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Cambridge Handbook

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PART ONE

THE FIRST PART

1

Sentential Semantics

1.1 Sentences and sentence meaning

There are three basic conceptions of a *sentence*, a syntactic, a semantic and a pragmatic (cf. Stainton (2000)). According to the syntactic conception, a sentence is an expression with certain grammatical properties, as specified in a grammar. According to the semantic conception, a sentence is an expression with a certain type of meaning, for instance a sentence expressing a *proposition*, something that is true or false (with respect to the actual world). According to the pragmatic conception, a sentence is an expression with a certain kind of use, typically that of making a *speech act*.

These three conceptions are naturally enough pretty well correlated. Speakers of natural languages typically use sentences in the grammatical sense for making speech acts and expressing propositional thoughts by means of the sentence meaning. Nevertheless, in many cases they come apart. On the one hand, speakers often use sub-sentential expressions, such as ‘Reserved for tonight’ (pointing to a chair; (Stainton, 2000, 446), for making a speech act.

On the other hand, very often, what is a grammatical sentence, does not have a meaning that is simply a propositional content in an ordinary sense. This can happen for a variety of reasons: indexicality, presupposition, conventional implicature, discourse phenomena, interrogative mood, etc.

In this chapter, we shall be concerned with sentences in the syntactic sense, and we shall look at how semantic theories of various types model sentence meaning. In some cases we will also consider their philosophical motivations. The topic will be delimited in certain ways. We shall only discuss *declarative* sentences; see Part 4 for chapters on non-declaratives). We shall also not cover dynamic phenomena in discourse semantics (cf. Asher, Chapter 4). We are also not going to discuss presupposition and similar phenomena in the seman-

tic/pragmatics interface (cf. Schlenker, Chapter 22). We *shall* be concerned with semantic context dependence and related phenomena.

One of the key features of the syntactic conception of a sentence is that sentences are syntactically (or morphosyntactically) *complex*. Since they result from combining linguistic elements, there is a question of how the meaning of the sentence is related to the meanings of its *parts* and the way they are combined. This will be the topic of the section 1.3. The rest of the chapter is organized as follows: Section 1.2 gives a conceptual background for talk about meanings and semantic values. Section 1.3 presents the idea of semantic compositionality, informally and formally. Section 1.4 presents Frege's views on sentence meaning, and section 1.5 does the same for Davidson's. Section 1.6 gives a presentation of possible-worlds semantics, and is followed by sections on Montague semantics (1.7), Kaplan style semantics (1.8), centered-worlds propositions (1.9), relativism (1.10), two-dimensionalism (1.11), and situation semantics (1.12). Section 1.13 is concerned with structured meanings, and section 1.15 with procedural semantics. Section 1.16 contains some concluding words.

1.2 Semantic values and meta-semantics

There are two main formats that a semantic theory takes with respect to sentences. Either it ascribes one or more *properties* to sentences, and specifies the *conditions* under which a sentence has this property or properties. Typically the property is that of *being true*, or some property similar to or related to that. Truth definitions are of this kind. Let's call this the *axiomatic* style. The alternative is to assign explicit *semantic values* to sentences. The semantic theory then takes to format of specifying one or more *semantic functions* that map expressions on semantic values. Let's call this the *algebraic* style.

These two formats are typically inter-translatable. For instance, in a *truth-theoretic* (axiomatic) format, the meaning specification for sentences takes the form of material biconditionals of the form '*s* is true iff *p*' (cf. section 1.5). Whether the sentence *s* is true then depends on whether *p* is the case, which is determined by the (actual) world. In a corresponding algebraic framework we have a function μ that assigns values 1 (for truth) or 0 (for falsity) to sentences, and we can equally ask for the conditions under which the value is 1.

By contrast, whether we include possible worlds, and therefore have an *intensional* semantics, or leave possible worlds and similar entities out of the semantics, makes a crucial difference. This difference, in turn, is related to the distinction between semantics and meta-semantics. In an *extensional* seman-

tics, the standard semantic value of a one-place predicate is a set of objects, informally, the set of object of which the predicate is true.

The *conditions* for being in the extension of the one and for being in the extension of the other, however, are intuitively distinct. You can take account of this in two different ways. The first is semantic. You add *intensions* to your semantic theory, typically as functions from possible worlds to extensions. Then you have a theory with two levels: on one (upper) level intensions, and on the other (lower) level extensions *with respect to* worlds.

The second way is meta-semantic. Semantics proper only deals with extensions, but there are certain facts in the world which combine to determine what the semantic value is. These facts, how they combine and how they select the semantic value, on this view fall strictly outside semantics. The debate concerning the meaning of proper names, between Fregeans and Millians, exhibit this conflict over meaning determination. For Fregeans it belongs to semantics (*sense*), while for Millians it does not.

Many semantic frameworks include more than one type of semantic value or property, often but not always at different levels. Whether the framework has certain formal properties, such as compositionality, can then be asked for each of the types of value separately (is *extension* compositional; is *intension* compositional?). In some cases the different kinds of value interact in such a way that it is rather the system as a whole that must be characterized, as we shall see.

1.3 Compositionality

There is a remarkable fact about human linguistic communication: language users manage to successfully communicate new thought contents (contents not thought before) by means of new sentences (not used or considered before). Since mind-reading is out of the question, and *chance* would deliver a microscopic rate of communicative success (given how many sentences and contents there are), there must be something about language itself that makes this possible, as was also noted by Frege (1914; 1923):

It is astonishing what language can do. With a few syllables it can express an incalculable number of thoughts, so that even a thought grasped by a terrestrial being for the very first time can be put into a form of words which will be understood by somebody to whom the thought is entirely new. This would be impossible, were we not able to distinguish parts in the thought corresponding to the parts of a sentence, so that the structure of the sentence serves as an image of the structure of the thought. (Frege (1923), opening paragraph).

The hearer's task in communication is that of finding an appropriate *interpretation* of an utterance. On a widely accepted view, the ability to discharge this task for *new* sentences is made possible by a systematic correlation between the syntactic build-up of sentences and their meanings. It is common to spell out this correlation by means of the principle of *compositionality*:

- (PC) The meaning of a complex expression is a function of the meanings of its parts and its mode of composition.

(first stated in this format by Partee (1984, 281)). We shall say that the *semantics* of language is compositional or not, intending the assignment of meaning by some particular semantic function or semantic theory. In a derivative sense, we can say that the *meaning property* of a particular language is compositional, if the *correct* semantics for it is compositional in the first sense.

In interpreting (1a), given the syntactic structure of (1b),

- (1) a. John saw the dog
b. [_S John_{NP} [_{VP} saw_{VT} [_{NP} the_{Det} dog_N]]]

the hearer knows the meaning of 'the', 'dog', 'John', and 'saw', and the semantic significance of a) the Determiner + Noun (Det+N) combination, b) the Verb (transitive) + Noun Phrase combination (VT+NP), and c) the Noun Phrase + Verb Phrase combination (NP+VP). He starts with working out the meaning of 'the dog', using a), goes on working out the meaning of 'saw the dog', using b), and finishes by working out the meaning of (1a) from there, using c).

Although (PC) is a standard formulation, what is meant by 'part', as the principle is normally understood, is *immediate part* (immediate constituent). The principle is often incorrectly stated as saying that the meaning of the complex expression is a function of the meanings of the *simple parts* and the way they are combined. But this principle is degenerate. The mode of combination of the *simple* parts in (1) is in itself a combination of Det+N, VT+NP, and NP+VP constructions, and the speaker would have to know the semantic significance of that complex mode. In fact, there are denumerably many ways of combining simple parts, and so if the hearer needs to know the semantic significance of each, the explanation of how he can understand new sentences cannot any more appeal to a working out strategy based on *finite* knowledge.

A principle closely related to (PC) is

- (PS) If in a complex expression *A* a constituent *e* is replaced by a constituent *e'* that has *the same* meaning as *e*, then the meaning of the new expression $A' = A[e'/e]$ has the same meaning as *A*.

(where ‘ $A[e'/e]$ ’ designates the expression that results from substituting e' for e in one or more occurrences). The intersubstituted constituents need not be immediate. In fact, if the semantics is *total*, so that each grammatical expression is meaningful, then (PC) and (PS) are *equivalent*.

If, by contrast, the semantics is *partial*, the two principles can come apart. On the one hand, if not all parts of a complex expression are meaningful, then the meaning of the complex is trivially not a function of the meanings of the parts ((PC) does not hold), but it can still hold that when two parts with the same meaning (i.e. meaningful parts) are intersubstituted, the meaning of the complex is preserved ((PS) holds). On the other hand, it may also be that A is meaningful, and that e and e' mean the same, yet $A[e'/e]$ is *not* meaningful ((PS) does not hold), while it is still true that the meaning of every complex expression that *has* meaning is function of the meaning of its parts and their mode of combination ((PC) holds).

These observations are due to Wilfrid Hodges (2001). He calls the principle that the parts of every meaningful expression are meaningful *the domain principle*. The principle that if two expressions mean the same, then substituting the one for the other does not lead to loss of meaningfulness in the complex is called *the husslerl principle* (and the semantics *husserlian*) by Hodges. He also proved that given that the domain principle and the husslerl principles hold, (PC) and (PS) are again equivalent, even if the semantics is partial.

Using the equivalence, we can see that (PC) in several respects is quite weak. To get a *counterexample* to (PS), and thereby to (PC), we need two expressions e and e' with the *same* meaning, and two complex expressions, A and $A[e'/e]$ with *different* meanings. If there is no counterexample, (PS) and hence also (PC) holds. Now, if no two different expressions in the language in question have the *same* meaning (meaning is *hyperdistinct*), then no counterexample is possible, and hence the semantics is vacuously compositional. Similarly, if no two expressions in the language *differ* in meaning, again the semantics is trivially compositional.

The first of these two observations, that hyperdistinctness entails compositionality, is somewhat damaging for the explanatory power of compositionality. It may be that the meaning of complex expressions of a language obeys no regularity whatsoever, so that it is impossible to *work out* the meaning of a new complex expression, and yet because of hyperdistinctness, meaning is compositional. So compositionality alone does not explain how speakers can work out the meaning of new complex expressions. Some further property related to processing is required (cf. Pagin (2012)).

So far we have been talking as if semantic values or properties are assigned to *expressions*, where expressions are understood as *surface* forms, i.e. types of

spoken utterance, types of written inscriptions, or types of other concrete marks or events. Surface forms are, however, often syntactically ambiguous. Two different words may have the same surface form (homonymy), and complex expressions may on top be structurally ambiguous. Since different disambiguations often yield different meanings, we must define the semantic function for *disambiguated expressions*, such as analysis trees, or *grammatical terms*.

For setting out compositionality formally, we therefore need a syntactic framework, which specifies disambiguated expressions of the language, together with a domain of possible semantic values. Then the semantics is defined as a function from disambiguated expressions to semantic values. In the modern tradition, there are two approaches to this. Both are algebraic, in the sense that the syntax is conceived of as an *algebra* with syntactic operations defined over a basic set of expressions. In the tradition from Montague (1970b; 1973, Janssen (1986, 1997), Hendriks (2001)), the syntax is built up from *categories* of expressions and corresponding sets of expressions of these categories. There are also rules that specify the categories of the arguments and values of syntactic operations. We shall look more closely at this idea in section 1.7 on Montague semantics.

In the more recent tradition from Hodges (2001), there is no appeal to categories and types. Instead, syntactic operations are taken to be *partial*; they are defined only for certain arguments (combinations of arguments). We shall here follow Hodges, with some modifications. The syntax for a language L is a triple (G_L, E_L, V_L) , where G_L is a *grammatical term algebra*, E_L is the set of *expressions* of L , and V_L is a mapping from grammatical terms to expressions (for convenience we shall henceforth drop the subscript). G itself is a triple (T, Σ, A) , where T is the set of *grammatical terms*, Σ the (finite) set of *operations* that map n -tuples of grammatical terms on grammatical terms, and A is a (finite) set of *atomic* grammatical terms. T is the *closure* of A under Σ , i.e. the set of terms that are generated from A by means of (possibly repeated) applications of the operations in Σ .

To exemplify, let A be the set $\{\text{'John'}, \text{'saw'}, \text{'the'}, \text{'dog'}\}$ and Σ the set $\{\alpha, \beta, \gamma\}$, corresponding to the rules for forming Det+NP, VT+NP, and NP+VP, respectively, of example (1). Then the grammatical term that corresponds to the phrase structure analysis (1b) is

$$(2) \quad \gamma(\text{'John'}, \beta(\text{'saw'}, \alpha(\text{'the'}, \text{'dog'}))).$$

The V function maps the grammatical terms on the expressions of L . For each operation σ on terms, there is a corresponding operation $\bar{\sigma}$ on expressions such that

$$(V) \quad V(\sigma(t_1, \dots, t_m)) = \overline{\sigma}(V(t_1), \dots, V(t_m))$$

In the very simple case of our example, we just have

$$(3) \quad V(\sigma(t_1, t_2)) = V(t_1) _ V(t_2)$$

where σ is α or β or γ , and ‘ $_$ ’ marks a word boundary (space). We therefore get, after three applications of (V),

$$(4) \quad V(\gamma(\text{‘John’}, \beta(\text{‘saw’}, \alpha(\text{‘the’}, \text{‘dog’})))) = \text{‘John’} _ \text{‘saw’} _ \text{‘the’} _ \text{‘dog’}$$

which is a structural-descriptive name of ‘John saw the dog’.

No abstract limitations are imposed on V (such as that the value of the first argument should appear in the expression (surface string) to the left of the value of the second argument), although a number of restrictions will be empirically motivated, in order that the hearer be able to parse the string. The algebraic framework as such is very general; it can be adapted to phrase structure rules as well as to transformations or movements.

A *semantic* function μ is also defined on the grammatical terms, mapping terms on a domain M of semantic values. Given the algebraic framework we can now state a more formal version of (PC):

$$(PC') \quad \text{For every } n\text{-ary syntactic operation } \sigma \in \Sigma \text{ there is a function } r_\sigma : M^n \longrightarrow M \text{ such that for all grammatical terms } t_1, \dots, t_n \text{ such that } \alpha(t_1, \dots, t_n) \text{ is defined and } \mu\text{-meaningful, it holds that } \mu(\alpha(t_1, \dots, t_n)) = r_\sigma(\mu(t_1), \dots, \mu(t_n)).$$

We call the function r_σ a *meaning operation*. If (PC') holds for a semantic function μ , we say that μ is compositional. Compositionality is a general formal property that any particular semantic function, *given* a syntax, either has or lacks.

Historically, the first precise statement of (PS) was given by Gottlob Frege (1892, 32), for *Bedeutung*. Clarity about (PC) developed slowly after that, and did not reach maturity until in the mid-late 1970s. In the following sections we shall see how this definition applies to various types of semantic theory. In some cases, we will find reason to go beyond the standard compositionality expressed in (PC'). For more on compositionality, see Pagin and Westerståhl (2010a,b, 2011), Janssen (1997), Szabó (2008).

1.4 Frege

During the 17th, 18th, and 19th centuries, the idea of *judging* something to be the case, and *what* one judges to be the case, were not sharply distinguished. On the contrary, it was assumed that a judgment has at least two components (a *subject idea* and a *predicate idea*), and it is precisely through the *judging*, and in particular the *affirming*, that the two ideas are combined into a complex whole.

Anticipated by Bolzano, Frege insisted that the judging activity and content must be separated. He argued in the late essay 'Negation' (Frege (1918b)) that logically complex sentences, such as negations and conditionals, when affirmed, contain subsentences with contents that may be denied (in the case of negation) or not judged at all (in the case of the conditional). Since the content of the complex sentence *contains* parts that correspond to the subsentences, the subsentences too must have contents, even though they are not affirmed. Having content must therefore be distinct from being affirmed.

The view itself was already in place in Frege's middle period (especially 1892), when he developed his mature ideas of linguistic meaning. Frege employed two semantic values, *reference* (*Bedeutung*) and *sense* (*Sinn*). These notions are introduced in the beginning of Frege (1892), applied to the case of proper names, in order to solve the problem of the difference between informative and uninformative true identity statements. The concept of the sense of an expression is explained to be that which contains the *mode of presentation* of the referent.

In the case of a proper name, the reference is the bearer of the name. To exemplify different modes of presentation of the bearer, Frege uses definite descriptions. For instance, for the name 'Aristotle', Frege suggests 'the student of Plato and teacher of Alexander the Great' (1892, note 2) as articulating the sense / mode of presentation. However, Frege does not say that it is invariably the case that the name is synonymous with some (non-trivially formed) definite description.

For Frege, truth values, The True and The False, are objects. The sense of a sentence, then, what Frege called a *Thought* (ein *Gedanke*), is then (what contains) a mode of presentation of either The True or The False. So like in most theories of sentence meaning, the non-extensional semantic value is defined in relation to truth and falsity. But Frege's theory is not truth-conditional in any ordinary sense. *Sense* is not meant to encode the conditions under which the sentence refers to The True.

Frege does not specify the relation between sense and reference in purely semantic or metaphysical terms, but rather in *cognitive* terms. For instance,

as spelled out by John Perry (1977), Frege appears to accept as a *criterion of difference of sense* that

- (Dif) If A understands S and S' , and accepts S as true while not accepting S' , then S and S' have different senses.

So, sense is as *fine-grained* as the discriminations that subjects make in their attitudes. This goes well together with his semantic view about difference of sense. As mentioned above, Frege stated the (PS) substitution principle for Bedeutung, but did not state it separately for Sinn. He did, however, seem to believe in the substitution version of *inverse compositionality* for sense:

- (PIC) For any complex expressions A and A' , if A and A' have the same meaning, then A' results from A through replacing some sub-expressions $e_1, \dots, e_n$ by some expressions $e'_1, \dots, e'_n$, respectively, where e'_i has the same meaning as e_i , for $1 \leq i \leq n$.

(PIC) is a sufficient condition for *difference* of meaning. Given two complex expressions A and A' , if their top structure, i.e. the mode of composition of their immediate constituents, are different, then they differ in meaning, and if any of their corresponding immediate constituents differ in meaning, then A and A' differ in meaning as well. As pointed out by Heck and May (2011), Frege seems to have believed in the inverse compositionality for *sense*. For Frege it was important that mathematical expressions differing as much as e.g. ' 4×4 ' and ' 2^4 ' also differ in sense (discussed especially in Frege (1891)). Compositionality does not force the expressions to differ in sense, only allows them to.

The (Dif) principle is closely related to Frege's semantics for attitude contexts, or more generally, what he called *indirect contexts*. Indirect contexts include *oratio obliqua* contexts and attitude contexts. It is part of Frege's doctrines about sense (in Frege (1892)) that expressions that occur in indirect contexts have an *indirect reference*, and that the indirect reference is the same as the ordinary sense. Thus, in

- (5) John believes that Hesperus is a planet

the embedded sentence 'Hesperus is a planet' does not have its ordinary reference (The True), but its indirect reference, which is the Thought *that* Hesperus is a planet. This doctrine of indirect reference avoids violations of the (PS) principle for reference. For it may be that (5) is true, while

- (6) John believes that Phosphorus is a planet

is false, despite the coreference of ‘Hesperus’ and ‘Phosphorus’. This would violate the (PS) principle for reference, since we get (6) from (5) by substituting ‘Phosphorus’ for ‘Hesperus’. By the doctrine of indirect reference, the two names *differ* in reference in this context, given that they already differ in sense.

Nonetheless, the standard principles (PC) and (PS) of compositionality are not satisfied for reference in Frege’s semantics, since they do not make provision for the idea that the semantic value of an occurrence of an expression may depend on the *linguistic context* of that occurrence. In fact, Frege’s semantics makes the reference of belief sentences depend on the *senses* of some of its part. Letting μ_r be the reference function and μ_s the sense function, we can state the general clause for belief sentences as

$$(7) \quad \mu_r(B(N, p)) = r_b(\mu_r(N), \mu_s(p))$$

where ‘ $B(N, p)$ ’ is short for ‘N believes p ’, and r_b is a function such that $r_b(x, y) = \text{True}$ iff x is belief-related to y (where y is a Thought).

This clause is clearly not compositional, since there is a *switch* from μ_r to μ_s for the second argument to B . There is, however, a generalization of standard compositionality that accepts such switches. *General compositionality* holds for a set $S = \{\mu_1, \dots, \mu_n\}$ of semantic functions, where one element, say μ_1 , is *designated* as applying to *unembedded* occurrences of expressions. So semantic evaluation starts with μ_1 . The semantics makes use of a *selection function* $\Psi : S \times \Sigma \times N \rightarrow S$, that maps a semantic function, a syntactic operation and an argument place on a semantic function. The principle of general compositionality can then be stated as follows:

- (GPC) A system $S = \{\mu_1, \dots, \mu_n\}$ of semantic functions is *general compositional* iff there is a selection function Ψ such that for every k -ary operation α and every member $\mu_i \in S$ there is a meaning operation r_{α, μ_i} such that for any terms $t_1, \dots, t_k$, if $\alpha(t_1, \dots, t_k)$ is μ_i -meaningful, then

$$\mu_i(\alpha(t_1, \dots, t_k)) = r_{(\alpha, \mu_i)}(\mu_{j_1}(t_1), \dots, \mu_{j_k}(t_k))$$

where $\mu_{j_m} = \Psi(\mu_i, \alpha, m)$, $1 \leq m \leq k$.

Standard compositionality is the special case where S has just one element (cf. Pagin and Westerståhl (2010c)).

As stated in (GPC), a general compositional system S has finitely many members. There is a question whether Frege’s semantics meets this condition. In the equation (7), the semantics only makes use of the fact that the reference of the belief sentence depends on the sense of the embedded sentence, not

on the *additional* idea that the sense of the embedded sentence also is the reference, *in that context*. Given Frege's idea that the sense of an expression *presents the referent*, and hence *determines the referent*, it may seem that the sense of the *embedded* occurrence of the embedded sentence in (5), 'Hesperus is a planet', must have a sense different from its ordinary sense, an *indirect sense*. It is therefore a common interpretation of Frege that there is an infinite *hierarchy* of indirect senses. In a simply iterated belief sentence like

(8) Bill believes that John believes that Hesperus is a planet

the sentence (5) occurs in an indirect context, and so has indirect reference. The sentence 'Hesperus is a planet' occurs *doubly embedded*, and so occurs in an indirect indirect context. On some interpretations of Frege, the sentence then has a *doubly* indirect reference. The doubly indirect reference, in turn is the *simply indirect sense* it has as embedded in (5). Doubly embedded in (8) it has a doubly indirect sense. And so on. Using superscript indices for level, where $\mu^0 = \mu_r$ and $\mu^1 = \mu_s$, and a corresponding index on the meaning operations r_b^i , we would have

(9) $\mu^i(B(N, p)) = r_b^i(\mu^i(N), \mu^{i+1}(p)).$

There is some textual evidence that Frege actually believed in indirect senses (cf Frege (1902)). With infinitely many senses μ^j , $j = 0, 1, 2, \dots$, the condition of general compositionality that S is a finite set is not met. Frege has also been criticized in the literature (e.g. in Davidson (1965)) for providing an *unlearnable semantics*. Note that it is not the semantic switching in itself that motivates the hierarchy, but the ideas that the sense plays the double roles of reference in the indirect context *and* reference determination.

One last consequence of this idea deserves to be mentioned. In Frege's semantics, syntactic combination invariably has the form of letting one expression fill an *argument place* in another expression. A one-place predicate is an *unsaturated expression*, i.e. it has an argument place, and in this case for a singular term. When the argument is given, we get a sentence. Correspondingly, the semantic significance of such combination is *function application*: the reference of the unsaturated expression is a function, which applies to the reference of the argument expression. Thus, we have in general

(AP) $\mu_r(\alpha(t)) = \mu_r(\alpha)(\mu_r(t))$

Now, although Frege did not claim that sense is compositional, the idea that reference is compositional (modulo context), and that ordinary sense is a kind of reference, naturally leads to the claim that sense is compositional (modulo

context) as well. That is, we should, at least in all cases that do not involve context shift, apply (AP) to sense as well (just substitute 's' for 'r').

But this idea is problematic. It cannot plausibly be combined with the idea, which Frege also had (e.g. in (1923)), that the sense of a *part* of an expression is a *part* of the sense of the whole. For if the sense of α is a function that applied to the sense of t gives as value the sense of $\alpha(t)$, which in turn contains the sense of α as a proper part, then the sense of α is a non-wellfounded entity: it is a function defined partly in terms of itself (cf. (Dummett, 1981a, 293)).

All in all, Frege's conception of the sense of a sentence contains several strands that are in conflict with each other. This comes out even more in his account of indexical expressions (Frege (1918a)).

1.5 Davidsonian truth-theoretic semantics

On the face of it, Davidson style truth-theoretic semantics is a straightforward truth-conditional semantics, where sentence meaning is specified in the format

s is true in L iff p .

However, things are more complicated. On one level, there is a semantic theory of an axiomatic kind, which uses only extensional concepts. On a second level, there are meta-semantic ideas about the *modal force* of the theorems of such a theory. On a third level, again also meta-semantic, there is an idea that meaning is captured by *sets* of such theories. On top, there is an elaborate meta-semantic theory, of *radical interpretation*, for selecting the right set of theories. This presentation will be based on the papers collected in Davidson (1984).

A truth-theory T is intended to have the *form* of a Tarskian truth definition, but is meant to be an *empirical* theory about a natural language L . The language is identified as the language spoken by a particular speaker, (call her S). Davidson (1965; 1967) argues that a meaning theory must show how it is possible for a speaker with finite knowledge to have infinite capacity, i.e. the capacity to understand in principle each of the infinitely many meaningful sentences of a natural language. Although he does not use the term, his general requirements are, nearly enough, that such a theory should be compositional. More specifically, it should be an *axiomatic* theory with

- i) Axioms for simple singular terms
- ii) Axioms for simple predicates
- iii) Recursive semantic clauses for constructions
- iv) Theorems for sentences

For each sentence s of the object language, the theory must contain a theorem that specifies the relevant semantic property of s . The theorems are to be derivable from the axioms, by means of the recursive clauses, and a suitable set of rules of inference.

He also argues (1967, 20-22) that such a theory should use only *extensional* semantic vocabulary. The reason is that intensional vocabulary, such as ‘...means that’, creates non-extensional contexts that create problems for the derivations, rendering some needed rules of inference invalid. He suggests that the proper way of satisfying these requirements is to use the Tarskian format of a truth definition. The semantic ingredients are, then,

- i) A *reference* function R that assigns referents to simple closed terms,
- ii) a *satisfaction* relation SAT relating infinite sequences of objects and open sentences (possibly containing free variables)
- iii) a truth property

All of these are relativized to an object language. Davidson’s official position here is to assume a prior understanding of *truth*, while *reference* and *satisfaction* are *instrumental* notions, used only for deriving the theorems. The set of theorems, specifying sentence meanings, makes up the entire empirical content of such a semantic theory, called a *T-theory*. For the simple case of the language of predicate logic, we set out a version of the format of the clauses below. s with subscripts ranges over open and closed sentences; σ with subscripts ranges over infinite sequences of objects, and $\sigma_i(j)$ is the object in the j :th position of sequence σ_i . $\sigma[a/b]$ is the sequence that results from σ by replacing object b , wherever it occurs in σ , by object a . We use x with subscripts for object language variables, and t with subscripts for object language closed singular terms. F_i is used for an object language predicate, and G_i for the corresponding meta-language predicate. $A(t_1, \dots, t_n)$ is an object language (open or closed) sentence that contains the terms $t_1, \dots, t_n$. We use $\frac{}{T}$ to indicate that sentence that follows is derivable in the T-theory. Then we have

(TT) Clauses in a T-theory for a first-order language:

- i) $\frac{}{T} R(t) = a$
- ii) $\frac{}{T} \text{SAT}(\sigma, F_i(x_1, \dots, x_n)) \text{ iff } G_i(\sigma(1), \dots, \sigma(n))$
- iii) $\frac{}{T} \text{SAT}(\sigma, A t_1, \dots, t_n) \text{ iff } \text{SAT}(\sigma[R(t_i)/\sigma_i], A x_1, \dots, x_n),$
 $1 \leq i \leq n$
- iv) $\frac{}{T} \text{SAT}(\sigma, s_1 \ \& \ s_2) \text{ iff } \text{SAT}(\sigma, s_1) \text{ and } \text{SAT}(\sigma, s_2)$
- v) $\frac{}{T} \text{SAT}(\sigma, \neg s) \text{ iff } \text{it is not the case that } \text{SAT}(\sigma, s)$

vi) $\frac{}{\overline{T}} \text{SAT}(\sigma, \exists x_i A)$ iff there is an object a such that $\text{SAT}(\sigma[a/\sigma(i)], A)$

vii) $\frac{}{\overline{T}} T(s)$ iff for all sequences σ , $\text{SAT}(\sigma, s)$.

i) gives the general form of reference axioms for simple terms, and ii) gives the form of satisfaction axioms for simple predicates. iii) provides the semantics for predication, i.e. atomic sentences. iv) and v) give the recursive clauses for conjunction and negation, while vi) gives the clause for the existential quantifier. vii) finally, equates truth with satisfaction by all sequences, just as in Tarski. We derive a theorem, a so-called T-sentence, by starting with vii), and then applying rules according to the form of the object language sentence, substituting on the right-hand-side, until the right-hand side no longer contains any occurrence of ‘SAT’ or ‘ R ’.

Together with these clauses we need to specify the inference rules that apply. It cannot be the case that the T-theory is closed under all *logically valid* rules, because that would generate many theorems that would not be of the right kind. Davidson suggested what he called “canonical proofs” (1973, 138). He did not spell out the details, but suggested that a canonical proof “moves through a string of biconditionals”. In particular, a rule of substitution must be added: If it holds that $\frac{}{\overline{T}} p$ iff q , then ‘ p ’ and ‘ q ’ may be inter-substituted in $\frac{}{\overline{T}}$ contexts. By these means, we will be able to derive T-sentences of the form

$\frac{}{\overline{T}} T(s)$ iff p .

Davidson and others set out a program to develop the truth-theoretic framework to handle other features of natural language. Davidson himself adapted it to simple context dependence, quotation, and indirect discourse. Others have extended it much further, applying it to other natural language constructions, and spelling out proof procedures (cf. Larson and Segal (1995) and Lepore and Ludwig (2005).)

From the point of view of capturing natural language meaning, there is a strong suspicion that T-theories, being extensional, are much too weak. Davidson himself pointed out that a sentence like

(10) ‘Grass is green’ is true in English iff snow is white

is true, since both the left-hand-side and the right-hand-side of the biconditional are true, and since the biconditional is material, nothing more than that is needed.

Part of the answer is to point out that it is not enough for a biconditional of the theorem form to be true in order to qualify as being a true T-theorem. In

order to be a true theorem the T-sentence must be derivable, in the canonical way, in a T-theory *all of whose* theorems are true. That will weed out all individual T-sentences that just happen to be true. But it is not enough to weed out systematic error (see the Foster objection below).

Another part of the answer by Davidson (1967; 1973; 1974) consisted in appeal to meta-semantic theory of *radical interpretation*, which selects T-theories. Radical interpretation relates T-theories to belief ascriptions (in the first place), by means of inferences of the following kind.

- (11) (1) Speaker S holds sentence s true.
 (2) $\frac{}{T} s$ is true iff p
 (3) Hence, S believes that p .

For the radical interpreter, who tries to find an appropriate T-theory for the speaker S, premise (1) specifies part of the *data*; without knowing what s means the interpreter can notice, on the basis of the speaker's behavior (like overt assent), that she holds a sentence true. Premise (2) is provided by the current semantic *hypothesis* of the interpreter. The conclusion is a belief attribution to S. If that attribution is reasonable, this confirms the semantic hypothesis. If it is *un*-reasonable, the hypothesis is *disconfirmed*.

What are reasonable belief attributions? The basic observation is that too much attribution of false beliefs and inconsistent beliefs undermines an interpretation that leads to them via inferences of type (11). *The principle of charity* says that *correct* interpretations *maximize* or *optimize* attributions of true and consistent beliefs. Charity is applied to the theory as a whole: only the best theories (those that are not inferior to others) are acceptable. The principle of charity is a criterion of acceptability, not primarily a heuristic for *finding* the best theories.

The fact that a language contains context dependent sentences helps selecting theories by appeal to charity: sentences held true in some contexts but not in others help confirm theories that correlate them with true beliefs about the current context.

Those theories that are acceptable by appeal to charity are sometimes called *interpretive*. So, it is part of the Davidsonian concept of sentence meaning that sentence meaning is specified by a T-sentence provided it is theorem of an interpretive T-theory.

This still leaves some loopholes, however. One was suggested by John Foster (1976). Suppose we an interpretive T-theory T_1 . Then, we devise another theory T_2 , so that they are related for any s and p as follows:

- (12) a. $\frac{}{T_1} T(s)$ iff p

- b. $\frac{}{T_2} \quad T(s) \quad \text{iff} \quad \text{the Earth moves and } p$

Given that the Earth *does* move, the two theories are equally well supported by charity, and should both be correct if one of them is. According to Davidson's reply (1976), acceptable T-theorems have a kind of modal force: they are *law-like*. That they are lawlike means that they are *counterfactual supporting*: if the speaker *were to hold* s true, she *would* believe that p . The upshot is that although T_2 is true if T_1 is true, its theorems can fail to be lawlike. Thus, it is part of Davidson's conception of sentence meaning that it creates a nomic connection between holding true and belief.

Finally, since there is no guarantee that there is a unique best theory, by the charity criterion, how do we make a selection among the best? We don't. According to Davidson, they are *all* correct. They may appear on the surface to be mutually incompatible, but according to Davidson the true empirical content of interpretive T-theories is precisely what is *common* to them. The underlying facts about the speakers' attitudes are captured differently by different theories, but they are equivalent in capturing the same *underlying* facts. Davidson compares the situation to measuring temperature with different scales, Centigrade and Fahrenheit; different numerical values are offset by the difference in scales, and so capture the same physical states (Davidson (1979)). This is Davidson's *indeterminacy* of interpretation. The meaning of a sentence is precisely what is shared between what all correct (interpretive) T-theories say about it.

1.6 General Possible-Worlds Semantics

Possible-worlds semantics is a purely semantic framework. It is not associated with any particular meta-semantic theory or any particular foundational view. The idea of possible worlds was first suggested by Leibniz. In the 20th century it was reintroduced by Ludwig Wittgenstein (1922; the space of logical possibilities) and Rudolf Carnap (1956—first edition 1947). For Carnap, a possible world was a total consistent state-description, hence a linguistic item. The possible-worlds framework was developed in the late 1950s by the addition of a so-called accessibility relation, due to Jaakko Hintikka (1962), Stig Kanger (1957), and Saul Kripke (1963).

The possible-worlds framework is used both descriptively and model-theoretically. In model theory, the main purpose is to give a semantics for modal operators and characterize logical properties of sentences containing them. Descriptive semantics assumes given a domain of possible worlds. The nature of possible worlds is largely a metaphysical question.

The basic semantic framework associates with each non-logical expression e semantic properties on two levels: e has an *extension* with respect to every possible world, and it has an *intension*, which is a *function* from possible worlds to extensions. If the semantics is partial, the intension may be undefined for some worlds; for instance, the intension of a proper name might be undefined with respect to worlds where the actual world referent of the name does not exist. Note that the intension is the *value* of the semantic function (μ), not the semantic function itself; the intension takes worlds as arguments, not expressions. Since we get extensions by application of the intension, one semantic function is sufficient.

Sentence meaning is then modeled as a function from possible worlds to truth values (sometimes as sets of possible worlds – those worlds where the sentence is true). This is the basic notion of a *possible worlds proposition*. In a truth definition format, the clause for the necessity operator $\Box$ is that $\Box p$ is true at a world w iff p is true at all worlds w' accessible from w :

$$(\text{Nec}) \quad \models_w \Box p \quad \text{iff} \quad \models_{w'} p \quad \text{for all worlds } w' \text{ such that } wRw'$$

where R is the accessibility relation. Where $\mu(p)$ is an *intension* I , the corresponding intension for $\Box p$ is a function I' such that for a world w , $I'(w) = 1$ iff $I(w') = 1$ for all worlds w' accessible from w . To render this in the algebraic format we define a function r_N such that

$$(13) \quad r_N(I)(w) = 1 \text{ iff } I(w') = 1, \text{ for all worlds } w' \text{ accessible from } w.$$

where I is an intension. And then the necessity clause is simply

$$\begin{aligned} (\text{Nec}') \quad \text{i)} \quad & \mu(\Box p)(w) = r_N(\mu(p))(w) \\ \text{ii)} \quad & \mu(\Box p) = r_N(\mu(p)) \end{aligned}$$

where the first sub-clause gives the application of the intension to a world w , and the second sub-clause gives the equivalent non-applied form. It clearly conforms to the compositional format.

One question here is whether possible-worlds semantics satisfies the condition of giving the content of attitudes by means of the truth-conditions of sentences. If Bill holds true (14a)

- (14) a. John may be a secret agent
 b. There is a world w accessible from the actual world a such that John is a secret agent in w ,

is the content of his belief really specified by (14b)? Is it a belief about the

existence of some possible world? From the point of view of possible-worlds semantics as a descriptive semantics, the answer must be *yes*. Bill represents a proposition to himself by means of (14a), and that same proposition is *more explicitly* expressed by means of (14b). In order to systematically describe the semantic properties of the object language, the meta-language has to be more explicit. Indeed, this is a theme in much of what follows: the object language, e.g. with indexicals, offers a particular cognitive perspective on a proposition that is not shared by other ways of specifying the same proposition. There is intuitively a difference in meaning between (14a) and (14b), but in order to characterize it, more abstract resources are needed than those offered in possible-worlds semantics itself.

A related crucial issue concerns the individuation of propositions. It is commonly held that logical truths, such as $p \rightarrow p$, and mathematical truths, such as $1 + 1 = 2$, are true in *all* possible worlds. Because of this, all these truths have the *same* intension: the constant function I that gives the value 1 for every world as argument. Again, that means they express the *same* possible-worlds proposition. Moreover, since a conjunction $p \& q$ is true at a world just in case both conjuncts are true at that world, we have the result that for any true mathematical sentence ϕ , $p \& \phi$ expresses the same proposition as p itself. Since this goes against our intuitive meaning discriminations, we must either reject these intuitions, or reject standard possible-worlds semantics as providing an adequate model of sentence meaning. The first alternative is seldom considered an option.

One possibility that has been used in the literature for several reasons (including modeling para-consistent logic, counterpossible conditionals, and inconsistent belief) is to add *impossible* worlds. Another reason is to get more fine-grained propositions. We can distinguish between p and $p \& \phi$ because there is a world where ϕ , although a mathematical truth, is false (cf. Priest (1997)). However, since accepting impossible worlds includes rejecting established parts of standard semantics (such as the interpretation of negation, or the recursive clause for conjunction), the topic cannot be pursued here.

In the following sections, various enrichments of the basic possible-worlds framework will be considered. Some motivations for these theories come from the need of more fine-grained meanings, and some from attempting to handle more complex linguistic phenomena.

1.7 Montague semantics

Richard Montague pioneered the application of formal semantics in general, and possible-worlds semantics in particular, to natural language, and did so in many respects. A first step was to generalize the possible-worlds framework to handle various kinds of *context dependence*. An ordinary possible world is a point where a sentence is true or false if there are no other sources of truth value variation in the sentence. A sentence like

(15) John is sitting

is true at some *times* and false at others. Montague suggested treating times on a par with possible worlds as points of evaluation. A sentence like (15) will be true or false with respect to *pairs* $\langle w, t \rangle$ of a world w and a time t . Such a pair is an *index*, or *point of reference*, a notion that generalizes that of a possible world. Instead of just a domain W of possible worlds, the domain of indices is the full set of pairs $W \times T$ of worlds and times. In Montague (1973), *intensions* are functions from world-time pairs to extensions. Together with a designated time t_0 (the now-point) of a model, and a temporal order $\leq$, this allows giving a semantics for tenses. The present tense corresponds to being true at t_0 , the present perfect to being true at *some* time before t_0 and the future tense to being true at some time later than t_0 .

In (1968) and (1970b), Montague considers indices more generally, including contextual factors like the *speaker* of a context. Instead of a set of times, there is a more general set J of *contexts of use*. Context-of-use indices allow a treatment of demonstratives and first- and second-person pronouns because there is e.g. a *speaker parameter* in the formal representation of a context of use. In (1970b, 228) Montague defines *meanings* as functions from $W \times J$, while *senses* are functions of just possible worlds, i.e. when the context of use parameter has been fixed. A sense is therefore an ordinary possible-worlds proposition, and this is the value of a meaning *applied to* a context of use.

A second big feature in Montague's work is the precise formulation and formal implementation of compositionality. Compositionality is not stated as a *principle*, i.e. a general statement about natural language, but as a requirement on the formal semantics. In (Montague, 1970a, 201), this takes the form of requiring that the *semantic operations* on so-called possible denotations *correspond to* syntactic operations, so that the compositional equation (cf. the identity in (PC'), page 9) is satisfied.

In Montague (1970b) and (1973), the implementation of compositionality is further technically developed. There, the semantic function is a mapping between *algebras*, a *syntactic algebra* and a *meaning algebra*. An algebra, as

Montague presents it, (1970b, 224) is a pair $\langle A, F_\gamma \rangle_{\gamma \in \Gamma}$, where A is a non-empty set, Γ an index set, and F a family of operations on A , of various arities; for $\gamma \in \Gamma$, F_γ is an operation in F . A compositional function will then be a homomorphism:

(MCP) A *homomorphism* is a function from an algebra $\langle A, F_\gamma \rangle_{\gamma \in \Gamma}$ to a *similar* algebra $\langle B, G_\gamma \rangle_{\gamma \in \Delta}$ iff $\Gamma = \Delta$ and for any $\gamma \in \Gamma$ and any n -tuple $a_1, \dots, a_n$, where $a_i \in A$ ($1 \leq i \leq n$), for which F_γ is defined, it holds that

$$h(F_\gamma(a_1, \dots, a_n)) = G_\gamma(h(a_1), \dots, h(a_n)).$$

When A is a set of linguistic expressions and B a set of meanings, h is a compositional semantic function. In his formal semantics, Montague introduces both a syntactic algebra and a meaning algebra and requires the semantic function to be a homomorphism.

In Montague's framework, we also need to add syntactic *categories*, and assign those to expressions. Each argument place i of an n -ary operation F_γ is associated with a syntactic category C , such that proper arguments at place i belong to C . When these conditions are met for each i , the *value* of F_γ belongs to a particular category. These categories of arguments and values are specified in *rules*. In (Montague (1970b)) this is done in a formal, set-theoretic way, while in (1973) the syntactic operations and their category requirements are presented together in a more informal manner.

Structurally ambiguous sentences, like

(16) John seeks a unicorn

can be generated from the basic expressions and the syntactic operations in more than one way. On the first alternative, the quantifier 'a unicorn' is directly embedded under 'seeks', and corresponds to the reading of 'unicorn' saying that John is trying to make it the case that he finds some unicorn or other. On the second alternative, the quantifier rule for indefinite phrases like 'a unicorn' is applied last, and this corresponds to the reading according to which there is a particular unicorn that John tries to find. These two alternatives are represented by two different *analysis trees* (Montague, 1973, 255), see Figure 1.1.

Semantic interpretation applies to analysis trees, which are unambiguous, not directly to the meaningful expression, like (16), which are not. Part of Montague's achievement was to actually provide grammars in this algebraic format for interesting fragments of English.

A third major feature in Montague's framework is his *type theory* of meanings. In (Montague, 1973, 258), an *interpretation*, or *intensional model* is struc-

Figure 1.1 Analysis trees for (16). A number indicates the relevant operation.

ture $\langle A, I, J, \leq, F \rangle$, where A is a set of individuals, I a set of possible worlds, J a set of times, $\leq$ linear order in J , and F an interpretation function for constants. There are two basic types: the type e of (possible) individuals (entities) and the type t of truth values, which are taken as the elements of $\{0, 1\}$. Derived types are function types: where a and b are types, $\langle a, b \rangle$ is the type of functions from the type a domain to the type b domain.

For each type a there is a set $D_{a,A,I,J}$ of possible *denotations* of type a , and a set $S_{a,A,I,J}$ of *senses* of type a . We have

$$\begin{aligned}
 D_{e,A,I,J} &= A \\
 D_{t,A,I,J} &= \{0, 1\} \\
 D_{\langle a,b \rangle, A, I, J} &= D_{b,A,I,J}^{D_{a,A,I,J}} \\
 S_{a,A,I,J} &= D_{\langle s,a \rangle, A, I, J} = D_{a,A,I,J}^{I \times J}
 \end{aligned}$$

where the notation X^Y denotes the set of functions from Y to X .

Each syntactic category corresponds to a denotation type and a sense type. A sentence has a denotation of type t , either 0, if false at the designated world-time pair, or 1, if true. Its sense is a (temporal) proposition, i.e. a function from world-time pairs to truth values. An intransitive verb (category IV) has its denotation in $D_{\langle e,t \rangle, A, I, J}$, a function from individuals to truth values i.e. an extension, and its sense in $D_{\langle s, \langle e,t \rangle \rangle, A, I, J}$, i.e. a function from world-time pairs to extensions.

In Montague (1970b) and (1973), Montague does not give the semantics for the defined fragment of English directly, but *indirectly* via translation from the fragment into a formal language, for which the semantics is given directly. The formal language is IL, intensional logic. IL has a very simple *categorical grammar* that corresponds directly to the type theory for meanings. Each meaning type is also a type of expressions of IL, for instance t the type of sentences. *Combining* an expression of type a with an expression of type $\langle a, b \rangle$

results in a complex expression of type b . Montague provides a homomorphic translation from the analysis trees of the fragment of English into IL, and a homomorphic, and thereby compositional, interpretation of IL to the meaning algebra. By composing the translation and the interpretation we get a homomorphic semantic function from the (analysis trees) of the English fragment into the meaning algebra. Montague found the indirect procedure to be more perspicuous.

Montague's semantics is at bottom intensional. This comes out clearly in the translation from the English fragment into IL. IL has two operators, $\hat{\cdot}$ and $\cdot'$, that perform type shifts by *abstraction* and *application* respectively. If expression α is of type a , and therefore denotes a meaning of type a , then expression $\hat{\alpha}$ is of type $\langle s, a \rangle$, and denotes the *sense* of α , a function from world-time pairs to denotations of α at those pairs. If α denotes a sense, then $\hat{\alpha}$ denotes the extension of α at the designated world-time pair.

Several operations in the English grammar that result in a combination of two expressions, correspond to function application in IL and its interpretation. For instance, by rule S4, the operation F_4 takes two arguments. The second is to be of category IV, that is of intransitive verbs, like 'talk', and the first of category t/IV, which yields a sentence when combined with an intransitive verb. $F_4(\alpha, \delta) = \alpha\delta'$, that is the concatenation of α with the expression δ' . δ' is the third person singular present of δ . As an example, we have $F_4(\text{John}, \text{talk}) = \text{John talks}$.

Let the translation of α be α' and the translation of β be β' . Then the translation of $F_4(\alpha, \beta)$ is $\alpha'(\hat{\beta}')$. This means that the denotation of α' applies to the *sense* of β' , not to the denotation of β' . This holds in general for the rules that correspond to function application IL ((Montague, 1973, 261-62)). Generally, then, in Montague semantics, linguistic contexts are treated as *intensional*. In an argument position, an expression will denote its sense, not its actual denotation.

This feature allows capturing the intensional character of e.g. the context that is the object position of the transitive verb 'seek'. The translation of (16) into IL according to the Alternative 1 reading ((Montague, 1973, 266)) becomes

$$(17) \quad \text{seek}'(\hat{j}, \hat{P}(\exists u([\text{unicorn}'_*(u) \wedge P(\hat{u})]))).$$

(where $\hat{P}$ is function abstraction over properties P). The denotation of this is 1 (true) in case the *seek* relation holds between the individual concept of John and a certain property Q of properties of individual concepts. A property P of individual concepts has this property Q just in case there is an object u

such that the individual concept of u both has P and has the *unicorn* property. Roughly, Q is the property of being a property that a unicorn concept has. Clearly, the property Q doesn't require the existence of unicorns. So, neither does the Alternative 1 reading of (16) in Montague's framework.

As can be seen from (17), however, also the subject position of **seek'** takes the individual concept of John as argument, not the individual John himself. In this case we ultimately do want the individual. To ensure this, Montague uses a number of *postulates* to guarantee that certain contexts, like the subject position of 'seek', are extensional. These have the form of axioms ((Montague, 1973, 263-64)) to be satisfied by a restricted range of ("logically possible") interpretations.

Let's finally reconsider the question of compositionality. The fact that the denotation of a complex expression depends on the *sense* of one of its parts, in argument position, means that a semantic *switch* takes place, in the sense general compositionality (cf. (GPC), p. 12). *Denotation* in the Montague semantics of 1973 is therefore not (standard) compositional.

Is *sense* compositional? The denotation of a belief sentence depends on the sense of the embedded sentence (translation rule T7 in (Montague, 1973, 262)). If the embedded sentence is itself a belief sentence like

(8) Bill believes that John believes that Hesperus is a planet

we have a doubly embedded sentence ('Hesperus is a planet'), and it will be the "sense of the sense", or indirect sense, that the sentence contributes to determining the denotation of (8).

This does in fact generate an infinite hierarchy of senses, just as in Frege, but in Montague's case it is harmless. The reason is that the indirect sense is determined by the sense itself. More precisely (Montague, 1973, 259), since $[\hat{\alpha}]^{u,i,j,g}$ is that function h that applied to a pair $\langle i', j' \rangle$ gives $[\hat{\alpha}]^{u,i',j',g}$ as value, and since this value does not depend on the pair $\langle i', j' \rangle$, the sense of the sense of α is a constant function from indices that gives the sense of α as value at each index. Although the sense of the sense of α is distinct from the sense of α , it is determined by the sense of α . Hence, no new interpretation function is required, and *sense* in Montague (1973) is indeed compositional.

1.8 Kaplan Style Semantics

David Kaplan's 'Demonstratives' (Kaplan (1989b)) was well-known for years before it was eventually published, together with the addition 'Afterthoughts'

(Kaplan (1989a)). Its project is to develop a version of possible-worlds semantics that takes semantic context-dependence into account. In particular, the semantics takes account of parameters such as the time of a context, the speaker and hearer of a context, the place of a context, the selection of what is demonstrated in a context. Because of this, Kaplan distinguishes between *three* levels of meaning: *character*, *content*, and *extension*. The content of an expression at a context of use may depend on features of that context. The character of the expression encodes the context dependence and does not itself depend on context. As we saw above, this idea was to some extent anticipated by Montague (1970b).

The character of an expression is a function from context of utterance to *content* (1989b, 505-07). The content, in turn, is a function from *circumstances of evaluation* to extensions. A circumstance of evaluation includes a possible world, but according to Kaplan it must also contain a time (we return to this below).

For an expression that is not context sensitive, the character is a constant function from context to content. Pure indexicals like ‘I’, ‘here’, and ‘now’, and demonstrative indexicals, like ‘you’ and ‘that’, have non-constant character. The sentence (18a)

- (18) a. I am here now
 b. David Kaplan is in Portland on 26 March 1977

as uttered by David Kaplan on 26 March 1977, provided he was then in Portland, has the same *content* as (18b), uttered by anyone at any time and any place.

A central part of Kaplan’s project is to capture the *logical* properties of certain sentences, characterized in his *logic of demonstratives*. There, a sentence like (18a) is a logical truth, in the sense that, because of its *character*, it is true in every context, for it holds in every context that the speaker of the context is at the place of the context at the time of the context. It was important that this logical property of sentences like (18a) can be combined with their modal *contingency*. For

- (19) □ I am here now

is false at every context. This very combination of features depends precisely on the fact that the modal operator takes the *content* of the embedded sentence as argument, and only shifts a parameter of the circumstances of evaluation, the possible world. Kaplan thereby manages to separate these two features: that in

every context, the content of (18a) is a content that is true *in the circumstances of that context*, while it still is false in *other* circumstances of evaluation.

Kaplan further attaches a direct cognitive significance to the concepts of character and content (1989b, 530). Contents are “Fregean Thoughts”, or the objects of thought. Contents are what one *believes*. Characters correspond to the *cognitive significance* of Thoughts. The *Thought* expressed by David Kaplan in Portland on 26 March 1977 by uttering (18a) would be the same as the *Thought* expressed by anyone at any time and any place by uttering (18b). Their perspectives would necessarily be different, and so the *cognitive significance*, or the presentation, of the Thoughts, would be different. This view of the psychological relevance of the semantic distinction is intuitively plausible, and serves as a strong *motivation* for the distinction. As we shall see soon, it also leads to trouble.

Kaplan requires a sharp distinction between contexts of use and circumstances of evaluation. This distinction is forced by some semantic facts about indexicals (1989b, 500):

- (T2) When what was said in using a pure indexical in a context c is to be evaluated, with respect to an arbitrary circumstance, the relevant object is always the referent of the indexical with respect to the context c .

Now consider

- (20) At some time it snows where John is now

and assume that we have a semantic clause for ‘at some time’ that says that ‘at some time, p ’ is true at a context c just in case, for some time t , the context c' that is like c except that the time of c' is t , p is true at c' . Let $\tau(c)$ be the time of c , and use ‘ $c[x/y]$ ’ for the context that is like c except that x replaces y .

- (21) $\models_c$ at some time p iff for some time t , $\models_{c'} p$

where $c' = c[t/\tau(c)]$. The clause (21) will have the effect that (20) is true at a context c just in case

- (22) It snows where John is now

is true with respect to some time t in the context $c' = c[t/\tau(c)]$. But then the value of ‘now’ with respect to c' is precisely t . So, (20) comes out, incorrectly, as true just in case there is some time t such that it snows where John is *at* t (not

where he is at the time of utterance of (20)) This gives the intuitively wrong result, a result that would be right for

- (23) At some time it snows where John is.

Correspondingly, it violates the principle (T2), that according to Kaplan holds of all pure indexicals, including ‘now’.

The conclusion is that when the *time parameter* has to be shifted, because of the occurrence of a temporal operator like ‘at some time’, what is shifted can *not* be a parameter in the context of use. Some other point of evaluation is needed, and that is precisely the circumstance of evaluation. There is therefore a division of labour between the context of use and the circumstances of evaluation: the former fixes the value of the indexicals and therefore determines *content*, while the latter contains all the *shiftable parameters*, corresponding to modal operators (which shift the world), and temporal operators (which shift the time). If ‘at some time’ would have the semantics of (21), it would shift the time of the *context*. It would then be an operator on *character*, which is what Kaplan calls a “monster” (p. 510). He claims that English does not contain any.

Since temporal indexicals like ‘now’ require their semantic values to be fixed by context, *both* the context of use and the circumstances of evaluation must contain a time parameter (“double indexing”, cf. subsection 1.11). For a sentence that does not contain any temporal indexical, the time parameter of the context does no work. The content of a sentence like

- (24) It snows where John is

at a context *c* is not a classical (eternal) proposition, true or false at possible worlds, but a *temporal* proposition, true or false at world-time pairs. Kaplan gives an argument for this (the so-called “operator argument”; 1989b, 502-03): “If we built the time of evaluation into the contents (thus removing time from the circumstances leaving only, say, a possible world history, and making contents specific as to time), it would make no sense to have temporal operators.” Whatever the value of this argument, the idea that we actually *believe* temporally neutral contents has met with a fair bit of philosophical opposition (starting with Richard (1981)).

The double temporal indexing has further consequences in connection with compositionality. Kaplan requires both that character is compositional and that content *with respect to a context* is compositional (1989b, 597 with slightly compressed wording):

- (F1) The character of the whole is a function of the characters of the parts (and the mode of composition)
- (F2) The content of the whole in a context c , is a function of content of the parts in c (and the mode of composition).

Now, compare (24) with (22). There is an intuition that we would *say* the same thing in a particular context, whether we use (24) or (22). But the assumption that the utterances would have the same content leads to a violation of (F2), compositionality for content. For the results of embedding (24) and (22) under ‘at some time’ are (20) and (23), respectively. Since (20) and (23) have *different* contents, compositionality for content is violated if they are formed with the same syntactic operation from sentences with the same content. Hence, (22) and (24) must differ in content (cf. Westerståhl (2012)).

This conclusion differs from that of David Lewis (1980) and Michael Dummett (Dummett (1981a), 446-47; Dummett (1981b), 572-74). Both argued that we must distinguish between the content of an utterance made by a sentence on its own (what Lewis called “what is said” and Dummett “assertoric content”) and what it contributes when embedded in larger linguistic contexts (Lewis’s “compositional value”, Dummett’s “ingredient sense”). Both suggestions would involve giving up standard compositionality for content (the content of (22) and (24) are the same, but they embed differently).

1.9 Centered-Worlds Propositions

An alternative approach to indexical sentences was proposed by David Lewis (1979). Following a suggestion in Quine, Lewis proposed that the meaning of a sentence is a set of *centered worlds*. A centered world is a pair (w, c) of an ordinary possible world w and a *center*. As Lewis proposed it, a center is a pair of a *time* and a *location*. Others have proposed that a center is a pair (S, t) of a *speaker* S and a time t . Using the latter, we would say that the meaning of

- (25) I am hungry

is the set of centered worlds $(w, (S, t))$ such that S is hungry at t in w . This set of centered worlds is supposed to be the meaning of the sentence, as well as *what is said* by means of it in a context, and the *content* of belief. The proposal to use centered worlds is therefore in a sense an idea of collapsing Kaplan’s levels of character and content into one single level, where the propositional content and the cognitive significance are merged.

One thing has to be added on the attitude level, however. For believing a classical proposition, a certain belief or *holding true* attitude must be taken towards that proposition. That attitude can be characterized by saying that the speaker or believer takes *the actual world* to be a world where that proposition is true. Usually we say that the proposition just is the content of that belief. This doesn't work for centered propositions, for we would lose the ingredient that it is the speaker or thinker *herself* that is hungry at the very time of speaking or thinking. The simple attitude of holding-true must therefore be replaced by something else, and Lewis proposes to take the idea of *self-attribution* as basic.

The idea therefore is that the speaker *self-attributes* the centered-world proposition. More precisely, the speaker attributes the centered-world proposition to the triple of the *actual world*, *herself* and the *current time*. That is, with $\mathbf{a}$ as the actual world, self-attributing the centered-worlds proposition amounts to taking the pair $(\mathbf{a}, (S', t'))$ of the actual world, the current speaker and the current time to be in the set of centered worlds $\{(\mathbf{w}, (S, t)) : S \text{ is hungry at } t \text{ in } \mathbf{w}\}$.

To see the connection with Kaplan's theory even more clearly, note that given a world, the pair of a speaker and a time uniquely determines a context in that world (and vice versa). We can therefore replace talk of centers with talk of contexts. And we can replace talk of the set of pairs of worlds and contexts with talk of the characteristic function from pairs of worlds and contexts to truth value. But then, with μ_K for character and μ_L for Lewis's corresponding semantic function, we have

$$\mu_L(\mathbf{w}, c) = \mu_K(c)(\mathbf{w}).$$

We conclude that the theories are in a sense equivalent (not taking issues of double indexing into account). The main difference lies, of course, in what is attributed as the contents of utterances and beliefs. For instance, as noted e.g. in Egan (2007), the hearer cannot simply *take over* the same content as expressed by the speaker, for if the hearer *self-attributes* the content of (25), he will think that *he*, the hearer, is hungry. So the reduction of levels of meaning results in a complication of the theories of assertion, belief, and communication.

1.10 Relativism

Relativism is the general philosophical idea that the truth or falsity of a proposition may depend not just on "the facts" in an ordinary sense, i.e. on a possible world, but on additional factors as well, and in particular on properties of *persons*. On this definition, already the temporalism of Kaplan, according to

which content is a function from pairs of worlds *and times* to truth values, is a species of relativism. And Lewis's theory of centered-worlds propositions, as functions from worlds and centers to truth values, is another.

Relativism has become a topic of interest in philosophy in recent years, for two reasons: Firstly, because of claims that certain phenomena are best treated by means of a relativist account, and secondly, because more precise semantic theories have been given to accommodate relativism (cf. García-Carpintero and Kölbel (2008)).

Three areas in particular have been in focus for relativist treatment: *predicates of personal taste* (see e.g. Lasersohn (2005)), *epistemic modals* (see e.g. Egan (2007)), *a future contingents*. Here we take a brief look at the latter.

In Aristotle's classical puzzle about future contingents we are asked to evaluate the sentence

(26) Tomorrow there will be a sea battle.

There are two conflicting intuitions about it. On the one hand, assuming that the future is open and the facts at the time of utterance of (26) do not determine whether a sea battle will take place, it seems that (26), at the time of utterance, is *neither true nor false*. On the other hand, if on the following day a sea battle does take place, it seems right to say that the utterance, or the sentence as uttered, *turned out* to have been true after all. Hence, it seems that it was in one respect neither true nor false, and in another respect true.

John MacFarlane (2003; 2008) has proposed to account for both intuitions by means of a relativist semantics. On MacFarlane's proposal, (26) must be evaluated with respect to both a context of use *and* a context of *assessment*. By the context of assessment that is identical to the context of use, (26) is neither true nor false, and by the context of assessment the following day, after observing the battle, it is true. In a picture of branching time where worlds are world histories which can overlap in contexts (pass through the same context), MacFarlane (2008, 13) gives the following definition:

(27) An occurrence of a sentence S at C_U is true as assessed from C_A iff for every world $w \in W(C_U|C_A)$, S is true at $\langle C_U, w, a \rangle$.

Here $W(C)$ is the set of worlds that overlap at C . a is an assignment of values to variables. $W(C_U|C_A) = W(C_U) \cap W(C_A)$, provided $W(C_U) \cap W(C_A) \neq \emptyset$, and equals $W(C_U)$ otherwise.

On this relativist view, what is expressed by a sentence, given a context of use, is a function from pairs of a world and context of assessment. The context of assessment is *not* determined by the context of use. As a matter of terminol-

ogy, a semantics that does take the context of assessment to be *determined* by the context of use is called *non-indexical contextualism* by MacFarlane (MacFarlane (2009)).

1.11 Two-Dimensionalism

The basic idea of two-dimensionalism is that *pairs* of indices, rather than single indices, are used for semantic evaluation. Thus we have two-dimensional possible-worlds semantics in case sentences are evaluated with respect to pairs of worlds, and a two-dimensional semantics for time dependence if pairs of times are used. In this sense, Kaplan's semantics is two-dimensional, since (possibly different) times are both in the context of use and in the circumstances of evaluation. The first to observe that a two-dimensionalist semantics of time might be needed because of the semantics of 'now' was Hans Kamp (1971). Kamp noted that the model theory can use two different methods of handling the "rigid" (in Kripke's sense) character of 'now'. One option is that the model includes a designated time t_0 , a *now* point, such that all sentences are considered as uttered at t_0 , and 'now' has a constant meaning:

(28) $\ulcorner \text{Now } p \urcorner$ is true with respect to a time t iff p is true with respect to t_0 .

The alternative is to allow that sentences can be uttered at different times, and then 'now' is an indexical. The time of utterance is then the *now*-point from the perspective of the utterance, and evaluable with respect to any arbitrary time. This is two-dimensionalism.

Correspondingly, in two-dimensional possible-worlds semantics, one world is considered to be the *world of utterance*, and what is uttered in that world can be evaluated at an arbitrary world. In that case, 'actually' is treated as an indexical. For evaluation of a sentence, we then need two worlds, the first to determine the content of the utterance, the second for evaluating the content as so determined. The first world then plays the role of *context of use*, in Kaplan's sense, and the second as the *circumstances of evaluation*. The *meaning* of a sentence is then a function from pairs (w_1, w_2) of worlds to truth values.

Robert Stalnaker (1978) used this idea to propose that in some cases, the standard possible-worlds *proposition* that is expressed by means of a sentence s is the so-called *diagonal*. If we think of the set of pairs of worlds as given by a two-dimensional matrix, with a pair of worlds in each cell, the diagonal is the subset of the matrix where the pair members are identical, i.e. $\{(w_1, w_1), (w_2, w_2), \dots\}$. The *diagonal intension* of a sentence p , $\mu_d(p)$, is an

ordinary possible-worlds proposition. It gives the value True for any world w such that the *pair* (w, w) on the diagonal is given the value True by the two-dimensionalist intension $\mu(p)$. Stalnaker's idea was that the *content* of an assertion that p in some cases is best taken to be $\mu_d(p)$, rather than a proposition fixed by the world of utterance.

The rationale for this proposal comes partly from the semantics proposed for proper names by Saul Kripke (Kripke (1980)). According to Kripke, the *intension* of a proper name like 'Hesperus' is a constant function: its value for any world as argument is the planet Venus (provided Venus exists in that world); proper names are in this sense *rigid designators*. Since 'Phosphorus' is another name for Venus, 'Hesperus' and 'Phosphorus' have the same intension. There will be no semantic difference between

- (29) a. Hesperus=Hesperus
 b. Hesperus=Phosphorus

However, we can associate different reference-determining conditions with the two names, so that in some *worlds of utterance*, 'Hesperus' and 'Phosphorus' corefer, while in others they don't. Therefore, in a two-dimensional matrix, (29a) will be true with respect to all pairs of worlds, while (29b) will be true at some and false at others. On a straight interpretation of (29b), it expresses the necessary true proposition (or at least a necessarily non-false proposition), but it is plausible to interpret the speaker as asserting the *diagonal* proposition p which is such that p is true in w just in case the referents of 'Hesperus' and 'Phosphorus', as determined in w , are identical in w . This is a non-trivial proposition, true in some worlds, false in others. So here, what is meta-semantic for the rigidity theorist is semantic for the two-dimensionalist.

Formally, with $\mu(e)$ as a binary function from pairs of worlds (w_i, w_j) to extensions, and with $\mu^1(e)$ as the primary intension of expression e and $\mu_w^2(e)$ as the secondary intension of e at world w , we have

- (30) a. $\mu^1(e) = \lambda w((\mu(e))(w, w))$
 b. $\mu_{w_i}^2(e) = \lambda w((\mu(e))(w_i, w)).$

Sometimes, suggested e.g. in (Chalmers (2006); Michels (2011)), the first element in each pair is to be a *centered world* in the sense of subsection 1.9, so as to bring in a context of use *within* the world of utterance. A central part of this appeal to two-dimensionalism is that different intensional operators depend on different intensions:

- (2D) i) A sentence $\Box\phi$ is true at (w_i, w_j) iff ϕ is true at all pairs (w_i, w_k) such that that w_k is accessible from w_j .
- ii) Where B is a *belief* operator, $B\phi$ is true at (w_i, w_j) iff $\mu^1(\phi)$ is true in all the worlds that are belief-alternatives to w_i .

The truth of $\Box\phi$ depends just on the soc-called *secondary intension* of ϕ at w_i , while the truth of $B\phi$ depends on so-called the *primary intension*, as the content of a belief entertained in w_i .

1.12 Situation Semantics

In situation semantics (cf. Barwise and Perry (1983) and Barwise (1989)), *situations* play several roles, some of them analogous to worlds in possible-worlds semantics, and some of them to contexts. Analogous to two-dimensionalism, the *meaning* of a sentence ϕ is a *relation*

$$u \mid \phi \mid s$$

between an *utterance* situation u and a *described* situation s (which is equivalent to a function from pairs (u, s) to truth values). This is again similar to Kaplan's concept of *character*, which can be viewed as a relation between contexts of use and circumstances of evaluation. The *interpretation* of a sentence ϕ as used in a real situation u is then $\mu_u = \{s : u \mid \phi \mid s\}$, the set of situations at which ϕ , as uttered in u , is true.

There are two basic kinds of situations, *real* and *abstract*. Real situations are particulars, concrete parts of reality that stand in causal relations to each other. They are therefore much like *events*. The utterance situation u is a *real situation*, and it fixes the *time* relevant for evaluation.

By contrast, s is an *abstract situation*, something that obtains or not, therefore much like a *state of affairs*, and again is thought of as a *partial possible world*. Abstract situations are set-theoretic constructions from a basic real entities of three kinds:

- a) Space-time locations
- b) Relations
- c) Individuals

Abstract situations are *sets* of *basic states*. A basic state is a *triple*

$$\langle l, \langle r, x_1, \dots, x_n \rangle, i \rangle$$

where l is a space-time location, r an n -ary relation, $x_1, \dots, x_n$ objects (basic

or constructed), and i is a *polarity*, either 1, for obtaining (truth), or 0 for non-obtaining (falsity). With polarity value 1, the basic state is that state where the objects $x_1, \dots, x_n$ stand in the relation r at space-time location l , and with value 0 that state where they do not. Two such states are *incompatible* iff they differ just in polarity. Two abstract situations are incompatible if they contain, respectively, incompatible states, otherwise compatible.

Abstract situations are related to real situations. An abstract situation is said to be *actual* iff it correctly and *exhaustively* represents some real situation, and it is said to be *factual* if it is *part* of an actual situation. *Types* of situations are abstract situations with an *indeterminate* (a parameter) instead of an object. A situation s is of a type T iff s results from T by substituting entities of the appropriate sorts (locations, individuals etc.) for the indeterminates.

There is also an *ordering relation* between situations. One situation s is said to be a *part of* a situation s' iff every basic state that is an element in s is also an element in s' . All real situations are mutually compatible. For any two real situations s, s' , there is a larger real situation s'' that contain both s and s' as parts. The real world has all real situations as parts, but it is not itself a situation, since the collection of all real basic states is to be regarded, from a set-theoretic point of view, as a *proper class*, while abstract situations are all sets. Similarly, maximal internally compatible collections of basic states are analogous to possible worlds.

Statements of these features and others of situations belong to *situation theory*, which concern the formal and ontological properties of situations *per se*, irrespective of the appeal to situations within semantics. Another ingredient of situation theory that should be mentioned is the central feature that situations may be *constituents* of other situations, since they are like real events, or representations of real events. This feature, like the others, are of course, designed with the semantics in view.

What are the semantic motivations? One basic motivation is that of achieving more *fine-grained* meanings than classical possible-worlds semantics. In the classical theory, all sentences that are necessarily true express the same proposition, and therefore have the same meaning within the semantics. This can be avoided in situation semantics because situations are partial, and therefore do not all contain everything that exists in maximal collections of basic sets. The first two sentences of

- (31) a. Albert is a man
 b. Albert is a man and $1 + 1 = 2$
 c. Albert is a man, and if Albert is a man, then Albert is a man.

are true in the same possible worlds, and so have the same possible-worlds intension. They are not, however, true in exactly the same *situations*, for some simple situations do not contain numbers. Hence, the interpretations of (31a) and (31b) are different.

The outcome is desirable, but this ontological move in situation theory is not sufficient to distinguish the interpretation of (31a) from the interpretation of (31c), since every situation that makes (31a) true also makes (31c) true, unless we countenance impossible situations or non-standard interpretations of the conditional. Hence, the desired fineness of grain is not really achieved.

A second motivation was that of making context-dependence, in a wide sense, an integral part of the semantic framework. In at least one respect, situation semantic goes beyond Kaplan style semantics when it comes to the context dependence, in a wide sense, of semantic evaluation. In Kaplan style semantics, contents are evaluated at world-time pairs. In situation semantics, they (i.e. interpretations) are evaluated at situations. Since situations are partial, an interpretation may be false at one situation even though it is true at a *larger* situation. An example (Barwise and Etchemendy (1987), 122; Kratzer (2011)) is an utterance of

(32) Claire has three of clubs

by a speaker watching a card game. That card-game is the *intended* real situation described. If he is mistaken about the identity of the player, and Claire, unbeknown to him, is actually taking part in *another* card game, and at that very time *does* have three of clubs, then the utterance is nonetheless *false*, according to this theory, since it is false of the situation described. This context dependence in evaluation goes beyond standard context dependence associated with indexicals and other context sensitive expressions. Whether it is the intuitively right result is perhaps not completely clear.

A third motivation derives from the possibility of making situations constituents of other situations. This has been used to model reports such as

(33) John saw Bill kiss Mary.

In the interpretation of (33) a situation *type*, the type $\langle y, \langle \text{kiss}, \text{Bill}, \text{Mary} \rangle, 1 \rangle$, with y an indeterminate, is a constituent of the situation of John's seeing something; it is what he sees. If (33) is true, then there is a real situation of this type, and this situation is a particular that John stands in a causal relation to. (33) is an example of *naked infinitive* constructions that situation semantics was designed give a semantics for.

A fourth motivation, finally, is the possibility of exploiting so-called *re-*

source situations. A resource situation is different from the described situation, but can be used, for instance, to offer an alternative domain of objects in order to restrict quantification or fix the reference of a definite description. Relative to a resource situation $r(u)$ of an utterance situation u the description ‘the butler’ may pick out a unique butler, which may be the entity relevant in the interpretation of e.g.

(34) The butler is at a butlers’ conference.

That the referent is not the unique butler at the described situation does not then cause trouble.

1.13 Structured Meanings

A radical move to make meanings more fine-grained than sets of possible worlds is to take meanings as *structured*. Instead of having an entity like a function as a semantic value, semantic values are seen as having *parts*, some of them with parts in their turn. This typically provides a *constituent* structure that mirrors the structure of syntax.

We need to distinguish between a weaker thesis that there are semantic values that have structure, and the stronger thesis that some particular values are in fact structured. Especially, if the meaning of a sentence is a proposition, can it be that the proposition itself is a structured entity? This may of course be a terminological issue, but if it assumed (as part of what characterizes the concept of a proposition) that propositions are the contents of beliefs, and *what is said* in assertions, then there is also a substantial question whether what is said, or believed, may be something structured.

The term ‘proposition’ was in fact used to stand for a structured entity before it was used as a term for possible-worlds intensions. Russell (1903) writes

Consider, for example, the proposition “ A differs from B ”. The constituents of this proposition, if we analyse it, appears to be only A , difference, B (Russell (1903), 47).

It has become common to render the propositions, analyzed in this way, by means of an ordered n -tuple notation, such as

$$\langle \text{difference}, A, B \rangle,$$

and ordered tuples of this kind are commonly known as *Russellian propositions*.

Russellian propositions are naturally generalized to more complex meanings by allowing ordered tuples to have ordered tuples as constituents. This

will generate *tree structures*, where the top node is the meaning of the whole expression, which is an n -tuple. Each element in the n -tuple is a simple meaning or itself a tuple of the same kind, which is subordinate to the topmost tuple. And so on.

One version of this was proposed in Cresswell (1985), where trees are built up from ordered pairs, where each pair consists of a function and an argument. The function is the semantic value of an incomplete expression (in Frege's sense), and its argument is the semantic value of the *syntactic* argument to the incomplete expression. In Lewis (1970, 33), meanings simply *are* trees. The simple nodes of the trees are pairs of a category and a possible-worlds intension of that category. The meaning tree mirrors the syntactic tree of the expression whose meaning it is. Jeff King (King (2007)) also takes structured meanings to be trees that mirror syntactic trees, but he takes the further step of actually characterizing the meaning tree by reference to the syntax: a meaning is part of a structured meaning because it is the meaning of an expression that occupies a certain position in a syntactic tree. In Bealer (1993) we find a slightly more abstract conception. Bealer does not explicitly speak about tuples or trees, but rather of an *algebra* with an ordering relation. The restrictions on that ordering relation nevertheless effectively entail that structured meanings have a tree structure.

We get an even more abstract characterization by imposing a structure on the *synonymy relation* rather than directly on the meanings themselves. The classical proposal is Carnap's idea of *intensional isomorphism* (Carnap (1956), 56-7)

- (ISO) i) Two simple expressions e and e' are synonymous iff they are co-intensional.
- ii) Two complex expressions A and A' are synonymous iff they have the same (top) mode of composition and their corresponding immediate parts are synonymous.

It can be shown that with synonymy, i.e. sameness of meaning, defined this way, meanings must be individuated as structured meanings are; they can therefore be represented as structured (cf. Pagin (2003), and compare (PIC), page 11).

A main motivation for postulating structured meanings is that they provide the more fine-grained meanings that are needed both for intuitions about difference of meaning, and for belief reports. It clearly helps to distinguish (31a) both from (31b) and (31c), and the latter two from each other. A main problem with using structured meanings as contents of belief, and as *what is said*, i.e.

as *propositions*, is that it is unclear how anything at all is *said*, or *represented*, by means of a structured meaning.

The quote from Russell above continues as follows:

Consider, for example, the proposition “A differs from B”. The constituents of this proposition, if we analyse it, appears to be only A, difference, B. Yet these constituents, thus placed side by side, do not reconstitute the proposition. The difference which occurs in the proposition actually relates A and B, whereas the difference after analysis is a notion which has no connection with A and B. . . . A proposition, in fact, is essentially a unity, and when analysis has destroyed the unity, no enumeration will restore the proposition (Russell (1903), 47-8).

The problem Russell points to has come to be known as *the unity of the proposition problem*, even though there is nothing generally agreed on to be *the* problem. One question is how there can be anything at all that has an essential unity and represents possible states of affairs.

Another question is how anything can have parts and structure and still *intrinsically* represent states of affairs. Propositions as meanings are what makes sentences into representations. So propositions should not *themselves* be in need of interpretation. But trees or ordered tuples do not intrinsically represent states of affairs; we need to add a method of projecting for instance $\langle \text{taller, Plato, Socrates} \rangle$ on the proposition *that Plato is taller than Socrates*. With another method than the intended one, the triple could be mapped on the proposition *that Socrates is taller than Plato*. Indeed, it could be mapped on any proposition that in some sense or other contains or is about Plato and Socrates and the *taller than* relation. It is an open question whether the required fineness of grain can be combined with intrinsic representational content.

1.14 Verificationism

In the narrow sense, *verificationism* is the view that the meaning of a sentence is its *method of verification*. In a wider sense, it covers theories of meaning that in some way or other relate sentence meaning to evidence.

The idea that the meaning of a sentence is its method of verification seems to have been first proposed by Wittgenstein in the late 1920s. He writes for instance “The verification is not *one* token of the truth. It is *the* sense of the proposition (Wittgenstein (1975), 200).”

The idea was taken up by the logical positivists, in particular Moritz Schlick (Schlick (1936), 341), Rudolf Carnap (1936), and Alfred Ayer (1936) (for an overview of the position and its development, see Hempel (1950)). Carnap’s statement is particularly explicit:

If we knew what it would be for a given sentence to be found true then we would know what its meaning is. And if for two sentences the conditions under which we would have to take them as true are the same, then they have the same meaning. Thus the meaning of a sentence is in a certain sense identical with the way we determine its truth or falsehood; and a sentence has meaning only if such a determination is possible (Carnap (1936), 420).

According to Carnap, *synonymy* amounts to sameness of method of verification (or falsification), which provides a clear sense of saying that the meaning *is* the method of verification. Carnap also states the so-called *criterion of meaningfulness*, that only sentences that *can* be verified or falsified are meaningful. This demarcation criterion should be distinguished from verificationism itself, but they go very naturally together.

Especially in Carnap, there is a historical background in his own *Aufbau* (Carnap (1928)) and Russell's *External World* (Russell (1914)), which were (sketches of) attempts at *reducing* sentences that appear to describe an external world to sentences that describe what is immediately given in experience. In the verificationism of the 1930s, by contrast, the most basic sentences themselves do describe the external world. They are, however, *observation sentences* (or even so-called *protocol sentences*, such as 'Red here now'), sentences whose truth value can be *settled* by means of direct observation. One problem with this approach is that it is hard to understand the semantic difference between a sentence that *describes* experience and a sentence that can be directly established as true or false on the basis of that same experience but in fact describes an external state of affairs instead.

There was an attempt to reduce theoretical sentences of scientific theory to observation sentences by means of so-called *operative definitions* (e.g. to define 'temperature' in terms of the use of thermometers), but this had the effect of restricting the scope of scientific theories to what is in fact measured. Similarly there are problems with *universal* sentences, such as

(35) All ravens are black

which cannot be conclusively verified even assuming that its instances can. Ayer also tried to exclude cognitively meaningless sentences from scientific theories by appeal to having, together with *other sentences*, observational consequences, but that turned out to be very difficult (cf. Hempel (1950)). Carnap's (1936) reaction to these problems was to turn from conclusive verification to degree of *confirmation*. However, the relation between evidence, degree of confirmation, and linguistic meaning, then becomes much more complex and less direct.

A more recent form of verificationism was developed in the 1970s and -80s

from a background in intuitionism in logic and mathematics, and in proof theory. Verificationism in the 1930s had kept classical logic, and thereby the principle of *bivalence*, that every (cognitively meaningful, non-indexical, declarative) sentence is either true or false. But if there is no general guarantee that every apparently meaningful sentence can be either verified or falsified, either bivalence should be given up, or many apparently meaningful sentences must be deemed meaningless after all.

The new verificationism does not accept the principle of bivalence, or classical logic. It has been primarily concerned with logic and mathematics, rather than with empirical sentences. It takes two closely related forms. In one form, the concept of a *proof* is basic. According to this conception, which is close to classical verificationism, the meaning of a sentence is characterized by what *counts* as a proof of it. That is, what characterizes meaning is not a one-place property but a relation: *x is a proof of y*.

For any given provable sentence *A*, there are infinitely many proofs, some of them differing only marginally, some very much. It seems hard to characterize the conditions of being a proof of *A* in an informative way, and especially in a compositional way. This problem was addressed in the early seventies by Michael Dummett and Dag Prawitz, who made the distinction between *canonical* and *non-canonical* (or *direct* and *indirect*) proofs (Dummett (1975), 240-47, Prawitz (1974), 63-77). Although a proof in general of a sentence *A* can have any form, a *canonical* proof of *A* reflects the form of *A* itself:

- (36) $\wedge$ A canonical proof of $A \wedge B$ is a pair $\langle a, b \rangle$ where *a* is a proof of *A* and *b* is a proof of *B*.
- $\vee$ A canonical proof of $A \vee B$ is a pair $\langle a, b \rangle$ where either *a* is *l* and *b* is a proof of *A* or *a* is *r* and *b* is a proof of *B*.
- $\rightarrow$ A canonical proof of $A \rightarrow B$ is a function *f* that for any proof of *A* as argument gives a proof of *B* as value.
- $\forall$ A canonical proof of $\forall xAx$ is a function *f* that for any term *t* in the language as argument gives as value a proof of $A(t/x)$.
- $\exists$ A canonical proof of $\exists xAx$ is a pair $\langle t, b \rangle$ where *t* is a term in the language and *b* is a proof of $A(t/x)$.

$\neg A$ is defined as $A \rightarrow \perp$ (where $\perp$ is Falsum, the emblematic falsity constant).

This is the modern version of the Brouwer-Heyting-Kolmogorov explanation of the meanings of the logical constants. A proof *in general* of a sentence *A* is then seen as a *method* which, when applied, yields a canonical proof of *A*. Hence, when there is a proof, there is a canonical proof. The law of excluded middle is not validated by this semantics (although $\neg\neg(A \vee \neg A)$ is valid).

A speaker is assumed to understand a sentence A *compositionally*, from understanding its parts and the way they are put together, and this idea of understanding is realised with the recursive specification of canonical proofs. Specifications of the conditions for being proofs of atomic sentences, e.g. arithmetic equations, can be added. The concept of a proof here is general and informal, not restricted to proofs in any particular formal system. If it were, any expansion of the system would automatically change the meaning of the logical constants.

The other form of the new verificationism focuses on conditions for *correctly asserting* a sentence (utter it with assertoric force). That the meaning of sentence should be characterized in terms of assertibility is especially stressed in Dummett (1976). The specifications of what counts as canonical proofs correspond to *introduction rules* for the logical constants. For instance, the introduction rule for $\wedge$ says that $A \wedge B$ may be inferred from the set of premises $\{A, B\}$. Unlike the canonical proofs form, this alternative explanation appeals to a particular kind of deduction, exemplified by Natural Deduction systems.

The appeal to canonical proofs does offer a very fine-grained conception of linguistic meaning. For instance, a canonical proof of a sentence $A \wedge B$ will always be different from a proof of A , even if B is a simple logical truth made from the same linguistic material as A itself (compare (31a) and (31c)).

This feature holds in particular of the intuitionistic type theory by Per Martin-Löf (Martin-Löf (1984); the theory has evolved since Martin-Löf (1984), but there is no later canonical book-length presentation). Here the relation between proofs and propositions are built into the formal system. Proofs are proof objects, and propositions are *types* of proofs objects. They are not mere collections, but intensional in nature. That a proposition is *true* consists in the circumstance that it has at least one element. The basic sentences of type theory are so-called *judgments*, and among the forms of judgment we have $a : A$, which says that a is of type A (is a proof of the proposition A). By means of operations on proof objects we can form more complex proof objects that belong to correspondingly more complex propositions.

Martin-Löf's type theory has been applied in formal semantics, by Aarne Ranta in particular (Ranta (1995)). The general idea is that sentences of type theory provide the underlying logical form of sentences of natural language. Proof objects are rich in information (in this respect similar to *events* in event semantics). They can contain other objects as parts, which can be exploited in tracking anaphoric relations in sentences.

1.15 Procedural Semantics

Rather different semantic ideas have been called “procedural”. The unifying idea is rather loose, but in all cases there is an idea that some level of linguistic meaning is associated with some sort of procedures or transitions. We can, I believe, distinguish between two main kinds:

- a) Meaning is associated with *updates* of information, i.e. transitions between propositions;
- b) Meaning is associated with fine-grained methods of deriving ordinary intensions.

Procedural semantics in the a) sense is usually called “dynamic” (cf. chapter xx). In semantics of the b) variety, the procedure in question is an abstract *interpretation* process, the process of interpreting a linguistic expression and arriving at an *intension*. This is meant to apply generally, irrespective of whether the content represents information updates in the sense of a). The procedure of getting to the intension of the sentence is taken to be encoded in a separate layer of meaning, the procedural level. I am aware of two abstract semantic systems where this basic idea has been technically developed. One, TIL (Transparent Intensional Logic) was originated by Pavel Tichý and carried on by Pavel Materna, Mari Duži, and Bjørn Jespersen. The other is developed by Yiannis Moschovakis.

Technically, both are type-theoretic systems with some similarity to Montague semantics. Philosophically, both stress the affinity to Frege and to verificationism. Frege thought of sense as (containing) a mode of presentation of the referent, and has often been interpreted as taking sense to be (or contain) *a method of identifying the referent*, in particular in the case of proper names (cf. Dummett (1981a), 95-6). Analogously, in verificationism, the *method of verification* or *method of falsification*, is a method for determining the truth value of a sentence. These are ideas that can range from a *condition* (necessary and/or sufficient) for *being* the referent, and a step-by-step series of instructions for determining or constructing the referent.

The latter, algorithmic conception was suggested by Tichý in 1969, taking the intension of an expression to be a Turing machine. Conceptions similar to this became popular in cognitive science. Johnson-Laird (1978, 249) said that “compiling and executing a program correspond rather naturally to stages in a person’s comprehension of an utterance” and (quoting himself, p 151) “we might speak of the intension of a program as the procedure that is executed when the program is run, and of the extension of a program as the result the program returns when it has been executed.”. This suggests that the procedural

meaning is not itself what the hearer *understands*, but rather the meaning of instructions that lead to understanding when executed. In general, the two levels must be kept apart: the semantic value the language user *comes to know* by means of applying or instantiating a certain abstract procedure, and the abstract procedure itself as a separate semantic value.

In Moschovakis (2006) meanings are said to be algorithms in the literal sense. More precisely, they are so-called *referential intensions* and the referential intension $\text{int}(A)$ of an expression A is said to be an algorithm for computing the *denotation* of A relative to an assignment g , $\text{den}(A)(g)$ (2006, 51).

Denotations are type-theoretic entities over some basic types: a type of individuals, a type of truth values, and a type of *states*. A state is quintuple of a world, a time, a spatial location, a speaker, and a function δ that assigns values to proper names and demonstratives. Functions that takes states as arguments are called *Carnap intensions*.

The computational element comes in with the so-called *recursion variables*: free variables of various types that may depend on other recursion variables of *lower rank*. This is exemplified by

- (37) a. John likes Mary and he dislikes her husband
 b. $p \ \& \ q$ **where** $\{p := \text{loves}(j, m),$
 $q := \text{dislikes}(j, h), h := \text{husband}(m), j := \text{John},$
 $m := \text{Mary}\}$

(37b) is a *rendering* of (37a) in the formal language $\mathbf{L}_{\text{ar}}^\lambda$. It denotes the Carnap intension of (37a), which is a function from states to truth values. The recursion variables p, g, h depend on the values of the recursion variables j, m , and their values are computed compositionally, and in some cases also capture anaphoric relations.

Proper terms (complex terms or constants) are said to be *referentially synonymous* iff their referential intensions are *naturally isomorphic*, where natural isomorphism between terms is similar to Carnap's *intensional isomorphism* (cf. (ISO), page 38). Thereby the referential intensions of Moschovakis are similar to Carnap's (1956) *meanings*, i.e. what is identical between synonymous expressions according to (ISO), with the added element of recursion variables whose values correspond to the Carnap meanings of syntactic constituents. The procedural element is seen in the *perspective* of computing the values of the recursion variables step by step, in the order of dependence, but does not seem crucial to the *individuation* of referential intensions.

In TIL, the algorithmic perspective was given up in favour of a *constructional* (cf. Materna (2009), Duži et al. (2010)). It is still meant to be procedural,

but semantic values are not always computable. Like Moschovakis's system, TIL is based on a type theory, with basic types those of individuals, truth values, times/real numbers, and possible worlds, together with the non-basic types of partial functions between already constructed types.

To these basic types are added so-called *constructions*. And with the construction comes a hierarchy of *orders*: The types of the basic function hierarchy belong to *order* 1. Constructions of order n are those that construct members of types of order n . The *collection* of all constructions of order n is itself a type of order $n + 1$. Orders are cumulative.

The peculiar features of TIL are its various *construction operators*, including $^0(\cdot)$ and $[\cdot, \dots, \cdot]$. 0X is the *trivialization* of X , or *mention* of X . The expression ' $3 + 7$ ' simply *denotes* the number 10, but it corresponds to particular way constructing or computing the number 10, distinct from e.g. that of ' $4 + 6$ '. The construction operators provide a way of denoting the constructions themselves, without executing/evaluating the constructions, reflecting the syntactic build-up rather than simply denoting the result.

Thus, 03 is the trivial construction of 3, an entity distinct from the number 3 itself. Analogously $^0+$ is the trivial construction of the addition function. These constructions can be combined by means of the *composition operator* $[\cdot, \dots, \cdot]$: given a construction of a function, and constructions of arguments to that function, the composition operator constructs the value of the function:

$$[^0+^03^07],$$

which is a construction of 10. In some cases, what is wanted is not denoting the construction of the value, which we get by composition, but rather the construction of the *composition itself*. This is achieved by another trivialization:

$$^0[^0+^03^07].$$

This is then taken to denote an abstract procedure which, when executed, delivers as result a construction of the number 10. This is again a procedure, which, when executed, delivers the number 10 itself.

In case the composition operator contains a free variable, as in $^0[^0+_x^07]$, what results is a so-called concept of a construction type. By contrast, $\lambda x[^0+_x^07]$ is a *function* that for a given value of x , gives a construction of the sum as value.

0X entities are hyperintensional meanings, and clearly are very much like structured meanings, with a structure that reflects the syntactic structure of the expressions they provide a meaning for. In what sense are they of a *procedural* nature? As far as I understand, they are procedural only in so far as they are viewed from a procedural *perspective*, i.e. as offering a method of reaching, step by step (starting from the construction itself), what is ultimately

constructed (e.g. the number 10). The same perspective can be applied to structured meanings of other kinds.

1.16 Conclusion

The modern tradition of formal semantics evolved out of an effort to place mathematics on a firm logical basis. It has remained close to logic, in employing formal methods and keeping the concept of *truth* as one of its core concepts. Connected with the concept of truth is the general notion of *truth conditions*, a notion made use of in trying to capture the non-extensional character of linguistic meaning. As we have seen, this theme has been developed in many different ways. And there are yet further approaches, such as *dynamic semantics* and *event semantics*, covered in the handbook although not in this chapter. A common feature in all the various types of semantics, is the attempt to model in a precise way how the meaning of linguistically complex expressions are determined by the meanings of their parts and the way these are combined. This is indeed one of the defining features of formal semantics.¹

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