rangle\rangle$ and $\phi' = \langle\langle R', f', i' \rangle\rangle$ are compatible, if and only if $R = R'$, $i = i'$ and f and f' are compatible as functions.

Now we can state what is meant by merging two compatible infons.

Axiom 5.15. If $\phi = \langle\langle R, f; i \rangle\rangle$ and $\phi' = \langle\langle R, f'; i \rangle\rangle$ are compatible infons, than

$$\phi \oplus \phi' = \langle\langle R, f \cup f'; i \rangle\rangle$$

This function is mainly used to fill missing arguments of infons, and we will not use it further.

At last, we will assert that every infon has a complement.

Axiom 5.16. For all infons $\phi = \langle\langle R, a; p \rangle\rangle$ exists another infon denoted as $\bar{\phi}$ with $\bar{\phi} = \langle\langle R, a; 1 - p \rangle\rangle$.

5.2.6 Dependence relations of situoids and states of affairs

An interesting aspect is whether infons or situoids can exist on their own, or if they need other entities, before they can come into existence. This relation between entities is called *existential dependence*.

Definition 5.14 (Existential dependence). An entity A is existentially dependent upon the entity B if and only if it is logically impossible for A to exist if B does not exist. The category C is existentially dependent upon the category D if and only if for every instance of C it is logically impossible to exist if not at least one instance of the category D exists.

Now, what is the relation between situoids and states of affairs, and the relation between situoids and infons. One part of this question can be answered by researching whether there could be an empty situoid, namely a situoid s_0, such that $\forall \phi(\neg(s_0 \models \phi))$. What would such a situoid behave like? Let us consider some region of empty space over some chronoid. Are there any infons that obtain in this situoid[18]?

Is there a special class of infons, that does obtain in every part of existence, in every part of the world, of reality? Those would be logical tautologies. As an example, consider the infon $\langle\langle =, p, p; 1\rangle\rangle$, stating the logical tautology $p = p$. This infon would be true in every part of reality. Wherever there is existence, the laws of logic obtain. However, consider the following excerpt from Wittgenstein's Tractatus:

> Tautologies and contradictions are not pictures of reality. They do not represent any possible situations. For the former admit all possible situations, and latter none. In a tautology the conditions of

[18]Note that we are still undecided, whether this can be a situoid at all.

> agreement with the world — the representational relations — cancel one another, so that it does not stand in any representational relation to reality. [Wittgenstein, 1959]

This explains our — suspicious — feeling when we considered the infon $\langle\langle \rightarrow, p, p; 1 \rangle\rangle$. In this infon is no information about a situoid, but it rather defines a frame for any possible situoid. Even worse, there is no state of affairs corresponding to this infon. However, if it was an infon, it would obtain in every part of reality, in every situoid in every possible world.

We believe that there is no such thing as an empty situoid, there are always states of affairs present in every part of reality. The reason for this are again due to Wittgenstein. If reality is the collection of all the facts, all the states of affairs, then any part of reality, which we believe situoids are, must contain some states of affairs.

Axiom 5.17.

$$\forall s(Situoid(s) \rightarrow \exists \phi(s \models \phi))$$

This answers one part of our question: Situoids are existentially dependant on infons.

Now we will focus on another question.

Can infons exist outside a situoid? Are there states of affairs, that do exist in reality, but not in any situoid?

If we use alternative 5.5 in section 5.1.5 and assume that there are states of affairs that cannot be pictured, then certainly the above is true. But what if we use the other alternative, 5.6?

States of affairs mediating abstract entities like numbers or sets would be another possibility for states of affairs that are not part of any situoid.

We will leave again two alternatives here, and leave it open for the user of this theory to choose amongst them. The first asserts that all states of affairs exist in some situoid. The second assumes that there is at least one state of affairs outside all situoids. Note the similarity to the alternative axioms 5.5 and 5.6.

Axiom 5.18. Alternative 1

$$\forall\phi(Infon(\phi) \rightarrow \exists s(Situoid(s) \wedge s \models \phi))$$

Axiom 5.19. Alternative 2

$$\exists\phi(Infon(\phi) \rightarrow \forall s(s \not\models \phi))$$

There is another class of infons that never obtains (and their negations always obtain). Those are infons about natural sciences. The infon stating that the gravity constant is 1.5, $\langle\langle =, gravity-constant, 1.5; 1\rangle\rangle$ is never true in the current world. In this sense, it could serve as a class of never-obtaining infons. However, it is *possible* to obtain in some world[19], it does not deny existence. Therefore there could be some part of reality, some world made up of situoids, where it obtains. The relation between situoids and worlds will become clear later. For now we assume that these are infons with pictural states of affairs and corresponding states of affairs.

5.2.7 About the structure of situoids

We will now discuss a central issue of this thesis – what is meant by a comprehensible whole that is a part of reality.

[19]If it was not possible, then only due to the laws of physics, which are of little concern to philosophers and ontologists.

To fully understand the form of existence of a situoid we will have to answer some questions. First, we will state what we mean by an act of “comprehension”. Then we will say what we mean by “comprehended as a whole”, and then we will say what we mean by situoids being a “part of reality”.

5.2.8 Comprehension

Any experiences come to us serially in time. Experiences here may be the steps of an inference, a proof, a melody or the words of a sentence, all of which can be embedded in a situoid. Any of those events are experienced one after another, but must be considered in a single mental act, before they can bear any meaning at all. Such an act is what we will call “comprehension”. This act differs from inference or judgement, it comes before both. Judgement, the assertion or denial of a relation between concepts, presupposes considering both concepts together. Where inference refers to the drawing of conclusions from premises, comprehension refers to considering the premises together with the conclusion, as in mathematics, where we do not see a proof as a series of manipulations according to rules, but rather as something whole.

In [O.Mink, 1987], Mink writes:

> [...] comprehension operates on all levels of reflection and inquiry. At the lowest level, it is a grasping of the data of experience and issues in the perception and recognition of objects. At an intermediate level, it is the classification together of a set of objects and issues in the formation of concepts. At the highest level, it is the attempt to order our knowledge of the world into a single object of understanding.

This suggests, that there are fundamentally different modes of comprehension. A number of entities may be comprehended as instances of the same law or formula or generalization. This kind of comprehension refers to some entities in virtue of their possession of certain common characteristics, omitting everything else. This specific kind of comprehension, that Mink in [O.Mink, 1987] called "theoretical" or "hypothetico-deductive comprehension", lets us understand all instances of the consequence of some hypothesis.

Another mode of comprehension is understanding a number of entities as elements of a single complex of concrete relations. It is this mode, that lets us understand the multiple lines, multiple images of a song or poem, or a sentence in this thesis. Mink called this "configurational comprehension", described by Pascal as "the ability to hold together a number of elements in nice balance".

Plato envisioned another mode of comprehension: "to hold together a number of things as examples of some category, and in fact a system of categories incapable of abstraction from each other." The question arises, if this subsumption under categories falls together with deduction from hypotheses. As Mink points out, there are a number of differences why these two views are not identical. First, hypotheses are meaningful even independent of each other, while the meaning of categories is dependant on their interconnection. Also, according to Kant, categorical connections are not falsifiable by experience, since they give form to experience itself. This mode of comprehension is called "categorical comprehension".

Theoretical comprehension therefore is the understanding of relations between universals and particulars. Comprehending a particular at this mode lets us identify an universal, of which this particular is an instance. Theoretical comprehension of a universal lets us identify the class of all particulars, that are instances of this universal. Configurational comprehension is understanding of the relation between particular and particular. Configurational comprehension of some particular lets us identify the roles this particular takes in the relations to other entities in some whole, as well as the relations this particular is in. Categorical comprehension is understanding the relations holding between universal and universal. It lets us identify relations like $part-of$ or existential dependence of categories. Comprehending a number of categories is understanding them as a web of categories with relations holding amongst them.

None of these modes is primal to another. They are self-justifying, and when we speak of comprehension we will have to consider all three modes.

Let us apply our knowledge of comprehension to situoids, now. What is meant by comprehending a situoid in the various senses?

Let us start with theoretical comprehension. For a situoid to be comprehensible in this sense we have to be able to find a universal this situoid is an instance of. Therefore we state that a situoid is an instance of at least one universal. We can formulate this as an axiom:

Axiom 5.20.

$$\forall s(Situoid(s) \rightarrow \exists u(Universal(u) \wedge s :: u))$$

Objects can be treated as situoid. Therefore a universal "house" may have situoids as well as substances, processes, concepts, etc. as its instances. Because universals in our background ontology General Formal Ontology are intentional entities, all those universals are different, because they have different intentions. There exists only one universal "house" with house-situoids as its instances.

In [Heller and Herre, 2002], situoids are *associated* with a set of universals. Therefore, if we consider a house as a situoid, it may be associated with the universals *Building*, *House*, *Window*, *Door*, et cetera. However, in [Heller and Herre, 2002] it never becomes clear what this association relation between situoids and sets of universals really is, in an ontological sense.

It is obvious, that these universals are needed to describe a situoid of some kind, and that there are entities in the situoid, that are instances of these universals. We consider the description in [Heller and Herre, 2002] insufficient and unnecessary. We cannot deny the existence of a set of universals in a situoid, so we state that every situoid is an instance of the complex universal that is formed by all universals, that are said to be associated with it in [Heller and Herre, 2002]. After all, universals are intentional entities, and they define properties and structure of their instances.

However, we will associate with situoids what we will call "categorization devices". A categorization device is a universal with universals as its instances, and they specify a context for a situoid. They are needed to give semantic to natural language, especially referring terms, in situoid theory, and are discussed in section 6.1.1.

Let us turn our attention to the second kind of comprehension, configurational comprehension. For a situoid to be comprehensible in this sense, we have to be able to identify the relations it is in with other entities "in some whole". We will proceed with a discussion of wholes in the next section. For now we will consider at least every situoid as some whole. We state, that every situoid can be embedded in another situoid, in which more infons obtain. This captures the ability of the human mind and speech, to add more and more qualities, properties or entities, and therefore more information, to some whole. Image a stone laying in a desert as a situoid. We can add, in mind or speech, more and more information about this situoid. We could start by stating the color, shape or weight of the stone. Then we can add some other entities, maybe the stone is part of a pile of stones. We can go on by adding information about the desert or the history of the stone, up to its position in the universe. Let us summarize this with the following axiom:

Axiom 5.21.

$$\forall s(Situoid(s) \rightarrow \exists t(Situoid(t) \wedge s \leq t) \wedge t \neq s)$$

Now the remaining problem is, finding the relations of some entity in the larger situoid. If this is possible our task is done, because then we can identify the relations and roles a situoid plays in some whole by identifying the relations that obtain in some larger situoid. How can we assure that this is possible? There is a set having all the infons that obtain in some situoid as elements. If we are able to decide, if some infon is an element of this set, we can identify all the relations that hold for any entity in a structured whole (situoid). Therefore, we request the following to be true for situoids:

Axiom 5.22. The set $S(s)$ of all infons obtaining in a situoid s is decidable.

This axiom is required for comprehending a situoid. It also captures the feeling we had, when the phrase "can be comprehended as a whole" came into being. Because infons are the means we use to express knowledge about situoids, we have to be able to say what these infons are for a particular situoid. If we are not able to do this, then we have not comprehended the situoid. And even stronger, if we are not able to say what infons in the relevant part of reality exist, then this part of reality cannot be regarded a situoid.

Categorical comprehension can be disregarded in this discussion, because universals and categories are not at issue here. However, let us point out, that this entire work is dedicated to comprehension of the categories "situoid" and "situation" in the system of the General Formal Ontology.

We will proceed with a discussion of wholes in general and whole situoids in specific.

5.2.9 Whole situoids

Before we can proceed with our discussion of the meaning of "can be comprehended as a whole", the basic feature of situoids, we will have to draw our attention to the nature of wholes in general. Investigation of part-whole relationships dates back as far as Aristotle. In our investigation of comprehending situoids as a whole we will refer to more recent work, namely [Rescher and Oppenheim, 1955]. Their investigation of wholes and their parts is gestalt theoretical in origin.

Since gestalt theory presupposes a subject capable of comprehension, it is most suited for our theory. We will regard gestalten with situoids as their instances. Gestalt is a German word and refers to the concept where an entities properties cannot be discovered from the total properties of its parts alone [The Internet Community]. There are similar but different views on the part-whole relationship, the most influential probably being those of phenomenologicians like Husserl [Sokolowski, 1968, Krecz, 1986], who uses the term "figural moment" instead of "gestalt". More differences between both approaches can be found in [Gurwitsch, 1955].

Alternative theories of the part-of relation, of parts and wholes can be used in an integrated top-level ontology parallel to our theory of whole situoids and their parts, as there may be other categories in the top-level ontology, that do not behave like situoids, as comprehensible wholes.

The philosophy of Brentano, Meinong and Husserl eventually led to the development of gestalt theory [Reiser, 1930]. The founder of the gestalt theoretical movement is Max Wertheimer, although the term "gestalt theory" has first been introduced by Christian von Ehrenfels, a disciple of Brentano. Another root of gestalt theory is Ernst Mach [Becher, 1905], whose work "Beitraege zur Analyse der Empfindung" (Contributions to the Analysis of Sensations, 1886) influenced gestalt theorists like Ehrenfels, but also phenomenologists like Husserl.

In [Rescher and Oppenheim, 1955], three conditions are stated as prerequisites for a whole entity:

1. The whole must possess some attribute in virtue of its status as a whole, an attribute peculiar to it and characteristic of it as a whole.
2. The parts of the whole must stand in some special and characteristic relation of dependence with one another. They must satisfy some special condition in virtue of their status as parts of a whole.
3. The whole must possess some kind of structure in virtue of which certain specifically structural characteristics pertain to it.

All those three conditions have to be regarded concerning a specific part-of relationship, and therefore a specific decomposition.

Definition 5.15 (Decomposition). Let w be a specific object and Pt a specific part-of relation, then the class D of Pt-parts of w is a decomposition of w if every Pt-part of w has some Pt-part in common with at least one element of D.

There are attributes of a whole, that can be shared or unshared by its parts. An attribute, a quality, the whole possesses and none of its parts do is called unshared, and shared if all parts of the whole possess the attribute.

Definition 5.16 (unshared attributes, shared attributes). An attribute or quality Q is called a D-unshared attribute of a whole w relative to a decomposition D of w into Pt-parts, if Q is an attribute of w which is inhered by no Pt-part of w belonging to the decomposition D. Q is called a D-shared attribute of w relative to D, if Q is inhered by all Pt-parts of w belonging to D.

It is clear, that if some attribute is not D-unshared, it does not necessarily have to be D-shared, and vice versa.

Underivable attributes of a whole are attributes, that are not a logical consequence of some set of attributes of a set of parts of the whole. Underivable attributes, again, have to be regarded relative to a specific set of parts and attributes. An example of some underivable attribute is the weight of a pile of stones. Of course every part of this pile of stones has a weight, but summoning up the weight of the pile by using the weight of the parts requires the additional natural law that weight is additive. An attribute or quality is derivable if it is a logical consequence of the attributes of some set of parts. Rescher and Oppenheim gave the following definition in [Rescher and Oppenheim, 1955]

Definition 5.17 (underivable attributes, *G*-characterization). An attribute Q of a whole w is a D-G-underivable attribute of w relative to a decomposition D of w and to a set G of attributes if '$Q(w)$' is not a logical consequence of the characterization of the elements of D with respect to G. By 'characterization of the elements of D with respect to G', or briefly 'G-characterization', is meant a sentence which, for any n-adic relation g of G, and any n elements $d_1, ..., d_n$ of D states whether or not the relation holds between these n elements.

Definition 5.18 (derivable attribute). An attribute Q of a whole w is a D-G-derivable attribute of w relative to a decomposition D of w and to a set G of attributes if '$Q(w)$' is a logical consequence of the G-characterization of the D-parts of w.

As mentioned, the weight of a pile of stones is not derivable by purely logical means from the weight of the stones alone. However, we could add a theory of some kind, and derive this attribute with the help of this theory. We will call this attribute then D-G-T-derivable, if T is the theory concerned, or D-G-T-underivable, if it is impossible to deduce the attribute of the whole with the means of T. We will call D-G-T-underivable attributes simply "underivable" attributes.

The existence of an underivable attribute corresponds to the First Ehrenfelscriterion, that has been formulated in Christian von Ehrenfels' first study of Gestalttheory, "Ueber Gestaltqualitaten": "The whole is more than the sum of its parts."

Sometimes those attributes, that only come into existence when the parts are assembled, are called emergent attributes.

Considering the second condition for wholes, the dependence of certain characteristics of one part upon those of other parts, we will have to consider configurations. "An ordered set of objects, $p_1, p_2, ..., p_n$, which stand in the relation R to each other, i.e. for which $R(P_1, p_2, ..., p_n)$ holds, will be said to form a *configuration of kind R*."[Rescher and Oppenheim, 1955] As we can see, Rescher and Oppenheim's configurations are certain kinds of states of affairs, in our terminology, and the kind of the configuration, the kind of the state of affairs is defined by the relation universal.

For the easier part of quantitative attributes, an attribute f of a part p_1 is called ϕ-dependant upon some class G of quantitative attributes of the objects p_i, if the f-value of p_1 in every configuration of kind R is related by ϕ to the values of the attributes in G of p_i. ϕ may be strong or weak, defining the value of f completely, or just statistically. It is possible for the configuration to consist only of one object, or the class G consisting only of the attribute f.

For non-quantitative attributes, similar observations can be made. The perceived impression may depend on other parts surrounding or the whole, as can be seen in figure 5.5.

For the requirement that the parts of the whole must stand in some special, characteristic relation of dependence with one another, wholes may form dependence systems, that are defined as follows in [Rescher and Oppenheim, 1955]:

Definition 5.19 (Dependence system). A configuration is a ϕ-dependence-system relative to a set G of attributes if each part of the configuration has some G-attribute which is ϕ-dependent upon the G-attributes of the remaining parts.

The third criterion refers to some kind of structure the whole must possess in virtue of its status as a whole. This involves three things:

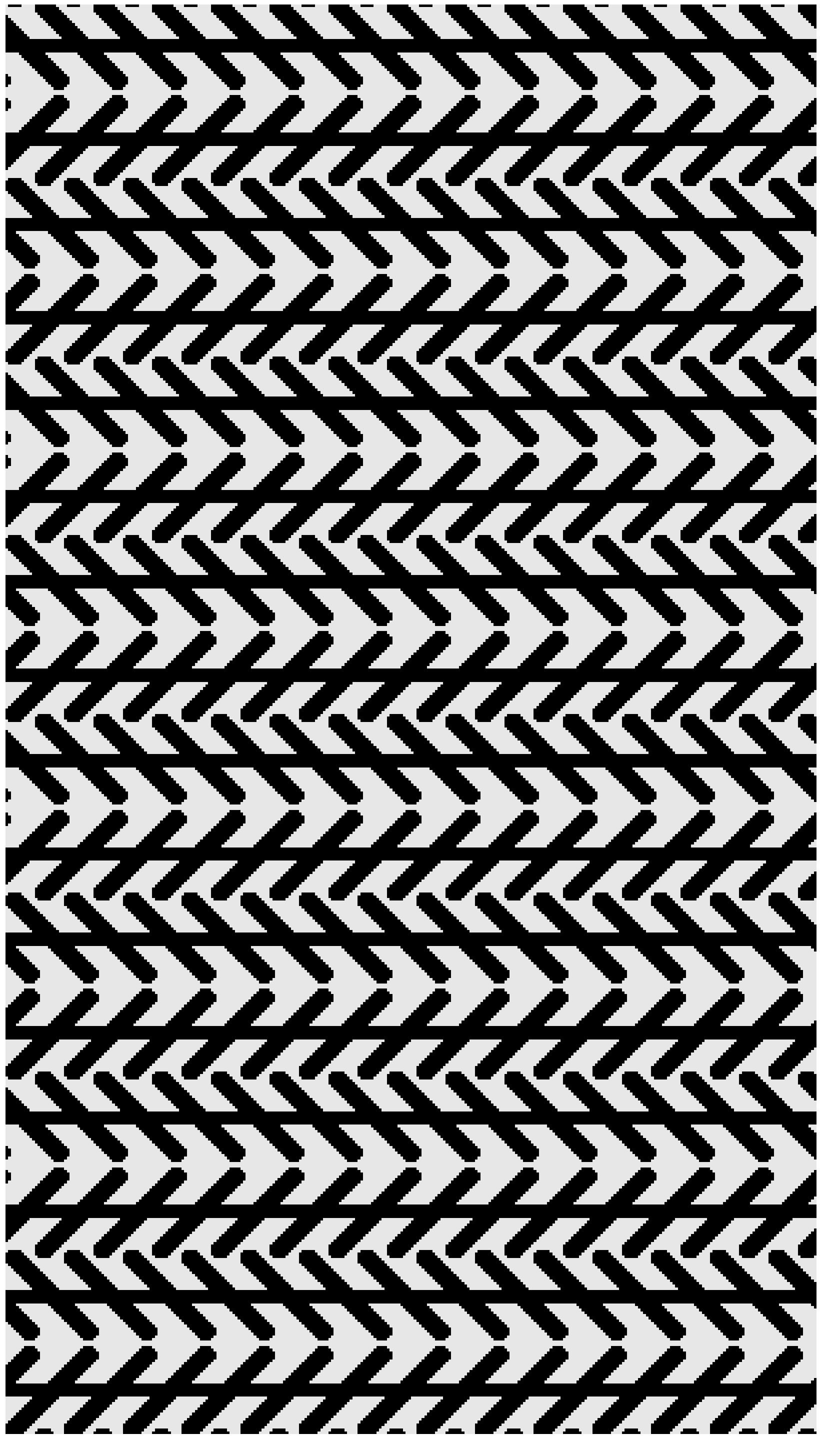

Figure 5.5: Zoellner Illusion, parallel lines

1. The parts of the whole.
2. A domain of positions in some kind of topological structure.
3. An assignment assigning the parts to positions of the domain.

Often, we are not interested in the specific parts of some whole, but only the types of the parts and the position they occupy in the whole. This leads us to the concept of a complex:

Definition 5.20 (Complex). A complex is characterized by the following three features:

1. A set G of topologically structured attributes.
2. A topologically structured space X, constituting the domain of positions.
3. An assignment f of exactly one G-attribute to each X-position.

Different complexes may have the same structure, they are isomorphic. For two complexes to be isomorphic, their topological domains must have the same structure, the sets of attributes of the two complexes must have the same structure and the attributes of both complexes have to be assigned to corresponding positions of the domains[20].

Isomorphic complexes are related by transformations. Different but isomorphic complexes possess certain structural similarities. Consider a piece of music and another, different piece of music, that is a transposition of the first. They are certainly different, but isomorphic, and they share the same melody. Therefore, there are attributes that are shared by all complexes of a group of isomorphic complexes. They are called complexial features, attributes that are invariant under isomorphic transformations. As Rescher and Oppenheim point out, those

[20] For a more detailed discussion of complexes and isomorphisms between them, see [Rescher and Oppenheim, 1955] or Russel's "Human Knowledge".

attributes may even be underivable. The possession of attributes that are invariant under those transformations is stated as the Second Ehrenfels-criterion.

Let us now apply this formalism to situoids. First we examine what kinds of decompositions of situoids exist. We will examine some possible decompositions shortly, without much discussion and motivation, before we concentrate on one specific decomposition which we will examine further.

Since situoids exist in time and space, our first possible decomposition is a *spatio-temporal* one. We will denote this part-of relation with $\leq_{st}$. For this we project the situoid on parts of its framing chronoid or topoid or both[21]. The attributes we may consider are the duration or spatial size the resulting entities have. Then we do have a derivable attribute, namely the new duration and spatial extent the whole situoid has. The spatio-temporal parts of the situoid, possibly, but not necessarily, situoids on its own, may be cause and result of each other, however, this does not always have to be the case, especially if the spatio-temporal parts are not situoids.

We could also decompose one situoid in multiple sub-situoids, all of which are part of one situoid. We call this a *situoidal* decomposition and denote the appropriate part-of relation $\leq_s$. The parts form a web of situoids, influencing each other and being cause or result of each other. However, the structure of the whole situoid is generally derivable by the structure of its subsituoids.

Because situoids are described by infons, we can consider an *infonic* decomposition of situoids, formed by the relation $\leq_{inf}$ or simply $\leq$. The entities that are part of a situoid in this sense behave much like situoids and sometimes are situoids, but they contain less information. They may provide a more abstract view on a situoid, or a more limited. Consider a situoid w of a specific plaza.

[21] Please note, that the result of this projection may be a situoid, but in the general case it is not. We could end up with some empty region of space over a period of time. In the most general sense, the parts of a situoid in this sense are processes.

Then the infonic parts of this situoid may contain a single human, a fountain, a tree, one square meter of concrete plate, and so on. When all those parts are assembled, the situoid w is an instance of the universal *Plaza*, but none of its parts are. The attribute of "being a plaza" emerged, when the parts where put together. The second condition however will fail. There is no interdependence between infons in a situoid. Each infon describes some basic information of a situoid by stating a relation, a configuration of objects. They may be informational equivalent, or one is entailing another (logically or with respect to some theory), but many infons obtaining in situoids are independent of each other, and are describing different aspects of the situoid.

We have not discussed all the possible decompositions in detail, as we just wanted to get the idea. There is another decomposition that we will discuss in more detail, namely decomposing the situoid into situations by using the relation $\leq_{sit}$, entities that exist at time points. This can be achieved by projecting the situoid on the boundaries of its framing chronoid. As a result, we get a sequence of situations. We will now examine this decomposition in detail and try to find out, whether situoids fulfil all three conditions of wholes regarding this decomposition.

First we have to examine whether the relation $\leq_{sit}$ defines a decomposition of situoids. A situation is the projection of a situoid on one of the time boundaries of its framing chronoid. Therefore, $sit \leq_{sit} w$, iff sit is a situation, w a situoid, chr the chronoid framing w and sit is the projection of w on one of the time boundaries of chr. Let D be the class of all situations of the situoid w. We can see, that $\leq_{sit}$ is not reflexive, so we will consider it an irreflexive part-of relation. Then, D is a decomposition of w regarding the part-of relation $\leq_{sit}$ if every $\leq_{sit}$-part of w overlaps with some $\leq_{sit}$-part of D. However, our understanding of the relation $\leq_{sit}$ defies the usual understanding of a part-of relation, as it is a relation between two distinct classes of entities, situations and situoids, and cannot be applied to the parts. For the sake of the argument, we will make the relation $\leq_{sit}$

reflexive: $\forall x(x \leq_{sit} x)$.

Now we can show, that D, the class of all situations defined by a situoid w, is a decomposition of w. Let $overlaps(x, y) = \exists z(z \leq_{sit} x \land z \leq_{sit} y)$. Then it can be easily shown, that $\forall x(x \in D \to \exists y(y \leq_{sit} w \land overlaps(x, y)))$, because D contains all the situational parts of w.

The result is pretty trivial, but will become more useful when we start extending the relation $\leq_{sit}$. The class D of all situations of the situoid w is still a decomposition of the relation $\leq_{sit} \cup \leq_{s}$. We can also extend this relation further, by adding an infonic part-of relation on situations, and D will still be a decomposition of w.

Obviously, the sum of all situations in chronological order is a sequence of entities, that can be described by states of affairs, just like in situation theory, or situation calculus. Our second condition for wholes is satisfied, because situations may be causes of their following situations, or results of previous situations. Therefore, the infons obtaining in one situation may depend on the infons obtaining in previous situations and with this, the perception of one situation may depend on their neighboring situations and the whole.

Let us consider an example to illustrate this idea. Imagine a 100 meter race as a situoid. Two people are running, A and B. So we will have a situoid s with a topoid t and $top(s, t)$. The runners start at the location x_{start} and finish at x_{finish}. The race lasts 20 seconds, so there is a chronoid c_{20} with $prt(s, c_{20})$. A needs 10 seconds to reach the finish line, therefore running during the chronoid c_{10}, B needs 20 seconds. We will express this with the timed infons $\phi_A = \langle\langle Runs, A, x_{start}, x_{finish}; 1; c_{10}\rangle\rangle$ and $\phi_B = \langle\langle Runs, B, x_{start}, x_{finish}; 1; c_{20}\rangle\rangle$ and $s \models \phi_A$ and $s \models \phi_B$. Projecting s on the right boundary of $c_1 0$ we will obtain a situation s_A where A is finishing the entire race, s: $s_A \models \langle\langle Finishes, A, s; 1\rangle\rangle$. The second situation will be the projection of s on the right boundary of c_{20}, s_B. A similar infon obtains here, $s_B \models \langle\langle Finishes, B, s; 1\rangle\rangle$, but due to the position of

s_A in s we know, that he did not win the race: $s_B \models \langle\langle Wins, B, s; 0\rangle\rangle$. However, a detailed investigation of causality in the framework of GOL, and therefore also in the framework of situoids and situations is still an open research topic.

The situoid is structured into situations as the chronoid is in time boundaries, because we are only projecting the situoid on its framing chronoids time boundaries. For the third condition – that the situoid must possess some kind of structure, in virtue of which certain structural characteristics pertain to it – to be satisfied we will need to identify the parts, a domain of positions the parts may occupy and an assignment function assigning each part to a position. The parts are the situations, the positions the time boundaries and the assignment function is our projection of the situoid on the time boundaries. As Rescher and Oppenheim point out in [Rescher and Oppenheim, 1955], we usually do not care about the individual parts, but rather about the types of the parts. Doing so, they call the entity of concern a "complex", while we will talk about "universal" in a more general approach.

We assumed that every situoid is an instance of some universal. Universals define the structure whose possession is required of wholes in [Rescher and Oppenheim, 1955]. Universals may require the existence of certain situations in a situoid. These are the parts that are assigned to spatio-temporal locations inside the situoid by the universal. Then, a "transposition" in the sense of [Rescher and Oppenheim, 1955] is nothing more than another instance of the same universal. And usually, there are features of a situoid which are solely due to its being an instance of a specific universal.

For example, the universal "100 meter race" will require the existence of certain situations, at least a starting and an ending situation, which are assigned to the left respectively the right boundary of the chronoid framing the situoid w. The other parts (situations) required by an universal which w is an instance of, if any, behave as well and are accordingly assigned to certain spatiotemporal locations.

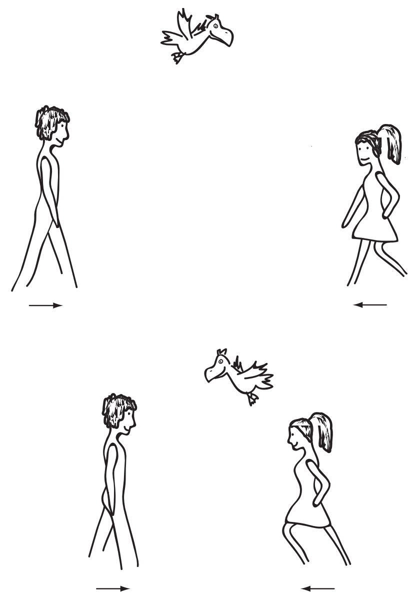

Figure 5.6: Flying bird example

It is this structure – the assignment of situations to proper space-time locations – which makes some situoid a 100 meter race[22] and which makes it an instance of the universal "100 meter race".

Now the question is, whether a situoid is more than just a mere sequence of situations. This is the case, because situoids are continuous. Just like chronoids cannot be understood as sets of time boundaries, but are inherently more, situoids are inherently more than collections of situations. There are even processes, that can never be fully understood in the domain of situations, but only in a continuous structure like situoids.

Let us consider an example, illustrated in figure 5.6[23]. There are two people, *A* and *B* 100 meter apart. Both are walking towards each other in a straight line

[22]Please note, that this statement is valid only with regard to the specific part-of relation which we have used.

[23]The illustration is due to Karen Walzer.

with a velocity of one meter per second. A bird flies between A and B, starting from A, with 100 meters per second. When the bird reaches A or B, it turns around in no time, and flies the other way. There are three concurrent processes, one depending on two others. These processes can be embedded in a situoid, but cannot be understood in the domain of situations. In the domain of situations this example would be modelled by a sequence of situations, at least one for every occurring change. So whenever the bird reaches A or B, a situation is needed to state that the bird is changing direction. But when we would ask which direction the bird would be facing when A and B meet, we cannot get an answer if these processes are modelled as sequences of situations. We will not get an answer either in the domain of situoids, but there we cannot ask the question. There are just three processes, one depending on two others, and the changes of heading are of no concern.

There are more Zeno-like paradoxa which can be used to argue in favor of situoids being more than a mere sequence of situations. Imagine Zenos arrow, which is not moving at any point in time, but still changing position. In the domain of situoids, this arrow is indeed moving in a straight line with a velocity v, while in the domain of situations this arrow may be changing positions while its velocity is zero. However, more research has to be done with respect to examples such as the above flying-bird example, as the explanation of why it is impossible to determine the direction in which the bird is flying at the end is somewhat awkward.

But still we believe the first condition for wholes satisfied. The whole situoid is more than the sum of its $\leq_{sit}$-parts.

We have found a decomposition and discussed a set of attributes, that fulfills all our conditions for wholes, and can therefore regard situoids as “whole” at least with regard to the $\leq_{sit}$ relation.

5.2.10 Being part of reality

It may be puzzling to raise the question of what is meant by something being a part of reality, since it appears so obvious. However, in order to specify what situoids are and what they are not, we pursue this path.

"Being a part of reality" suggests, that reality can be comprehended as something whole. According to Wittgenstein in [Wittgenstein, 1959], the world, reality or all there is, consists of all the facts and their being all the facts. Situoids, however, are parts of reality, that can be comprehended as wholes. Therefore, their internal structure should correspond to the one of reality, namely being a set of facts. We will, as Barwise did in [Barwise, 1989], use (hyper-)sets of infons for modelling situoids and situations.

We can ask the question whether reality, all there is, can be considered a situoid. Reality would have to be a maximal situoid, with all states of affairs settled. However, due to our axiom 5.21, this cannot be the case. We could always objectify one situoid, and embed it in another, even larger situoid, a situoid with more information. Therefore, there is no largest situoid and reality is not a situoid. Reality cannot be comprehended as a whole.

We assume that there exists a world and reality independent of our mind and beliefs. This reality can be decomposed in situoids, that can be comprehended as totalities[24]. We will sometimes refer to this kind of situoids as "real" or "actual" situoids. Then there is a second class of situoids, that we will call "intentional". They exist in a different mode of reality. They exist as entities in mind. As an example of a situoid of this kind, consider a situoid, where a unicorn stands in a forest.

[24] We have to emphasize, that these situoids do not come into existence through our act of comprehension. They do exist independently, with the property of being comprehensible. They would exist even without any subject with the ability of comprehension.

The question is, whether intentional situoids are a part of reality, or in what sense they exist. To clarify this, we will have to state the following definition. Remember the beginning of this chapter, where we defined a partial part-of order for situoids, regarding the infons that obtain in those situoids.

Our intention is, that all of reality can be structured in two classes, situoids and worlds. We will simply state the existence of a class of all parts of reality, and define a partial order on this class. The order relation is indeed the infonic part-of we have been using throughout this chapter, although this is not explicitly stated here. Most things should become clear after axiom 5.23.

Definition 5.21 (World). Let S be the set of all situoids. Let $T \supseteq S$ be the set of all parts of reality. The relation $\leq$ defines a partial order on T. Every maximal element of the $\leq$-order on T is called a world.

The idea behind this definition is perhaps not obvious. Of concern to us are situoids, either real or imagined. These situoids can be informationally extended in various ways. Usually, we can add either an infon or its complement as information. This gives rise to various different ways the situoid behaves, and therefore to various different ways of how reality is. What we obtain is a partial order. Now, if this partial order has some kind of maximal element, we will call it a world. However, the idea behind a world was that all issues are settled. So we need another axiom to ensure this.

We can then state the following axiom:

Axiom 5.23. Let S be the set of all situoids and $T \supseteq S$ the set of all parts of reality. $partof$ defines a partial order on T. Every totally ordered subset A of T has a unique upper bound m in T, such that $\forall x(x \in A \wedge x \neq m \rightarrow x \in S)$.

What worlds are and how we can model them will become clear with the following theorems.

Theorem 5.1. *There is a world.*

Proof. Because of axiom 5.23, every totally ordered subset of the set of all parts of reality T has an upper bound. Therefore, according to Zorn's lemma, the partial order $(T, \leq)$ has a maximal element. ∎

We do not only know, that worlds exist, we can say what they look like, because we defined the $\leq$-Relation as referring to sets of states of affairs. For this, we need to extent the relation $\models$ to all elements of the set T of all parts of reality.

Definition 5.22 (Supports relation for worlds). Let w be a world, and i be a state of affairs. Then $w \models i \iff \exists s(Situoid(s) \wedge s \leq w \wedge s \models i.$

Then every chain of situoids in the partial order of parts of reality defines a world, namely an entity, in which every state of affairs that obtains in any situoid of this chain obtains. With this, we are again back to Wittgenstein, where a world consists of all the facts, and their being all the facts [Wittgenstein, 1959].

We also know, that worlds are not situoids, they are always more, according to axiom 5.21.

This view on worlds and their correspondence to situoids gives us the liberty of choosing, whether we want to accept the existence of multiple, possible worlds or only a single, real world. This choice has to be formulated in another axiom. We therefore have to choose between the following two axioms:

Axiom 5.24. There is only one world.

Axiom 5.25. There is more than one world.

There is another view on worlds. Let Σ be a finite set of infons. Then a world w is a binary partition of Σ, (Γ, Δ). The idea is, that Γ is the set of infons that holds of the world w, and Δ is the set of infons that does not hold: $\forall\phi(\phi \in \Gamma \rightarrow w \models \phi)$

and $\forall\phi(\phi \in Delta \to w \not\models \phi)$. This is a useful limitation of our view, because in many applications only a finite set of infons is of concern. Let us see if it converges to the previous view on worlds.

Definition 5.23 (Consistence of sets of infons). A set of infons Σ is consistent, if the following is true: If some infon $\phi \in \Sigma$ with $\phi = \langle\langle R, a; p\rangle\rangle$, then $\bar{\phi} \notin \Sigma$ with $\bar{\phi} = \langle\langle R, a; 1-p\rangle\rangle$.

We need one more axiom in order to obtain our desired result.

Axiom 5.26. Every consistent, finite set of infons Σ defines a situoid s, such that $\forall\phi(\phi \in \Sigma \to s \models \phi)$.

Please note that the situoid may support more infons, for example due to certain constraints.

Theorem 5.2. *Let Σ be the set of all infons. A partition (Γ, Δ) of Σ, Γ and Δ consistent, defines a world w in the way that $\forall\phi(\phi \in \Gamma \to w \models \phi)$ and $\forall\phi(\phi \in \Delta \to \neg w \models \phi)$.*

Proof. First we prove that w is maximal coherent. No w' with $w \leq w'$ and $w \neq w'$ is coherent. Let us assume, there was such a w'. Let us assume that $w' \models \phi$ and $w \not\models \phi$. Since (Γ, Δ) is a partition of the set of all infons, $\phi \in \Delta$. The complement of ϕ, $\bar{\phi}$, is in Γ, $\bar{\phi} \in \Gamma$, because Δ is consistent. But $w' \models \phi$ and, because $w \leq w'$, also $w' \models \bar{\phi}$, so w' is incoherent.

Every finite subset Γ' of Γ defines a situoid s such that $\forall\phi(\phi \in \Gamma' \to s \models \phi)$. There is a situoid s_0 defined by a finite set $\Gamma' \subset \Gamma$ such that $S(s_0) \subseteq \Gamma$. If this was not the case, then there would be a $\phi \in \Delta$ and $s_0 \models \phi$ for all s_0 defined by Γ'. But $\bar{\phi} \in \Gamma$, and $\Gamma' \cup \{\bar{\phi}\}$ defines a situoid, so there is a situoid s_1 defined by Γ' and $s_1 \models \bar{\phi}$, which is a contradiction.

There is a situoid s_0 with $s_0 \leq w$. w is the maximal element in the part-of order, s_0 is part of reality, therefore w is a world. ∎

5.2.11 Granularity and levels of reality

Let us revisit section 5.2.8. We want to investigate further how a human agent comprehends something. This time, we are more interested in a psychological view, and therefore more focused on the comprehensive abilities of the agent but on the ontological properties of situoids. For this we will investigate some results of modern cognitive psychology, linguistics and discourse analysis. The goal will be to distinguish real from intentional entities in situoid theory.

Whenever a human, intelligent agent uses its cognitive abilities to gather information, for example to read a text, watch a soccer game or follow the steps of a proof, small chunks of information are placed into short term memory, like a single word, a certain move or setting on a game field or a formula. This information is forgotten after approximately 30 seconds, unless rehearsed [The Internet Community]. Short term memory has only a limited capacity. The number of chunks that can be stored in short term memory has been identified by George A. Miller in his article "The magical number Seven, plus or minus Two" as approximately seven. This refers to the amount of meaningful pieces of information or chunks people can reliably remember for a few minutes.

In [van Dijk, a], the steps for discourse production are summarized as follows, and they can be, slightly modified, applied to comprehension of entities in general.

- Text/talk is read/heard and interpreted on line, unit by unit (e.g., word for word)
- On the basis of world knowledge, as well as knowledge of words, syntactic structure, overall meaning (topics), discourse structures and aspects of context (goals, etc) such units are assigned provisional meaning

- Meanings of smaller units are combined (and where necessary corrected) into those of bigger units, such as propositions, and sequences of propositions, until the Short Term Memory buffer is (nearly) full.
- The thus interpreted bigger chunks are stored in a Textual Representation (TR) in Episodic Memory.
- Parallel to this understanding of the respective units of the text and the formation of a TR in Episodic Memory, language users activate an old, or construct a new (mental) model of the events or situation the text is about.
- Understanding a text means the construction of such a model: A text is meaningful or understandable when a recipient is able to construct a model for it.
- Apart from meaning elements from the (mental representation of the) text, also information from previous (old) models (= earlier experiences), as well as specific instances of general (socially shared) knowledge help to build up such models.
- Models are both personal (featuring individual knowledge, beliefs, opinions of language users) as well social (applying general, socially shared knowledge), but each model is unique. The same person may construct a different model (=a different interpretation) of the same text tomorrow.
- The whole process of understanding is coordinated by the model language users have of the communicative situation, namely their context model (or simply: context). The context model tells the language user what the aims of the discourse are, who the participants and their roles are, what they know and do not yet know, in what setting the discourse is being understood, and so on. Such crucial information is necessary to understand such diverse properties of discourse as its intonation, lexical and syntactic

style, which meanings are expressed or left implicit and what speech acts are being performed.

- Once formed –or updated– a (mental) model of a discourse, language users may generalize such models and thus construct more general, more abstract knowledge structures. It is in this way that language users may learn from their experiences. Of course, they may also make false generalizations, and thus, form prejudices.

In cognitive psychology, these principles are reflected by the concept of chunking. Short term memory with a limited capacity is the place where all incoming information from our senses is analyzed and interpreted first. Chunks of information are assigned a conceptual meaning in short term memory. Perception, comprehension or reasoning takes place in short term memory. The information from short term memory is then stored in the long term memory. However, it cannot always be retrieved. Because short term memory has a limited capacity, the process of assigning conceptual meaning to some whole happens in several chunks. We do not just read in a whole text and start assigning a meaning to it. And we do not perceive all the states of affairs in a situoid at once and start assigning a meaning to the situoid.

This process has to happen in several chunks. Cognitive interpretation, sometimes referred to as comprehension, begins immediately with the perception of the information. The appropriate concepts are then transported to long term memory as soon as the memory capacity of short term memory requires it. Also, the chunks of information have to be semantically connected, in order to assign a meaning to them. We do not simply give some meaning to a state of affairs and place this concept in long term memory, and remove it from short term memory right after. We must assume, that the state of affairs, or at least its interpretation, is still available in short term memory when we start interpreting the next.

This semantic interpretation is purely local. It consists of perceiving chunks of information one after another, and assigning meaning to them and their relations to each other. However, this does not lead us to a conceptual meaning of some whole, a text or a situoid. It does not let us assign the chunk its appropriate role or place in the whole. In cognitive discourse analysis, this concept of global interpretation is made explicit in terms of a semantic macro-structure[van Dijk, b]. In cognitive psychology, it is explained through consecutive chunking up[25].

As situoids are comprehensive entities, the same principles apply to them. Therefore, situoids can be described on different levels, from different perspectives, in a lot of different ways. Different ways of describing a situoid result in different models of the situoid.

Imagine a situoid of a plaza. First this situoid is the instance of a universal, say, $plaza_U$. This universal requires of its instances certain features, say, the existence of certain infons like $\langle\langle Tree, x; 1\rangle\rangle$, $\langle\langle Fontaine, x; 1\rangle\rangle$ or $\langle\langle Person, x; 1\rangle\rangle$, stating that there must be a tree, a fountain and a person on the plaza[26].

[25] With the chunks of information possessed and comprehended, we can generalize the information, and therefore move to some higher, more abstract concepts. This is referred to as "chunking up". On the other hand, if we already possess high-level information and assigned it an appropriate conceptual meaning, we can particularize these concepts, and move to more concrete, lower-level chunks. This is referred to as "chunking down". When chunking down, we could ask question like

- How did this happen?
- Why did this happen?
- What is the root cause of this?
- What specifically is it about?
- What is an instance of this concept?
- What are the parts of this?

When chunking up, we may ask the following questions:

- What does this mean?
- How is this related to...?
- What is this a part of?
- What is this for?

[26] We are aware of the fact that there are plazas without people, trees and fountains, but we suppose $Plaza_U$ is the universal for plazas of this kind.

Now we imagine to stand on this plaza and describe it to our blind friend, B, and call this situoid s_1. We state that

- $s_1 :: Plaza_U$
- $s_1 \models \langle\langle Person, person_a; 1\rangle\rangle$
- $s_1 \models \langle\langle Has-red-hair, person_a; 1\rangle\rangle$
- $s_1 \models \langle\langle Is-attractive, person_a; 1\rangle\rangle$
- $s_1 \models \langle\langle Fontaine, fontaine_a; 1\rangle\rangle$
- $s_1 \models \langle\langle Is-high, fontaine_a; 0\rangle\rangle$
- $s_1 \models \langle\langle Person, person_b; 1\rangle\rangle$
- $s_1 \models \langle\langle Walks-from-to, person_b, x_1, x_2; 1; c_1\rangle\rangle$
- $s_1 \models \langle\langle Sees, B, s_1; 0\rangle\rangle$
- and so on...

Now this may be a detailed description of the plaza ahead, with a description of the persons, the fountain and even a process that involves a person. The existence of a tree is not further described but already acknowledged by stating that $s_1 :: Plaza_U$. Individuals are referred to by name.

Now time has passed, we are back home and recall the plaza to write a report about it in our diary. Let us call the situoid described there s_2. Certain features will be lost. We will probably still remember that $s_2 :: Plaza_U$. Maybe we also remember that there was this attractive red haired person. But the fountain was of no interest to us, so we forgot whether it was high or not. Therefore the situoid s_2 is different from s_1.

However, there is another view on granularity. In the ontology of GOL it is believed that reality exists in at least three different strata, that can be distinguished by the categories they incorporate. The physical stratum is the most fundamental, and the mental and social strata are founded on this stratum. Properties of the entities in the mental and social strata are supervenient[27] on properties of the physical stratum.

We believe that the physical stratum defines a continuous reality, and situoids may exist in the physical stratum. Entities existing at a point in time, endurants, are constructions of a mind, and do not belong to the physical stratum. They belong to the mental or social stratum. Situations are entities of this kind. However, situoids may participate in the mental stratum, too.

5.3 Situations

Situations are entities in the realm of endurant. They are projections of situoids on time boundaries. They are wholly present at a point in time. Otherwise, mostly the same principles apply to situations as they do to situoids. They are comprehensible entities that exist in reality.

[27] Supervenience is a well defined property in philosophy. A group of properties of some higher level, such as the mental stratum, X supervene on the properties of some lower level, such as the physical stratum, Y, if and only if the following is true for all objects a and b:

- a and b cannot differ in their X-group properties without also differing in their Y-group properties.
- If a and b have identical Y-group properties, then they also have identical X-group properties.
- If a and b do not have identical X-group properties, then they also do not have identical Y-group properties.

Note that if a and b have the same properties on the higher level, X, they do not necessarily have to have identical lower level (Y) properties

5.3.1 Axioms for situations

Of course, situations are much simpler than situoids. There can be no progress, no change in situations. Only instantaneous states of affairs exist in a situation. Let us state, without much discussion, the first axioms for situations. Most of them should be clear from our previous discussion of situoids.

Let us remember our definition for situations.

Definition 5.24 (Situation (2)). A situation is a comprehensible entity in reality, that exists at a point in time. It is the projection of a situoid on a point of time. The class of all situations is denoted by $Situation$.

Axiom 5.27.

$$\exists x Situation(x)$$

Situations exist at time boundaries. There is a function $tbs : Situation \mapsto TB$, where TB is the set of all time boundaries.

Axiom 5.28.

$$\forall x, b\,(Situation(x) \land tbs(x) = b \rightarrow tb(b) \land \exists y(Situoid(y) \land chrs(y) = c \land tb(c, b))$$

We can now define the relation, first mentioned in section 5.2.9, that a situation s is part of a situoid w.

Definition 5.25 ($\leq_{sit}$, situational part-of).

$$s \leq_{sit} w \iff Situation(s) \land Situoid(w) \land tbs(s) = b \land chrs(w) = c \land tb(b, c) \land \exists t(topoid(t) \land top(s, t) \land top(w, t))$$

We define the supports relation from section 5.2.2 for situations as follows.

Definition 5.26 (Supports relation for situations). Let $SInfon$ be the class of all infons except timed infons. The relation $\models \subseteq Situation \times SInfon$ is called obtains relation. We use infix notation to denote this relation: $s \models \phi$, which is read as "The infon ϕ obtains in the situation s.

Timed infons do not make sense in situations, as situations exist at precisely one point in time, a single time boundary, and the states of affairs that correspond to the obtaining infons have to exist at the same point in time. This does not mean, that the entities participating in the states of affairs have to exist at time-boundaries, too. As an example, consider the state of affairs "The process p's being earlier than the process q".

As we did for situoids, we can now define another, basic part of relation.

Axiom 5.29.

$$\forall s_1 \forall s_2 (Situation(s_1) \wedge Situation(s_2) \wedge s_1 \leq s_2 \implies \forall \phi (s_1 \models \phi \rightarrow s_2 \models \phi))$$

And also, two situations are identical, if and only if the same infons obtain in them, that is, if they are part of each other. Again, this is insufficient. They also have to exist at the same time boundary, and they have to be a situational part of the same situoid.

Axiom 5.30.

$$\forall s_1 \forall s_2 (Situation(s_1) \wedge Situation(s_2) \wedge s_1 = s_2 \iff s_1 \leq s_2 \wedge s_2 \leq s_1 \wedge \exists s (Situoid(s) \wedge s_1 \leq_{sit} s \wedge s_2 \leq_{sit} \wedge tbs(s_1) = tbs(s_2)))$$

We extend the function $S(s)$, taking situoids into sets, to accept situations as its arguments.

Axiom 5.31. There is a function $S : Situoid \cup Situation \mapsto Set$, such that

$$x = S(s) \iff \forall\phi(s \models \phi \leftrightarrow \phi \in x)$$

Again, the same as for situoids, we do not want to permit empty situations.

Axiom 5.32.

$$\forall s(Situation(s) \rightarrow \exists\phi(Infon(\phi) \wedge s \models \phi))$$

Now we said that situations are comprehensible entities. Some of the axioms of section 5.2.8 have to be adapted and applied to situations. The first important condition is, that every situations has to be the instance of at least one universal.

Axiom 5.33.

$$\forall s(Situation(s) \rightarrow \exists u(Universal(u) \wedge s :: u))$$

Again, given a certain situation, we can add more and more information to it, infinitely. This is different to situoids, as they can also be more and more extended in time, while situations cannot.

Axiom 5.34.

$$\forall s(Situation(s) \rightarrow \exists t(Situation(t) \wedge s \leq t \wedge s \neq t))$$

The last axiom needed for situations to be comprehensible entities is the following:

Axiom 5.35. The set $S(s)$ of all infons obtaining in a situation s is decidable.

5.3.2 Are situations part of reality?

Note, that we did not consider situations as parts of reality. This is a brake with Barwisean situation theory. Motion, actions, events are without beginning or end. Reality is a continuous process. Although motion, actions and events occur over time, and therefore are not instantaneous or eternal, every action, motion or event succeeds and precedes another. One may argue, that motion and action have a start, a beginning, a so-called first cause, but this cause is beyond reach of human understanding. The same applies to the end of all actions and events. We exist therefore in a continuous reality.

Although reality is continuous, our perception is not. We seem to be unable to comprehend the whole of this continuous reality. Therefore we brake up reality into discrete pieces, with starts and stops. We believe certain entities to exist between those pieces, entities we described as situoids, and sometimes they are called events. This braking up into pieces is totally subjective. The starts and stops is what we call "situations". "These boundaries of events are, of course, even more artificial and contrived than events themselves. Events do contain a portion of reality. Situations, on the other hand, do not. As boundaries, they have time-space locations, but while the space locations are necessarily extended [...], the time dimensions are not extended. Situations are, indeed, motion and action imagined to a standstill, movers and actors occupying space but deprived of their denoted characteristics."[Riker, 1957]

As a result of this, we end up with another axiom, namely that every situoid defines at least two situations, an initial situation and a terminal situation.

Axiom 5.36.

$$\forall x(Situoid(x) \wedge chrs(x) = c \rightarrow \exists s_1 \exists s_2 (Situations(s_1) \wedge Situation(s_2) \wedge$$
$$tbs(s_1) = b_1 \wedge tbs(s_2) = b_2 \wedge lb(c, b_1) \wedge rb(c, b_2)$$

5.3.3 Changes

Two situations are said to coincide, if the time-boundaries at which they exist coincide. Two situoids are called "successive situoids" if the terminal situation of the first coincided with the initial situation of the second.

Now let us define what we mean by a change.

Definition 5.27 (Change). A change c is an ordered pair of situations, s_1 and s_2, such that $S(s_1) \neq S(s_2)$ and $tbs(s_1) < tbs(s_2)$[28]. We will note a change of this kind as $c = (s_1, s_2)$. The class of all changes is called *Change*.

There are two kinds of changes, instantaneous changes and eventual changes.

The first type appears for example, when we consider a lamp that is being turned on as a situoid. In the initial situation, the lamp is off. Then there is the process of turning the lamp on. Let us end this situoid and the process of turning on the lamp with the lamp still being off. This is the terminal situation of the first situoid. A successive situoid starts with the lamp being on. The initial situation of the second, s_2, coincides with the terminal situation of the first, s_1. At least one infon changed polarity, and therefore $S(s_1) \neq S(s_2)$, and (s_1, s_2) is a change.

Let us consider the same process of turning on a lamp in a somewhat larger situoid. Then, the lamp is turned off in the initial situation, s_1, but turned on in the terminal situation, s_2. Those two situations do not exist on coinciding time boundaries, but again, at least one infon changed polarity, and therefore (s_1, s_2) is again a change.

Considering two situations, s_1 and s_2. What happens, if there is an infon ϕ that obtains in s_1, but neither ϕ nor its complement obtains in s_2. Would we consider

[28] It is assumed here that right boundaries are before (<) left boundaries.

this a change? Our answer is yes, because somehow, information appears to have got lost. If we start out knowing the lamp is turned off, but we end up with a situation in which no information about the lamp's being on or off is present, certainly something changed.

Another problem appears, when we consider two seemingly unrelated situations, for example one, s_1, with the lamp being turned off, and another one, s_2, with John kissing Mary. Most people would not consider this a proper change, although both situations are totally different. This may even be the case with coinciding situations. As changes happen in the frame of situoids, we will state another axiom, in order to prevent these types of changes.

Axiom 5.37.

$$\forall c(Change(c) \land c = (s_1, s_2) \rightarrow \exists s(Situoid(s) \land s_1 \leq_{sit} s \land s_2 \leq_{sit} s))$$

Changes therefore have to be considered with respect to a situoid.

5.3.4 Anchors

Situations as well as situoids are instances of at least one universal. Universals are intensional, they determine the properties of its instances. Unfortunately, we have no means of describing those properties, and the language GOL does not provide those means either. Because there is no plausible formalism how to specify universals, we will develop one ourselves, but just for situations and situoids. This may be generalized to other categories, but we will not take our approach that far.

Before we do this, we have to change our perspective a bit. While we have been concerned with ontological properties of situations, situoids, infons and states of affairs until now, we will need to focus more on formal details of those entities than we have done before. We omitted those details because they were not relevant in our previous discussion.

Remember that relations in the General Formal Ontology are special types of universals. Instances of those universals are called relators. Every relation R comes with a set of argument roles, $Arg(R)$. For example, the relation *eating* comes with the role of the *eater*, the *eaten*, and the *location* the eating takes place. Those roles are filled with objects of appropriate sort. The *eater* has to be some kind of living organism, the *eaten* some physical entity, the *location* a spatio-temporal one, specified by a chronoid or time-boundary and a topoid. An instance of the relation universal, the relator, connects entities of appropriate sort. The connection between those individual objects through the relator is what we called a state of affairs. Pictural states of affairs are determined by an instance of a relation R, the relator r, and an assignment function assigning appropriate objects to the set of arguments of R, $Arg(R)$. The assignment function may be partial. Let R be a relation, f the assignment function and $\{x_1, ..., x_i, ..., x_n\}$ be the set of arguments of the relation R in the pictural state of affairs $\phi = \langle\langle R, ..., x_i, ...\rangle\rangle$. Then $\langle\langle R, ..., x_i, ...\rangle\rangle[f] = \langle\langle R, ..., f(x_i), ...\rangle\rangle$. Sometimes, in situation theory, this function f is called an anchor.

We will use a similar notion for infons. Let i be an infon with the pictural state of affairs $\phi = \langle\langle R, x_1, ..., x_i, ..., x_n\rangle\rangle$. Let f be an assignment function: $f : \{x_1, ..., x_n\} \mapsto Entity$. Then f satisfies the infon i relative to a situation s iff $s \models i[f]$ iff $s \models i'$ and f is the assignment function of the pictural state of affairs of i'. Because we will need the assignment function more often in the future, we introduce the following definition.

Definition 5.28 (Anchor function). Let i be an infon with the pictural state of affairs ϕ, and let f be the assignment function that is part of ϕ. Then $anchor(i) = f$.

5.3.5 Compound infons

There are three kinds of compound infons, the meet of a set of infons and the existentialization of an infon respectively an argument x, and the negation of an infon.

Definition 5.29 (Meet of a set of infons, existentialization and negation of infons). Let I be a set of infons and i be an infon. Then $\bigwedge I$ is called the meet of a set of infons, and $\exists x(i)$ the existentialization of i with respect to x. $\neg i$ is called the negation of i.

This leads to another axiom.

Axiom 5.38. Let I be a set of infons and i be an infon and s a situation or situoid. Then

- $s \models \bigwedge I$ iff $s \models i$ for all $i \in I$
- $s \models \exists x(i)$ iff for some object a, $s \models i'$, where i' is identical to i except for the anchor of i' $anchor(i') = f$ and $f(x) = a$.
- $s \models \neg i$ iff $s \not\models i$.

Using this axiom leaves the ontological status of infons unchanged. They still correspond to pictural states of affairs which correspond to states of affairs. Compound infons do not correspond to pictural states of affairs, but we do not need to introduce such a notion, because we just use compound infons as a convenient way to express more complicated propositions in an easy fashion.

5.3.6 Universals

Now to universals. How can a universal with situations as its instances be specified? What would have to be specified? A universal specifies certain properties and relations of its instances. This may only be done using relations where at least one argument, one role has to be filled by the individual that is the instance of the universal. For example, the universal $Human_s$, human being as a social being, would have to be specified by the relations the instances of this universal have to other human beings. On the contrary, $Human_b$, human being as a biological entity, would be described by its anatomical parts and their spatial position, and maybe the function of those parts. In general, every universal defines a theory about its instances.

Let us assume, this theory is defined in standard first order logic[29]. Then $\Sigma = (F, R, C; ar)$ is the signature with a set of function symbols F, a set of relation symbols R and a set of constant symbols C, with $C \subseteq F$. ar is a function $ar : F \cup R \mapsto \omega$ and is called arity. The alphabet over Σ, $Al(\Sigma)$ consists of a set of individual variables Var, the symbols given by the signature Σ $F(\Sigma)$, $R(\Sigma)$ and $C(\Sigma)$, and the symbols $\exists, \neg, \wedge,), ($. The set $Tm(\Sigma)$ of terms is the smallest set containing $Var \cup C(\Sigma)$ and closed under $F(\Sigma)$ (that is, if $t_1, \ldots, t_n \in Tm(\Sigma), f \in F(\Sigma), ar(f) = n$, then $f(t_1, \ldots, t_n) \in Tm(\Sigma)$). An atom formula is a string of the form $R(t_1, \ldots, t_n)$, where $R \in R(\Sigma), t_1, \ldots, t_n \in Tm(\Sigma), ar(R) = n$. The set $Fm(\Sigma)$ of formulas is the smallest set of strings over $Al(\Sigma)$ containing the atom formulas and being closed under the conditions: if $A, B \in Fm(\Sigma)$, then $\{\neg A, A \wedge B\} \subseteq Fm(\Sigma)$. If $A(x) \in Fm(\Sigma)$ and x is free in A, then $\exists x A(x) \in Fm(\Sigma)$. Let $T(\Sigma) \subseteq Fm(\Sigma)$, then $T(\Sigma)$ is called a theory. If the signature is fixed, we omit Σ and write just T for theory.

An interpretation over a signature $\Sigma = (F, R, C; ar)$ is a structure (called Σ-structure) $\mathcal{A} = (U, (f^\delta)_{f \in F}, (R^\delta)_{R \in R}, (c^\delta)_{c \in C})$ which is defined by a set of individuals U, $f^\delta : U^{ar(f)} \mapsto U$, $R^\delta \subseteq U^{ar(R)}$, $c^\delta \in C$. Let $\mu : Tm(\Sigma) \mapsto U$, $\mu(t) \in U$ if $t \in Var$, $\mu(f(t_1, \ldots, t_n)) = f^\delta(\mu(t_1), \ldots, \mu(t_n))$ otherwise.

[29]This is actually a limitation, as there may be universals requiring more powerful formalisms, such as higher order logics.

A universal defines a theory and perhaps a signature. Therefore, we note a universal u by $u = (\Sigma, T)$, where Σ is a signature and T a theory. T has to fulfill the following condition: All formulas $F \in T$ have at most one free variable, at least one formula has one free variable.

Let Σ_{Ont} be the signature of an ontology such as GFO, $L(\Sigma_{Ont})$ be the ontological language and T be a theory defined in the language $L(\Sigma_{Ont} \cup \Sigma_T \cup \Sigma_=)$, where Σ_T may contain additional symbols for relations and functions and $\Sigma_= = \{=\}$. Let $Ax(Ont)$ be ontological axioms, such as the axioms of GFO, $T \cup Ax(Ont) = S$. Let $S^\vdash$ be the deductive closure of S. Then we do the following expansion: Let $Univ$ be the set of all occurrences of a string of the form $x :: u$ in elements of the set $S^\vdash$, where x is an individual and $u_i = (\Sigma_{U_i}, T_{U_i})$ is an universal, where z is the free variable in T_{U_i} (with $1 \leq i \leq |Univ|$). Then $S^\vdash_U = S^\vdash \cup \bigcup\{\exists z(\bigwedge T_{U_i} \wedge x = z) : 1 \leq i \leq |Univ|\}$.

Another way to achieve the same result is by extending the deduction relation $\vdash \subseteq 2^{Fm(\Sigma)} \times Fm(\Sigma)$ by $(\{A\}, A')$, where the following obtains:

- If the string A does contain a substring of the form $x :: u$ for any x and u, and $u = (\Sigma, T_u)$ is a universal and z is the free variable of T_u, then A' is the string which is the result of the replacement of $x :: u$ by $(\exists z \bigwedge T_u \wedge z = x)$
- $A = A'$ otherwise.

Sometimes this will lead to an infinite loop (if T_u contains itself a string of the form $x :: u$), which does not concern us at this time. A more detailed explanation of universals and how they are specified will be developed soon by the GOL-Group. We, however, believe, that any such explanation will have to satisfy at least the formalism described above.

There will be certain properties which the theories specified by universals will have to fulfill, for example, that the free variable in those theories can only occur as the argument in such relations, that take an appropriate[30] entity as its argument. There may be more restrictions imposed on those theories, either because it is necessary from an ontological perspective or from a computational. For example, we may assume, that all theories defined by universals are ∃-theories[31]. We may even impose restrictions on the theory, for example when we want to assert, that one and only one relation is used in it. Again, a further analysis will be left open to the GOL-researchers.

When the signature is known, clear from the context or unimportant, we will denote universals as follows:

Definition 5.30 (Notation for universals). A universal $u = (\Sigma, T)$ is denoted as follows:

$$u = [x|P(x)]$$

5.3.7 Situation types

Before we can proceed to a preliminary semantic for situations, we will need the notion of a type.

Definition 5.31 (Type of a situation, conditioning infon). Let i be an infon. Then $T = [s|s \models i]$ is a type of a situation, and i is the conditioning infon of T, $i = cond(T)$. A situation s is of the type T relative to f if $s \models i$, $cond(T) = i$, $anchor(i) = f$ and f is defined on all the parameters of i.

Situation types are universals, and we believe that this notation for situations types is sufficient for all situations. Similarly, universals can be specified for situoids.

[30]"Appropriateness" is here defined by roles.
[31]∃-theories are theories, where all formulas are of the form $\exists x_1 \exists x_2 \ldots \exists x_n F(x)$, where $F(x)$ is without quantifier.

5.3.8 Constraints and Involvement

Now, after defining universals, or situation types, we can show how to use this formalism in practise.

We will use constraints as in [Israel and Perry, 1990], infons with a pictural state of affairs, whose relation relates amongst situation types.

Definition 5.32 (Constraint). A constraint is an infon $i = \langle\langle R, a_1, \ldots, a_n; p \rangle\rangle$, such that $a_1, \ldots, a_n$ are assigned to situation types.

We will use two special types of constraints. There are more, the most basic being $\langle\langle \top, a, b; 1 \rangle\rangle$ ($\langle\langle \bot, a, b; 1 \rangle\rangle$), stating that if a situation is of type a than it is also (not) of type b. However, some more complicated types of constraints are of concern to us.

We can define what we mean by the involvement of two situations. We distinguish between simple involvement, which is a binary relation, and relative involvement, which is a ternary relation.

Definition 5.33 (Simple and relative involvement). Simple involvement is a binary relation. If the type of a situation T involves the type of a situation T', then for every situation of type T there is one of type T', noted as

$$\langle\langle Involves, T, T'; 1 \rangle\rangle$$

Relative involvement is a ternary relation. If T involves T' relative to T'', then for any pair of situations of type T and T'' there is a situation of type T', noted as

$$\langle\langle Involves_R, T, T', T''; 1 \rangle\rangle$$

The theory defined by a universal can assert constraints to situations. Let C be a constraint, then $s \models C$ will assert the constraint C to a situation s (which is the free variable in the theory defined by the universal the situation is an instance of).

Now we express the information carried by an infon. Information here is a proposition relative to some constraint of the form $\langle\langle Involves, \ldots; 1\rangle\rangle$.

Axiom 5.39. Let C be some constraint. The infon i carries the pure information that P relative to C iff

1. $C = \langle\langle Involves, T, T'; 1\rangle\rangle$
2. For any assignment f such that $i = cond(T)$, $anchor(i) = f$, P is the proposition $P = \exists s'(s' \models \exists a_1, \ldots, a_n(cond(T')[f]))$.

The assignment function for the conditioning infon of T has to be the same as for the conditioning infon of T', and all other parameters of $cond(T')$ are existentially quantified. Note also, that it is not required, that if $s \models i$ and therefore s is of the type T, it itself has to be of type T', but there only has to exist some situation of type T'.

We need another axiom for relative involvement.

Axiom 5.40. Let C be some relative constraint. Then the infon i carries the incremental information that P relative to C and the infon i' iff

1. $C = \langle\langle Involves_R, T, T', T''; 1\rangle\rangle$
2. For any assignment f such that $i = cond(T)$, $anchor(i) = f$ and $i' = cond(T'')[f]$, P is the proposition $P = \exists s'(s' \models \exists a_1, \ldots, a_n(cond(T')[f]))$.

Now let us assume, that for a universal u with situations as its instances, $u = (T, \Sigma)$, and $T = \{s \models C_1, \ldots, s \models C_n\, s \models B_1, \ldots, s \models B_m\}$, where $C_1, \ldots, C_n$ are constraints and $B_1, \ldots, B_m$ are basic infons. Of course are constraints only a special type of basic infons.

We will see in an example, how this formalism is applied.

5.3.9 A situation example

This example is due to John Perry [Israel and Perry, 1990]. The dog Jackie has a broken leg. There is an x-ray taken of Jackie, and this x-ray has a certain pattern, indicating that Jackie has a broken leg.

There are two types of situations of concern. The first is one with an x-ray, x, at a time t, that has a certain pattern Φ. This pattern is the pattern of a broken leg.

$$T = [s|s \models \langle\langle \text{X-ray}, x, t; 1\rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, x, t; 1\rangle\rangle]$$

The second type is one with the x-ray x of some object y and this object has a broken leg, all at a certain time.

$$T' = [s|s \models \langle\langle \text{Is-xray-of}, x, y, t; 1\rangle\rangle \wedge \langle\langle \text{Has-broken-leg}, y, t; 1\rangle\rangle$$

Our constraint will now state the following: If there is an x-ray x and it has a certain pattern Φ, the pattern of a broken leg, then it is an x-ray of some object y and this object has a broken leg.

$$C = \langle\langle \text{Involves}, T, T'; 1\rangle\rangle$$

We define a universal u_s, the universal of situations with an x-ray of a broken leg, in the following way:

$$u_s = (\Sigma, T_s)$$
$$\Sigma = (\models)$$
$$T_s = [s|s \models \text{X-ray}, x, t; 1\rangle\rangle \wedge s \models \langle\langle \text{Has-pattern-}\Phi, x, t; 1\rangle\rangle$$

The situation s is then defined as follows, where a is the x-ray and t' the time the x-ray has been taken.

$$
\begin{aligned}
s &:: u_s \\
s &\models \langle\langle \text{X-ray}, a, t'; 1\rangle\rangle \\
s &\models \langle\langle \text{Has-pattern-}\Phi, a, t'; 1\rangle\rangle \\
s &\models C
\end{aligned}
$$

Now f is an anchor defined on x and t, such that $f(x) = a$ and $f(t) = t'$. Now we obtain

$$
\begin{aligned}
& s \models \phi \\
\phi &= \langle\langle \text{X-ray}, a, t'; 1\rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, a, t'; 1\rangle\rangle \\
&= \langle\langle \text{X-ray}, f(x), f(t); 1\rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, f(x), f(t); 1\rangle\rangle \\
&= (\langle\langle \text{X-ray}, x, t; 1\rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, x, t; 1\rangle\rangle)[f] \\
&= \mathit{cond}(T)[f]
\end{aligned}
$$

Then P is the following proposition:

$$
\begin{aligned}
& \exists s'(s' \models \exists y(\langle\langle \text{Is-xray-of}, x, y, t; 1\rangle\rangle \wedge \langle\langle \text{Has-broken-leg}, y, t; 1\rangle\rangle)[f]) \\
= \; & \exists s'(s' \models \exists y(\langle\langle \text{Is-xray-of}, f(x), y, f(t); 1\rangle\rangle \wedge \langle\langle \text{Has-broken-leg}, y, f(t); 1\rangle\rangle)) \\
= \; & \exists s'(s' \models \exists y(\langle\langle \text{Is-xray-of}, a, y, t'; 1\rangle\rangle \wedge \langle\langle \text{Has-broken-leg}, y, t'; 1\rangle\rangle))
\end{aligned}
$$

This proposition is the pure information carried by the situation s, namely the proposition, that in some situation s' there has to be a dog y, and a is the x-ray of y at time t'.

Let us now see what we will obtain using the second type of constraint. Let the type T be the same as before, $T' = [s|s \models \langle\langle \text{Has-broken-leg}, y, t; 1\rangle\rangle]$ and $T'' =$

$[s|s \models \langle\langle \text{Is-xray-of}, x, y, t; 1\rangle\rangle]$, and $C' = \langle\langle Involves_R, T, T', T''; 1\rangle\rangle$.

The universal u_s is the same as above.

We could state that the described situation is the instance of another universal, a universal of situations with an x-ray of a broken leg of some person. Or we could define an additional universal and say that this situation is also an instance of another universal, the universal of situations with an x-ray of an individual. Again for the sake of simplicity we omit this.

The situation s_R is then defined as follows, where a and t' are as before, and b is assigned to the dog Jackie.

$$\begin{aligned} s &:: u_{sR} \\ s &\models \langle\langle \text{X-ray}, a, t'; 1\rangle\rangle \\ s &\models \langle\langle \text{Has-pattern-}\Phi, a, t'; 1\rangle\rangle \\ s &\models \langle\langle \text{Is-xray-of}, a, b, t'; 1\rangle\rangle \\ s &\models \langle\langle Involves_R, T, T', T''; 1\rangle\rangle \end{aligned}$$

Now f is an anchor defined on x and t as well as y, with $f(x) = a$, $f(t) = t'$ and $f(y) = b$, f has to assign y to the dog Jackie, b.

Now we obtain the following.

$$\begin{aligned}
\phi &= \langle\langle \text{X-ray}, a, t'; 1\rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, a, t'; 1\rangle\rangle \\
&= \langle\langle \text{X-ray}, f(x), f(t); 1\rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, f(x), f(t); 1\rangle\rangle \\
&= \langle\langle (\text{X-ray}, x, t; 1\rangle\rangle \wedge \langle\langle \text{Has-pattern-}\Phi, x, t; 1\rangle\rangle)[f] \\
&= cond(T)[f] \\
\phi' &= \langle\langle \text{Is-xray-of}, a, b, t'; 1\rangle\rangle \\
&= \langle\langle \text{Is-xray-of}, f(x), f(y), f(t); 1\rangle\rangle \\
&= (\langle\langle \text{Is-xray-of}, x, y, t; 1\rangle\rangle)[f] \\
&= cond(T'')[f]
\end{aligned}$$

Now we will obtain the proposition

$$\exists s''(s'' \models \langle\langle \text{Has-broken-leg}, b, t'; 1\rangle\rangle)$$

This is the information we wanted to obtain out of the described situation.

5.4 Models for situations

In this section we will discuss how to model situations. We want to be able to talk about situations, and validate, whether propositions about them are true, or if certain infons obtain in situations. Therefore we try to express knowledge about situations using some mathematical structure. Because situations are described by sets of infons, we will use sets to model situations. However, situations possess certain features that are hard to model in classical set theory. Especially inherently circular situations require close attention. Therefore, we will first introduce an alternative set theory, one with the axiom of foundation replaced.

Then we will see how we can model situations using this set theory.

The models constructed for situations here can be used for situoids as well. However, we believe that other means of modelling situoids are better. For example, there may be concurrent processes in situoids, or parallel processes that have a certain temporal extension. The temporal extension of these processes should be reflected in the model of situoids. Therefore, some graphical representation should be considered.

5.4.1 Aczel's ZFC/AFA

The set of axioms for classical set theory created by Zermelo-Fraenkel is called ZF. ZFC is the set theory of Zermelo-Fraenkel with the axiom of choice:

Axiom 5.41.

$$\forall x(\emptyset \notin x \wedge \forall uv(u, v \in x \wedge v \neq u \rightarrow u \cap v = \emptyset) \rightarrow \exists u \forall z(z \in x \rightarrow z \cap u \text{ has exactly one element}))$$

The axiom that is on question in this section is the axiom of foundation. This axiom states, that every set has an $\in$-minimal element:

Axiom 5.42.

$$\exists x(x \neq \emptyset \rightarrow \exists y(y \in x \wedge x \cap y = \emptyset))$$

The foundation axiom assures that sets cannot contain themselves as elements and that the class of all sets is not a set. It makes sure, that the universe of sets is hierarchical structured and can be created by iterated power-set construction. This is the axiom in question.

A set is well-founded, if it does not have an infinite descending membership sequence, otherwise non-well-founded. This notion is quite old, and well-founded

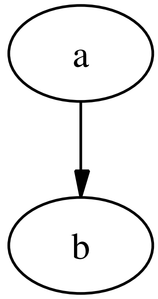

Figure 5.7: The set $a = \{b\}$

as well as non-well-founded sets have been studied for decades. The notion has been introduced 1917 by Dmitry Mirimanov. Although there have been a number of attempts to replace the foundation axiom of ZFC, there has not been a major breakthrough in applications for non-well-founded sets until the revolutionary work of Peter Aczel in 1988[Aczel, 1988]. Before Aczel, there have been a few anti-foundation axioms, due to M. Forti and F. Honsell, P. Finsler, or Dana Scott. The axiom AFA by Forti and Honsell has been adopted by Aczel.

Peter Aczel used a graph representation of sets, where an arrow between the nodes a and b denotes the membership relation $a \in b$. A set in graph representation is called well-founded, if it does not have any cycles or infinite descending branches. Figure 5.7 shows the simple well-founded set $a = \{b\}$. The more complex set $a = \{\{b, \{c, d\}\}, e\}$ is show in figure 5.8.

The anti-foundation axiom AFA states, that every set, well-founded or not, pictures a unique set. Removing the foundation axiom from ZFC and adding AFA instead leads to the hyperset theory ZFC/AFA. Now, the so-called Quine atom $x = \{x\}$ can be pictured by a graph, as can be seen in figure 5.9. However, the same unique set can be pictured by many different graphs, as can be seen in figure 5.10.

Aczel stated, that there has to be a fundamental structural difference between

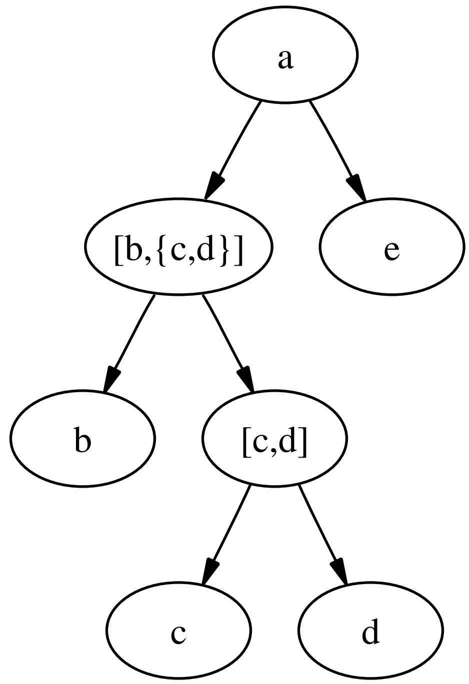

Figure 5.8: The set $a = \{\{b, \{c, d\}\}, e\}$

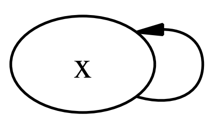

Figure 5.9: The set $x = \{x\}$

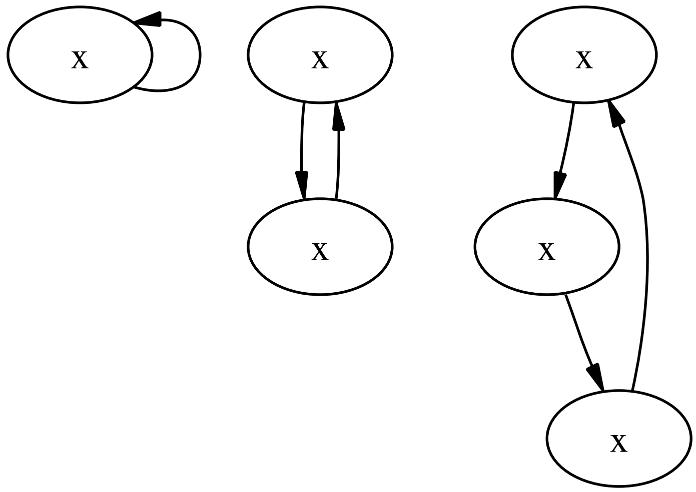

Figure 5.10: The set $x = \{x\}$ as different graphs

graphs to model different sets. He introduced the notion of a *bisimulation* between two graphs.

Definition 5.34 (Bisimulation of two graphs). A bisimulation between two graphs G_1 with point p_1 and G_2 with point p_2 is a relation $R \subseteq G_1 \times G_2$ satisfying

1. $R(p_1, p_2)$
2. if $R(n,m)$ then
   - for every edge $n \longrightarrow n'$ of G_1 there exists an edge $m \longrightarrow m'$ of G_2 such that $R(n', m')$.
   - for every edge $m \longrightarrow m'$ of G_2 there exists an edge $n \longrightarrow n'$ of G_1 such that $R(n', m')$.

Two graphs are called bisimilar, if a bisimulation exists between them.

If two graphs are bisimilar, they picture the same set. Therefore, a set is completely determined by a graph that pictures it. This solves some problems with equality of sets, and shows some interesting properties of extensionality. In classical set theory two sets are equal if and only if they have the same elements. But let $a = \{0, a\}$ and $b = \{0, b\}$. Then $a = b$ if and only if $a = b$. In the theory ZFC/AFA, a and b are indeed equal, because their corresponding graphs are bisimilar.

5.4.2 Hyperset-based model theory

We will now show how to model situations with hypersets. As Barwise has shown in [Barwise, 1989], there are inherently circular situations, and the best way to model them is by using hypersets.

We will use the same notion as did Barwise in [Barwise, 1989] of a state model: A state model is an ordered triple $< R, a, p >$, where R is a relation, a a function and $p \in \{0, 1\}$. A situation model is introduced as a set of state models.

Axiom 5.43. There is an operation $M : Entity \mapsto Set$, satisfying the following equations:

- If b is not a situation or infon, then $M(b) = b$.
- If $\phi = \langle\langle R, a; i\rangle\rangle$, then $M(\phi) =< R, b, i >$, where b is the function on $dom(a)$ satisfying $b(x) = M(a(x))$.
- If s is a situation, then $M(s) = \{M(\phi) : s \models \phi\}$.

We believe that more research has to be done concerning situation models. For example constraints and the semantic of the two types of constraints we discussed are not reflected by this approach to model situations.

Another approach of modelling situoids has been published by the GOL researchers in [Heller et al., 2004a].

6 Discussion

Before we compare the theory laid out in the last chapter with the situation theory by Barwise and Perry, we will have to remark on some semantic issues. Then we will compare it to Barwisean situation theory, and finally critically reflect on our framework laid out in the last chapter.

6.1 Semantic Issues

Historically, situation theory was supposed to provide a semantic for natural language, Situation Semantic as in [Barwise and Perry, 1981]. For this, the so-called relational theory of meaning has been developed, expressing the meaning of an utterance as a relation between an utterance situation and a described situation. In this section we will comment on the relational theory of meaning and describe how it can be incorporated in our approach. Afterwards, we will show how modalities can be expressed in our framework.

6.1.1 The Relational Theory of Meaning

Barwisean situation theory provided a semantic for utterances in natural language. Situoid theory does the same. Because utterances are always temporally extended, they have to be viewed in the domain of situoids, and not situations.

Before we can explain how the meaning of a term is modelled in situation theory, we have to explain the "categorization devices" we introduces in section 5.2.8. A categorization device is a universal. Only universals are instances of a categorization device, so it is a universal of universals. It has been introduced by Sacks in [Sacks, 1972] as a non-empty collection of categories together with rules of application. As an example there may be a categorization device "gender" with two universals as its instances, "$male_H$" and "$female_H$". The index H means here that these universals are applied to humans. Now we could formulate rules of application, like in [Devlin, 2003]: "If some population of persons is being categorized, and if a category from some device has been used to categorize one member of the population, then that category, or other categories of the same device, should preferentially be used to categorize further members of the population." or Sack's Economy rule: "A single category from any device can be referentially adequate." Several more preferential rules, for example for category-bound activities, can be found in [Devlin, 2003].

The meaning of a referring word or term ϕ is a relation $||\phi||$ between pairs (d, u) of situoids and pairs (T_ϕ, T_{dev}) of universals. The situoid u contains the utterance of ϕ, while the situoid d is the context in which ϕ has been uttered. The universal T_ϕ is the universal that ϕ is an instance of, while T_{dev} is a "categorization device determined by the contextual features in d."[Devlin, 2003]. T_ϕ is a member of T_{dev}. As in [Devlin, 2003], we will call T_{dev} the outer device, the connection between the context d and T_{dev} the outer link, the universal T_ϕ the inner type and the connection between u and T_ϕ the inner link.

Categorization devices are associated with situoids using the relation ass, with $ass \subseteq Universal \times Situoid$.

How can this be used to give meaning to a referring word, such as "man"? There are several meaning for the term "man", such as husband, human being with a certain gender or a stage in life.

Let us focus a situoid d. We know the following things about d:

- $d \models \langle\langle Student, John; 1\rangle\rangle$
- $d \models \langle\langle Sits-in-biology-class, John; 1\rangle\rangle$
- $d \models \langle\langle Teacher, Mary; 1\rangle\rangle$
- $d \models \langle\langle Teaches-about-sexual-reproduction, Mary; 1\rangle\rangle$
- $d \models \langle\langle Movie-of-reproduction, m; 1\rangle\rangle$
- $d \models \langle\langle Watches, John, m; 1\rangle\rangle$
- $d \models \langle\langle Utters, John, u; 1\rangle\rangle$

So our context is a situoid with at least two people, John and Mary. John is attending Mary's biology class about sexual reproduction. Apparently some kind of instructive movie has been shown to the class, and John is giving a report on what he saw. This context establishes a categorization device T_{sex}, and $T_{man} :: T_{sex}$. The categorization device T_{sex} has universals as instances that are relevant in the context of sexual reproduction. T_{man} is such a universal. When John utters "The man is more muscular than the woman" ($u \models \langle\langle More-muscular, man, woman\rangle\rangle$), the meaning of the word "man" is expressed as $(d,u)\|man\|(T_{man}, T_{sex})$. The same would hold for "woman".

Adjectival terms like "muscular" can be given a meaning, too. The meaning of an adjectival term ϕ is the relation $(d,u)\|\phi\|(T_{\phi}, T_{item})$ between pairs of situoids d and u and pairs of types, T_{ϕ} and T_{item}. As in [Devlin, 2003], T_{ϕ} is the universal with all the entities that can be referred to as ϕ as instances. T_{item} is the universal the item referred to by the utterance u in d is an instance of. So in our previous example, the meaning of "muscular" would be $(d,u)\|muscular\|(T_{muscular}, T_{man})$ and $(d,u)\|muscular\|(T_{muscular}, T_{woman})$ respectively.

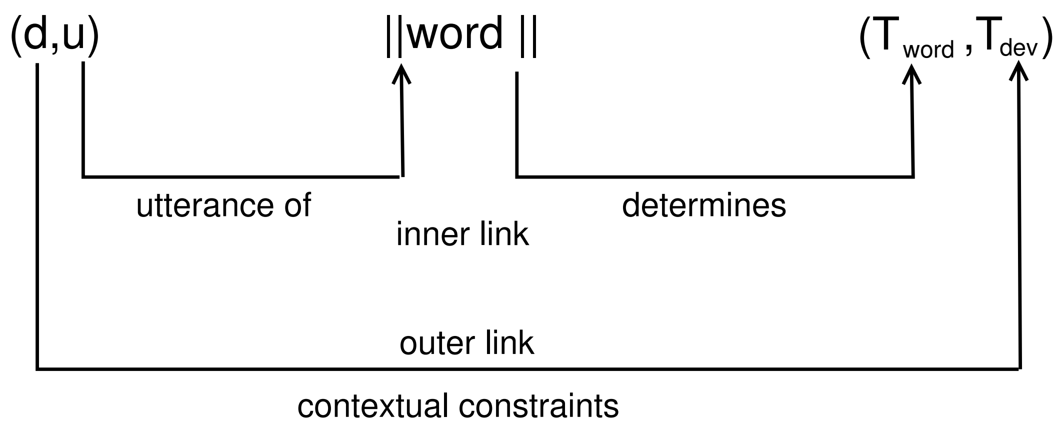

Figure 6.1: Word meaning (from [Devlin, 2003])

The relation between the context, the utterance, the uttered term, the universal of the uttered term and the categorization device has been illustrated in figure 6.1.

6.1.2 Situoid theory and modality

Jon Barwise showed in [Barwise, 1997] how to introduce modality into situation theory, while keeping a strictly realistic point of view. We will show how this is done and how to incorporate his approach in our framework.

Definition 6.1 (Classification, Boolean Classification). A classification $A = (S, \Sigma, \models)$ is a set of situoids or situations S, a set of infons Σ and the relation $\models \subseteq S \times \Sigma$.

A Boolean classification $A = (S, \Sigma, \models, \wedge, \neg)$ is a classification together with $\wedge$ and $\neg$, defined on infons, and satisfying the following:

- $s \models \phi_1 \wedge \phi_2$ iff $s \models \phi_1$ and $s \models \phi_2$

- $s \models \neg\phi$ iff $s \not\models \phi$

Barwise used Gentzen-type sequents to model information.

Definition 6.2 (Sequent). A sequent I is a pair $I = \Gamma \Rightarrow \Delta$, where Γ and Δ are sets of infons.

A sequent $I = \Gamma \Rightarrow \Delta$ holds of a situation (or situoid) s, $s \models \Gamma \Rightarrow \Delta$, if the following is true: If $s \models \phi$ for all $\phi \in \Gamma$, then $s \models \rho$ for some $\rho \in \Delta$.

A sequent I is information about a set of situoids or situations S if $s \models I$ for all $s \in S$.

The following propositions about sequents hold, just as for classical sequent calculus, such as LK [Gentzen, 1969].

Theorem 6.1. *Let s be any situation or situoid.*

1. $s \models \{A\} \Rightarrow \{A\}$ *(Identity)*
2. *If* $s \models \Gamma \Rightarrow \Delta$ *then* $s \models \Gamma \cup \Gamma' \Rightarrow \Delta \cup \Delta'$ *(Weakening)*
3. *If* $s \models \Gamma \cup \Sigma_0 \Rightarrow \Delta \cup \Sigma_1$ *for each partition* (Σ_0, Σ_1) *of some set of infons* Σ', *then* $s \models \Gamma \Rightarrow \Delta$ *(Global Cut)*
4. *If* $s \models \Gamma \cup \{A\} \Rightarrow \Delta$, *then* $s \models \Gamma \cup \{A \wedge B\} \Rightarrow \Delta$ *and also* $s \models \Gamma \cup \{B \wedge A\} \Rightarrow \Delta$ *(*$\wedge$*L)*
5. *If* $s \models \Gamma \Rightarrow \Delta \cup \{A\}$ *and* $s \models \Gamma' \Rightarrow \Delta' \cup \{B\}$ *then* $s \models \Gamma \cup \Gamma' \Rightarrow \Delta \cup \Delta' \cup \{A \wedge B\}$ *(*$\wedge$*R)*
6. *If* $s \models \Gamma \Rightarrow \Delta \cup \{A\}$ *then* $s \models \Gamma \cup \{\neg A\} \Rightarrow \Delta$ *(*$\neg$*L)*
7. *If* $s \models \Gamma \cup \{A\} \Rightarrow \Delta$ *then* $s \models \Gamma \Rightarrow \Delta \cup \{\neg A\}$ *(*$\neg$*R)*

Proof.

1. To show is that if $s \models A$ then $s \models A$, that is $s \models A \rightarrow A$[1], which is a tautology.

2. For all $\phi \in \Gamma$, $s \models \phi$, and for some $\phi' \in \Delta$, $s \models \phi'$. To show is, if for all $\delta \in \Gamma \cup \Gamma'$ $s \models \delta$, there is some $\delta' \in \Delta \cup \Delta'$ with $s \models \delta'$. If this was not the case, there would be no such $\delta' \in \Delta \cup \Delta'$, but a $\phi' \in \Delta \subseteq \Delta \cup \Delta'$, which is a contradiction.

3. Proof can be found in [Barwise, 1997].

4. To show is, that if $s \models \phi$ for all $\phi \in \Gamma \cup \{A \wedge B\}$ then there is some $\phi' \in \Delta$ so that $s \models \phi'$. If this was not the case, then $s \not\models \Gamma \cup \{A\} \Rightarrow \Delta$ which is a contradiction. The proof is similar for the other direction.

5. Given is $s \models \Gamma \Rightarrow \Delta \cup \{A\}$ and $s \models \Gamma' \Rightarrow \Delta' \cup \{B\}$. If $s \not\models \Gamma \cup \Gamma' \Rightarrow \Delta \cup \Delta' \cup \{A \wedge B\}$, then for all $\phi \in \Gamma \cup \Gamma'$ but for no $\phi' \in \Delta \cup \Delta' \cup \{A \wedge B\}$ $s \models \phi'$. There is some $\delta \in \Delta \cup \{A\}$ and some $\delta' \in \Delta' \cup \{B\}$ with $s \models \delta$ and $s \models \delta'$. If $\delta \in \Delta$ then there is a $\phi' \in \Delta \cup \Delta' \cup \{A \wedge B\}$ with $s \models \phi'$ which is a contradiction. The same holds for $\delta' \in \Delta'$. So $\delta = A$ and $\delta' = B$ and $s \models A$ and $s \models B$. But then $s \models A \wedge B$, which is again a contradiction.

6. Given is $s \models \Gamma \Rightarrow \Delta \cup \{A\}$. Assume $s \not\models \Gamma \cup \{\neg A\} \Rightarrow \Delta$, then for all $\phi \in \Gamma \cup \{\neg A\}$ $s \models \phi$, but for no $\phi' \in \Delta$ $s \models \phi'$, while there is a $\delta \in \Delta \cup \{A\}$ with $s \models \delta$. If $\delta \in \Delta$ we have a contradiction, so $\delta = A$ and $s \models A$, while at the same time $s \models \neg A$, which is a contradiction.

7. The proof is similar to the previous.

These rules taken as inference rules are complete [Barwise, 1997]. Barwise introduces information contexts, also called local logics.

[1] We take $A \vee B$ as an abbreviation of $\neg(\neg A \wedge \neg B)$ and $A \rightarrow B$ as an abbreviation of $\neg A \vee B$.

Definition 6.3 (Information context, Boolean information context). An information context $C = (A, \Rightarrow, N)$ is a classification A, a binary relation $\Rightarrow$ relating sets of infons and a set $N \subseteq S$ of situations[2] called normal situations. N is closed under identity, weakening and global cut, and for all $s \in N$ and all $I \in \Rightarrow$: $s \models I$.

A boolean information context is one where N is also closed under the rules $(\wedge L)$, $(\wedge R)$, $(\neg L)$ and $(\neg R)$.

The idea is that Σ, the set of infons from A, represents the relevant issues, $\Rightarrow$ the information present, while N are the situations supporting this information. They may, but do not have to be all the situations.

Barwise continues by introducing possible worlds, which he calls "states" to distinguish them from Lewisian possible worlds in [Lewis, 1986]. We will call them possible worlds anyway.

Definition 6.4 (Possible and impossible worlds, realization of worlds, possible and impossible situations). Let C be an information context.

1. A possible world is a binary partition (Γ, Δ) of the infons in C, Ω the set of all worlds.
2. The possible world of a situation s is the partition (Γ_s, Δ_s) where $\Gamma_s = \{\phi \in \Sigma | s \models \phi\}$ and $\Delta_s = \Sigma - \Gamma_s$. The world is denoted $world(s)$.
3. A possible world $w \in \Omega$ is realized by the situation s if $world(s) = w$.
4. A world $w = (\Gamma, \Delta)$ is impossible, if $\Gamma \Rightarrow \Delta$, otherwise possible. Ω_C is the set of all possible worlds in the context C.
5. A situation s is possible iff $world(s)$ is possible.

[2]For the rest of this section we will use "situation" when we mean a situation or a situoid. Barwise subsumed both ontological categories under the term "situation", and we will use his terminology in this section. But keep in mind that we are not solely talking about situations, but situoids as well.

Now it can be shown, that every normal situation is possible, and if the information context is sound, every situation is possible as well as if the information context is complete, then every possible world is realized by some normal situation.

Before we can introduce modalities, we need one more definition, defining what is meant by one information context being less informative than another.

Definition 6.5 (Less and more informative information contexts). Let $A = (S, \Sigma, \models)$ be a fixed classification, and $C_1 = (A, \Rightarrow_{C_1}, N_1)$ and $C_2 = (A, \Rightarrow_{C_2}, N_2)$ be information contexts. Then $C_1 \sqsubseteq C_2$ iff

1. for all sets of infons Γ and Δ, if $\Gamma \Rightarrow_{C_1} \Delta$, then $\Gamma \Rightarrow_{C_2} \Delta$ and
2. for all $s \in S$, if $s \in N_2$ then $s \in N_1$.

Now modalities can be introduced.

Definition 6.6 (Informational modal framework). An informational modal framework M is a classification $A = (S, \Sigma, \models)$, and an information context $C_s = (A, \Rightarrow_s, N_s)$ for each situation $s \in S$, satisfying the condition: If $world(s) = world(s')$ then $C_s \sqsubseteq C_{s'}$ and $C_{s'} \sqsubseteq C_s$. All $t \in N_s$ are called s-normal. All worlds possible relative to C_s are called s-possible.

Now propositions are taken as sets of possible worlds. It follows the final definition in [Barwise, 1997], modified to fit our terminology.

Definition 6.7 (Accessibility of worlds, $\diamond$p, $\Box$p). Let M be a fixed information frame.

1. A possible world w' is accessible from the world w provided that for some situation s with $world(s) = w$, w' is s-possible. (It follows that w' is s-possible for every s with $world(s) = w$.)

2. Given a proposition p, let

$$\diamond p = \{w \in \Omega | \text{some state } w' \in p \text{ is accessible from w}\}$$

and

$$\Box p = \neg \diamond \neg p$$

With these definition, Barwise shows in [Barwise, 1997] several theorems known from modal logics, and we will name the more important ones.

A proposition is valid in the informational modal framework M, written $M \models p$ iff $s \models p$ for all situations s in M. Then for any modal information frame M and any propositions p and q, $\Box(p \to q) \to (\Box p \to \Box q)$, $p \to \diamond p$ and $\Box p \to p$ are valid.

Several other theorems are proven in [Barwise, 1997], and all of them can be adapted to the framework of situoids and situation of this thesis. Therefore, this may be an elegant way of introducing modalities in the ontology of GOL.

6.2 Comparison to Barwisean Situation Theory

We developed a theory of situoids and situations on approximately the last hundred pages. First we introduced Barwisean situation theory, and then started to develop our own theory. Now we will have to ask what we have accomplished.

The main difference between Barwisean situation theory and what we called situoid theory is our distinction of situations and situoids as entities existing at a point in time and entities having a temporal extension. Especially in the last section one may have noticed that this distinction may not have been such a good idea after all. Situations and situoids appear to behave similar in many ways. And we have to admit, that the distinction of Barwisean situations into situoids and situations did not enrich the theory at all. If we would take Barwisean situation theory and write “situation or situoid” every time he writes “situation”, we would pretty much obtain what we have developed, from a functional point of view. Also our distinction of Barwisean states of affairs into states of affairs, pictures of states of affairs and infons gives not rise to a richer theory of situations.

But our goal was not to enrich situation theory, especially since most issues in situation theory are already answered. We integrated situations and situoids in a top level ontology, GFO, and to do this, several philosophical questions about the nature of situoids, situations and states of affairs had to be answered that were of no concern to Barwise and his followers.

Contrary to Barwise, we distinguished states of affairs, pictures of states of affairs and infons. Most of this distinction is based on [Wittgenstein, 1959]. For this purpose, a new ontological category had to be found, the category of infons, information-carrying entities. This has an ontological impact, because infons and states of affairs behave differently. The same is true for states of affairs and their pictures. The pictures are special states of affairs, and they behave differently than states of affairs. While this is an ontological difference, our infons are as rich as Barwisean’s, so we kept their expressive power needed for the various applications of situation theory, while adding ontological richness to the GOL-ontology. The decisions made by us are not the only possible, but we believe we tried to defend and support our views sufficiently to justify this change from situation theory.

The distinction of situations and situoids we made arose from some very basic assumptions in the GOL-ontology about time, a concept which situation theory is lacking, and the distinction between endurants and occurrents. This adds expressive power to the top level ontology we used as a background and provides us with the means of drawing fine-grained characterizations on the model of the world. In situation theory, a theory of time would have to be added to achieve the same level of modelling-opportunities.

While in situation theory, the phrase that situations “are parts of the world that can be comprehended as a whole” is taken as given and not explained further, we explained this phrase in great detail. Also, the implications of these explanations are only ontological in nature and motivation. They describe how situoids and situations behave in the world we want to describe with the means of the GOL-ontology. The axioms we developed reflect some of this knowledge about the behavior of situoids.

We showed how situoid theory in GOL can be applied to problems situation theory has been developed for, the most important being the meaning of natural language terms and phrases. And we have shown how the concept of modality can be introduced in the GOL-ontology based on situoids, situations and infons.

We believe that the expressive power of situation theory has not been lost, and that for every application of situation theory, situoid theory can be used as well, sometimes more easy because the background ontology of situoid theory provides additional knowledge, additional categories for characterizing problems.

7 Conclusion

We discussed situations as an ontological category in this thesis. Our research has been greatly influenced by the GOL-ontology, but also other works like Jon Barwise and John Perry [Barwise, 1989] or Ludwig Wittgenstein [Wittgenstein, 1959]. Most parts of this thesis are ontological, and in this sense philosophical discussions, but these are a necessary predecessor of a successful application of a top level ontology as the basis of knowledge representation systems. Therefore, most of our contributions are essentially of philosophical nature. We will summarize the contributions made in this thesis, and give some ideas to proceed the research of the ontology of situations.

7.1 Summary of contributions

- A distinction between infons, states of affairs, pictural states of affairs has been drawn. In GFO, only facts existed. In situation theory all relevant entities were infons. We developed a fine-grained distinction between the three categories, and supported and justified this distinction with reference to widely accepted philosophers such as Wittgenstein and our own argumentation.
- We accounted for the concept that some entity "can be comprehended as a whole". Because [Barwise, 1989] referred to situations as "parts of reality that can be comprehended as a whole", without further explanation, and

[Degen et al., 2001] used the same description, without giving a sufficient explanation, the clarification of this concept is one central part of this thesis. We investigated "comprehension" in general and comprehension of situoids specifically. Then we analyzed the part-whole relationship from a gestalt-theoretical point of view. We believe, this view should be adopted by the researchers of the GOL-group for their entire work, but we applied it only to situoids and situations. Finally, we analyzed the structure of reality, to show, how and in what sense situoids may be a part of it. We have shown how situoids can be extended to worlds. Multiple possible worlds arise naturally from our view on situoids as incomplete parts of reality.

- We showed how to introduce modality into GOL by using methods from situation theory. Jon Barwise himself showed how modalities can be introduced into situation theory, and we followed his work in most parts. Because the category of situoids in the ontology of GOL is one of the most fundamental, and most of the other entities of concern in GOL can be embedded in situoids, modality has been introduced in the entire ontology of GOL when introduced for situoids. As modalities were missing in GOL until now, we encourage the GOL researchers to use the results of this thesis to introduce modalities into GOL.
- We accounted for granularity in the domain of situoids and situations.
- We showed how to use situoid theory for the semantic of natural language. This has been a classical application for situation theory, one for which situation theory has been developed, and many work has been done to refine and improve the work of Barwise and Perry in this field. We followed a very recent paper on this issue, [Devlin, 2003], and the ontology of GOL and the theory on situoids introduced in this thesis are powerful enough to incorporate the results of [Devlin, 2003]. Together with the power of a top-level ontology in the background, an account for natural language

semantic may be given, that is richer than the account given by situation theory.

- We have shown how to incorporate processes and events into situoids. This is still a debated issue by the GOL researchers, and they do indeed disagree with us at this point. They believe that processes are something different than situoids or states of affairs, something even more basic. However, we tried to justify our point of view, and gave examples, which the GOL researches have to explain. This is not a central issue in this thesis, and the research on processes and events has been mainly motivated by the lack of a way of describing processes and events in GOL. So if the GOL researchers follow a different path than we have done, it is possible to ignore our statements on these issues entirely.
- We discussed the part-of relationships concerning situoids and situations, and the relationship between parts and wholes in general.

7.2 Future research

There are still some issues unresolved, and extensions and amendments to be made to this theory.

7.2.1 Causality

Causality, the relationship between causes and effects, is of importance in a knowledge representation system. The causation relation will be a relation between states of affairs, events, situations or situoids. A situoid, situation or state of affairs A is the cause of the situoid, situation or state of affairs B if A is the reason that brings about the effect B. However, this is somewhat circular, as it has to be clarified what it really means that A is the *reason* that B occurs.

David Hume held that causes and effects are not existent or at least not knowable, but imagined by our mind. Only correlations can be observed, but not causations.

But there are many philosophers that believe in causation. If one event[1] A is the cause of B, then A and B occur usually in a temporal sequence, B after A. But it is not the case that a situoid A causes the situoid B just because B follows right after A. There is even a logical fallacy, known as “post hoc ergo propter hoc” (after this, therefore because of this).

Strictly speaking, if A causes B, then A must always be followed by B[2]. A major problem is, that correlation does not imply causation. If two events occur usually together, they are correlated, but it is not necessary that one event causes the other event[3].

We believe that states of affairs, situations and situoids provide enough structure to give an account for causality. There are theories that allow only events to enter into causal relationship with each other. We believe, that, at least on the mental stratum, instantaneous states of affairs and situations may enter into causal relation with each other or situoids and other states of affairs.

However, more research has to be done on causality.

[1] We will write “event” for “situation, situoid, state of affairs or event”.
[2] Therefore, smoking does not cause cancer, and sex does not cause pregnancy.
[3] This is another logical fallacy, known as “cum hoc ergo propter hoc”, an argument of false cause.

7.2.2 Natural Language Semantic

We have shown a single application of situoid theory for natural language semantic. Many more applications of classical situation theory can be found in [Barwise, Gawron, Plotkin, and Tutiya, 1991]. However, using a philosophically well-founded top-level ontology as a background for a theory of natural language semantic may prove promising, because more knowledge about the world is available to such a theory. All the knowledge about reality in the ontology of GOL would have to be added to situation theory in order to reach the same expressive power.

More research is due to be done in this area, as this is an important application, and one way for GOL to show its power.

7.2.3 Classification of situoids

It will be shown that there are several classes of situoids (and situations, too), all with certain characteristic properties. Some are closely related to processes and a classification of processes, that is still missing in the ontology of GOL, too. Others may be related to issues of completeness, or closure regarding certain rules. With a detailed classification of situoids in GOL more information can be deduced from situoids, representation of knowledge concerning situoids is more detailed and precise. When applying situoids to natural language semantic, a classification can be made by the described entity, or by the kind of uttered statement.

While some distinctions can be made relatively easy, many useful classes of situoids and their relations to other classes will be difficult to find, especially in the field of natural language semantic.

7.2.4 Semantic of Situoids

What we have not done is given a semantic for situoids, except, of course, for the usual set theoretic semantic that follows from the axioms. But as this axiom system is far from being complete, it would be useful to construct models for situoids that incorporate all the discussed features and represent the other categories of the GOL ontology without the loss of their ontological features. Conceptual graphs [Sowa, 1999, Delugach, 2004] have been used to model situations [Ghosh and Wuvongse, 1996] in situation theory. We believe, that a graphical representation can be used to model the world [Dipert, 1997] and its parts, and therefore also situoids. A graph-representation of a situoid s has to be able to model the chronoid as well as all the relevant sub-chronoids and the topoid and its relevant sub-topoids of s. Concurrent, parallel and independent processes in a situoid have to be modelled as well as situations and the entities present in the situoid.

It should be possible to deduce certain properties of a situoid by graph–theoretical means. Also, if there are processes, states of affairs with a temporal extension, and their precise location inside the situoid is unknown (so the duration of the process is known, but not its temporal location), it may be possible to deduce its temporal location inside the situoid by the relation of these processes to other entities present in the situoid. Several possibilities will exist, and again by graph–theoretical means it may be possible to determine the set of possibilities.

However, conceptual graphs will probably be too weak to model all the richness of the categories in GOL, and therefore also the richness of a single situoid, so new means of modelling situoids by graphs will have to be investigated.

7.3 Final Remarks

We tried to give an account for situoids and situations in the ontology of GOL. Our attempt is incomplete, and can perhaps never be completed. Because situoids are complex, integrated entities, part of a world that can be comprehended as a whole, many properties depend on fundamental philosophical views that have been debated for centuries and will probably never be uniformly resolved.

In order to discuss some of the features of situoids, we had to take side in the discussion about the problem of universals. We did not take side in this debate for the classical beliefs of realists, nominalists or other fractions, but acknowledged the existence of different types of universals: universals existing *in re*, universals as concepts and even gestalten.

We acknowledge the existence of substances, and believe they are more than a bundle of properties.

We believe that there are several strata of reality, and they are different in that they define different categories. The physical stratum consists of temporally extended entities, sometimes called processes, here situoids. But on other strata, the mental and perhaps the social stratum, entities may exist at time points, boundaries of time intervals. Again, this decision is not in agreement with all philosophers.

Many more decisions of this kind had to be made by us, for example regarding states of affairs and infons, events and processes, and probably hoards of philosophers would criticize us harshly, and perhaps they would be right.

This was our first attempt of a mainly philosophical work. We hope, there are not too many errors in this thesis, so it will withstand some criticism, and may be be useful for some research, and at least parts of the ideas develop here can be integrated into the ontology of GOL, because this was our goal.

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