

## LANGUAGE, LOGIC AND SEMANTICS

Background: Logic as the basis of rational argumentation

**Goal:** Logical reconstruction of common language arguments (in modelling); determination of “logical form”.

⇒ Give support to “knowledge engineering”, in particular the knowledge acquisition process, by bridging the gap between (formal) semantics of natural language and formal logic.

- The contemporary view on (NL) semantics and the roots of the relation between language and logic:

Antique and scholastic logic and grammar, Rationalist logic and grammar:

Port-Royal and Leibniz, Structuralism

- Lexical semantics
- Compositional semantics:

First Order Logic (?), Montague semantics, Discourse Representation Theory

## Preliminary Remarks I: Linguistic Description and Explanation

### Linguistic abstraction levels

- Order (phonology, morphology, syntax) – grammatical structure
- Contents (semantics) – literal meaning
- Use (pragmatics and discourse) – contextual meaning

### Segmentation in Natural Language Processing.

On each level:

- Segmentation through identification of elements which are assigned a symbolic description
- Rule-based composition of segments and their assigned descriptions by means of restrictions (“constraints”) over
  - string order (time-linear sequence)
  - features

Between levels: Transformation of descriptions by translation rules

## Preliminary Remarks II: Language and Logic

(Natural) language as the basis of all “systems of distinction”; functioning as object and meta language

Semantics of natural language expressions

- Fundamental problem: Ambiguity on all linguistic levels
  - lexicon, syntax, semantics, pragmatics
- Approach for scientific/technical language: rational reconstruction of language use
  - ⇒ “controlled” (normalized) language

## Language and Logic

Logic is the science of the truth of propositions on the basis of its form only.

Clearly logic is related to natural languages – what else are propositions than constructs of language?

But in a sense logic is independent of natural languages. Logical structures are evident in language, but their validity is not dependent on the fact that such structures are realized in natural languages.

Example:

“If Socrates is sitting or standing and Socrates does not stand, then he sits.”

We consider this sentence as true not because it talks about Socrates or sitting or standing, even if its contents would be an arbitrarily different one, if only its form is preserved:

“If a or b and if not b, then a.”

This sentence is true based on its form only, i.e. logically true.

## Language and Logic (2)

**Thesis:** The logical structures in language are not syntactic conventions of language.

(But: Realize the criticism of Aristotelian logic, in particular the system of categories, by philosophers of language: Reflex of the grammatical structures of indogermanic languages.)

Examples of logical structures:

- Elementary propositions (predication)
- Terms (terminological rules)
- Concepts (abstraction: invariance wrt. terms)
- Logical particles (connectives: junctors, quantifiers)

## Pragmatic Foundation of Syntax and Semantics

General opinion:

Thinking is first, language is a means to express and communicate thoughts;

⇒ Channel model of communication (coding–decoding).

Semantics is a translation semantics — cf. formal calculi.

Competence: disposition of coding schema.

The order “first syntax, then semantics” cannot be strict —  
cf. lexical ambiguity: syntax is subject to semantic constraints.

Understand lexical semantics as “sense relational semantics”

— does not require a realistic position: The basic markers are also words of the language.

## Pragmatic Foundation (2)

WITTGENSTEIN: The meaning is the **use**. I.e., which kind of an action is predication? (vs. which kind of objects are predicates?)

**Pragmatic foundation:** Understanding of actions vs. relations between “signals” (signs) and “meanings” (abstract objects).

⇒ Semantic composition is to be understood how complex actions are composed (—→ dialogue logic).

The question of a semantic foundation of grammar must not be understood in the sense of a feature semantics (= predicators are attributes or features):

Unity of semantics and pragmatics (WITTGENSTEIN).

But how can the gap between speech act theory and formal linguistics be closed?

⇒ The pragmatic foundation of dialogue logic:

- Neither syntacticism nor ontology
- Potential to meet all requirements of a full formalization

## Semantics of Natural Language: Literal Meaning

Four aspects of meaning in linguistics:

- inner-lingual / textual meaning which relies primarily on the verbal meaning and has to be represented within the language system itself;
- referential meaning which refers to the common sense knowledge of the communication partners, i.e. on the knowledge of facts and action rules;
- communicative, situative meaning for the representation of which interaction rules are required; and
- social, emotive and rhetoric-stylistic meaning which must be explained through the socio-cultural environment.

### Tasks of Semantic Processing

- Semantic construction: Determination of the semantic potentials of the input strings based on linguistic knowledge; representation formalism
- Semantic resolution: Determination of the actual semantic value (disambiguation, identification of reference objects) with context knowledge
- Semantic evaluation: Determination of the “relevant utterance information” by means of inference mechanisms which employ world knowledge

⇒ “Meaning structure” – representation of the intra-textual functional and logical relations of the text elements; in particular

- Resolution of lexical ambiguities
- Representation of different readings
- Discovery of semantic anomalies

### Back to the Roots: Antique and Scholastic Logic and Grammar

Reception of Aristotelian logic: Categories, Analytics (Syllogistics, Topics)

Relevance of Scholastic logic: Theory of rational argumentation in the center.

New features:

- Metalinguistic formulation by means of rules referring to language expressions (and **not** presented by means of formulas containing variables replaceable by object-language expressions);
- Includes the semantic and syntactic dimensions of language analysis; is developed in terms of the basic concepts of denotation, truth, and consequence (or entailment).

The investigation of argument structures comprises the question for the semantic relations of terms which are combined in arguments, in particular reference and meaning postulates.

(As opposed to the modern separation between the construction of purely formal systems and a mere description of ordinary language communication)

**Logical sentence analysis:** Stepwise transformation of (linguistic) surface structure into (logical) deep structure.

vs.

**Linguistic sentence analysis:** committed to surface structure.

Correctness of a sentence is to be found in the immanent construction principles (“modi significandi” as formal universals), not logical principles.

Grammar as a (1) “speculative” (= theoretic) and (2) auxiliary science:

1. Goal is to describe and explain the nature of language (Latin) as the most important and convenient vehicle of communication.
2. Grammar, like logic, is not directly concerned with the world, but with its reflection in our descriptions.

### Lexical semantics: Words in Modistic Analysis

Word: Phonological and (two levels of) semantic components:

Lexical (specific) meaning and general meanings (modi significandi)

“Imposition” connects with content:

1st connection with referent;

2nd similar to valencies / deep cases; determines the grammatical category of the word, which turns it into a particular part of speech (pars orationis).

“Diasynthetic” (syntax): Two forms can be combined in speech only if at least one feature or mode of one form is related to the mode of the other form (**dependency!**) either by agreement or by government.

Two main types of constructions: transitive and intransitive.

The syntactic system is based on word forms and their potential constructions (vs. constituent structure).

### Semantic Problems Recognized: Anomalies with Quantification

... and modern approaches to their solution (“ $\Rightarrow$ ”) [problem list due to G. Klima]

- Sentences of evidently the same structure are represented by different quantificational formulae and vice versa; scope ambiguities  
 $\Rightarrow$  Logical form and analysis of truth conditions; Montague
- Unrepresentable sentences (in FOL); General NL quantifiers (e.g., “most”)  
 $\Rightarrow$  Theory of generalized quantifiers
- Variables vs. anaphoric pronouns  
 $\Rightarrow$  Discourse Representation Theory (DRT)
- Intensional contexts  
 $\Rightarrow$  Possible world semantics, also for tensed modal contexts
- Intentional contexts, e.g. those created by attitude words  
 $\Rightarrow$  Situation semantics, etc.
- Conflicts with traditional logic  
 $\Rightarrow$  Game theoretic approaches (in general)

### The Rationalist Grammar and Logic of Port-Royal

- Sign theory
- Separation of object and meta language
- Representation
- Doctrine of judgment and conclusion
- Universal language and universal grammar
- Mentalism — “innate ideas” (... Chomsky)

### Leibniz' Program:

#### Scientia Generalis, Characteristica Universalis and Calculus Ratiocinator

- Concept formation
- Calculization: Universal calculus language and logical calculus
- Lexicon and encyclopedia

#### Steps of Leibniz' “Calculus” Program

1. Specification of an arithmetic calculus, in which the conjunctive combination of concepts is represented by means of a prime number decomposition.
2. Designs for an algebraic calculus for equality and subsumption of concepts.
3. Two calculi which are derived from extensions of the algebraic calculus in which the transition from an (intensional) concept logic to a class logic is achieved. So, a formal system has been constructed for the first time.

### A Remark on Structuralism

F. de Saussure (1916):

Constitution of the object domain of linguistics as a sign system

- Human linguistic expression (langage)
- Speaking (parole)
- Language (langue)

**Closed System** of langue units and their relational classification.

Relations between signifiant and signifié

## Computational Semantics

aims at the automatic construction of formal semantic representations for natural language expressions to perform inference:

- Association of logical expressions representing the semantics of linguistic expressions, e.g. feature structure unification (in combination with unification grammars), or lambda-calculus as a construction (“glue”) language, with special provisions for dealing with ambiguity;
- Automatic reasoning, using theorem proving or model generation techniques.

What’s the gain?

- Many applications, e.g. Information retrieval, information extraction, question answering, interpretation of controlled language, etc.
- Insight into mechanisms of language and communication, interaction of various phenomena, etc.

## Lexical Entries: Elements of Semantic Construction

We need a semantic lexicon with hierarchical structure, representing various sense carrying relations between words: WordNet (cf. ch. 4).

Not (yet) represented in WordNet:

**Selection restrictions:** The meaning of a word imposes constraints on the meanings of other words to be “combined” with it.

So, more semantic information has to be provided.

Most ambitious project: Fillmore’s FrameNet (Berkeley).

In the long run: Integration with WordNet in the Global WordNet framework.

## Modern Lexical Semantics: Thematic Roles

**Thematic roles** in Fillmore’s Case Grammar (1968)

Underlying assumptions:

- Apart from the syntactic and functional relations, in a sentence there exist semantic relations between the verb and other sentence parts (e.g., the agent of an action), which are called **thematic roles** or **deep cases**.
- There is a (relatively small) universal inventory of deep case relations or thematic roles, which are empirically determined.
- Each verb is assigned a case frame which specifies the obligatory and optional thematic roles.
- A certain thematic role may occur in a sentence only once.

## Lexical Semantics: Inventory of Thematic Roles

Fillmore’s first list (1968):

Agentive	(who)	animate agent of an action
Instrumental	(how)	involved inanimate force or object
Dative	(who)	animate participant affected by an action
Factitive	(what)	resulting object of an action
Locative	(when, where)	local position of a state or an activity
Objective	(everything else)	inanimate affected objects

## First Order Quantificational Logic as Semantic Formalism?

### Advantages of FOL

- Intuitive transparency through denotational semantics (Tarski)
- Deduction calculi as controlled tools for semantic evaluation

### Disadvantages of “plain” FOL

- Semantic construction open:  
Natural language sentences are associated intuitively with logical formulas; no resolution procedure
- Not expressive enough as a representation formalism:  
Model structure too coarse (inadequate concept of consequence); syntax too poor
- Compositionality requires substitution principle:  
Denotationally equal expressions may be substituted for each other — problematic! ( $\Rightarrow$  intensional logic)

## Logic for Semantic Representation

Consider various extensions to FOL:

- Modalities: Kripke explains intensional operators in terms of first order quantification.  
Models are enriched by “possible worlds” or “situations”, an accessibility relation, and a selector for the actual world (in general: “nominals” to name worlds).
- Tense and Aspect: Either extend to a tense logic (Prior) or follow Davidson’s approach to enrich models with primitive events and relations over them.
- Plurals: Enrich models with plural entities.

Main problem with FOL: Lack of **dynamic potential**.

Solutions: Dynamic Logic, Discourse Representation Theory (see below)

## Compositionality in Semantic Construction

How are meanings of complex linguistic objects composed from the meanings of their components?  $\Rightarrow$  **Frege’s Principle**

**Fundamental idea:** Lambda-calculus as a systematic “construction language”

Associate with each constituent a logical form (LF), i.e., an expression of a logical language which has validity conditions corresponding to those of the constituent itself. Hence, semantic constraints are added (“annotated”) to each grammar rule.

Example:

**Syntactic rule 1:**  $S \rightarrow NP VP$

**Semantic rule 1:** Let  $NP'$  be the logical form of  $NP$ , and  $VP'$  the logical form of  $VP$ , then the logical form of  $S$  is given by  $VP'(NP')$ .

**Syntactic rule 2:**  $VP \rightarrow TV NP$

**Semantic rule 2:** Let  $TV'$  be the logical form of  $TV$ , and  $NP'$  the logical form of  $NP$ , then the logical form of  $VP$  is given by  $TV'(NP')$ .

Computation of the logical form (LF) of the sentence “Linus loves Lisa”

- Let the LFs for Linus and Lisa be *linus* and *lisa*, resp.
- LF of the verb *loves*:  $\lambda$ -expression  
 $\lambda x. \lambda y. \text{loves}(y,x)$
- According to rule 2 the  $VP$  “loves Lisa” is associated with the expression  $\lambda x. \lambda y. \text{loves}(y,x)(\text{lisa})$ , which is by means of  $\beta$  reduction (substitution) equivalent to  $\lambda y. \text{loves}(y,\text{lisa})$
- According to rule 1 the sentence is associated with the LF  $\lambda y. \text{loves}(y,\text{lisa})(\text{linus})$ , which is by means of  $\beta$  reduction equivalent to  $\text{loves}(\text{linus},\text{lisa})$ .

**Problem:** Such a straightforward approach works only in very simple cases; what we need is a systematic composition procedure which also takes care of semantic types (thematic roles).

## On the Semantic Formalism of Montague Grammar

Recapitulation: **Intensional Type Logic (Montague)**

**Approach:** Solution of the subproblems

- Model structure: Intensionalisation (cf. previous chapter)
- Syntax: extension to General Type Logic
- Semantic construction:  $\lambda$ -calculus

## Type Logic: Complex Types (Pinkal)

- Predicate constants (student, works):  $\langle e, t \rangle$
- Binary relation constants (friend, greater-than):  $\langle e, \langle e, t \rangle \rangle$
- Sentence operators (yesterday):  $\langle t, t \rangle$
- Adjectives (predicate modifiers) (fast, red):  $\langle \langle e, t \rangle, \langle e, t \rangle \rangle$
- Degree modifiers (very, rather):  $\langle \langle \langle e, t \rangle, \langle e, t \rangle \rangle, \langle \langle e, t \rangle, \langle e, t \rangle \rangle \rangle$
- Prepositions (in):  $\langle e, \langle t, t \rangle \rangle$ , result in sentence modifiers!
- Predicate-predicates (every student):  $\langle \langle e, t \rangle, t \rangle$

## $\lambda$ -Calculus and Type Logic

The  $\lambda$  operator binds variables:  $\lambda$  **abstraction**

If  $u$  is a variable of type  $\phi$  and  $\alpha$  is an expression of type  $\psi$ ,  
then  $(\lambda u.\alpha)$  is an expression of type  $\langle \phi, \psi \rangle$ .

### Example:

“works” has type  $\langle e, t \rangle$ :  $\lambda x.\text{works}(x)$

Basic operation is  $\lambda$  **conversion**:

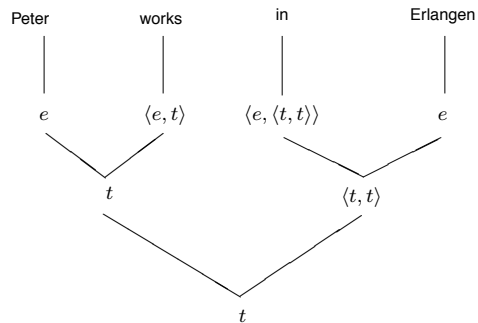
If  $v$  is a variable of type  $\sigma$  and  $B$  is an expression of type  $\sigma$ , then  $\lambda v.A(B)$  is  
equivalent to  $A[v/B]$

(= result of the substitution of every occurrence of  $v$  in  $A$  by  $B$ ).

**Example** of a derivation: “Peter works in Erlangen.”

$$\begin{aligned} & \lambda y \lambda Q(\text{in}(y, Q))(\text{Erlangen})(\lambda x.\text{works}(x)(\text{Peter})) \\ &= \lambda y \lambda Q(\text{in}(y, Q))(\text{Erlangen})(\text{works}(\text{Peter})) \\ &= \lambda Q(\text{in}(\text{Erlangen}, Q))(\text{works}(\text{Peter})) \\ &= (\text{in}(\text{Erlangen}, \text{works}(\text{Peter}))) \end{aligned}$$

### Example of a Derivation Based on Types



### Evaluation of Semantic Analysis in Montague Grammar

- Systematic semantic construction with  $\lambda$ -calculus
- Type logic for representation:  
Systematic tool for the analysis of complex meaning structures.  
**Problematic**, if semantic structures are described as genuine higher order phenomena (decidability) — not effective in a system for semantic evaluation.
- Methodological principle of structural richness and ontological parsimony ( $e, t$  and intensional enlargement): problematic
- Semantic resolution: limited to the sentence level

### Analysis of Quantifiers

Using type logic, quantifiers are directly defined as relations between predicates – without FOL standard quantifiers!

$\lambda$  abstraction is used to connect generalized quantifier analysis with FOL representation.

**Example:** “Every student works.”

$$[S[NP[Det\ Every]][N\ student]][VP[V\ works]]]$$

$$\lambda P\lambda Q\forall x(P(x) \rightarrow Q(x))(student)(works)$$

$$\lambda Q\forall x(student(x) \rightarrow Q(x))(works)$$

$$\forall x(student(x) \rightarrow works(x))$$

### Introducing Discourse Context (Knott)

Consider the semantic analysis of indefinite noun phrases (e.g. “a dog”).

Bertrand Russell proposed that they are translated using an existential quantifier:

$$\text{A dog barks.} \Rightarrow \exists x(dog(x) \wedge barks(x))$$

He noted that the NP doesn’t always introduce a particular dog, especially around “scope elements” like not and every: Translation into  $\exists x$  works as expected in these cases and it combines with other logical expressions in the right ways.

But this account does not scale up well to **discourse**, i.e. to a coherent sequence of sentences.

**Key problem:** How to interpret indefinite NPs?

Example: A dog arrived. The dog barked.

We want to keep asserting predicates on the variable  $x$ , but any subsequent occurrences of  $x$  will be outside the scope of the existential quantifier. In the example, “a dog” introduces a particular dog, which the definite NP refers back to.

## Discourse Representation Theory

A logical framework for semantic representation which takes care of context sensitivity and allows to deal with text semantic and discourse semantic phenomena. It is particularly well suited for semantic resolution.

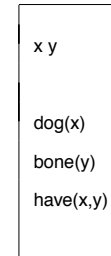
(Hans Kamp; Irene Heim; 1980)

**Discourse Representation Structures** (DRS) are the basal structures of DRT:

A DRS  $K$  is a pair  $\langle u(K), con(K) \rangle$  where

1.  $u(K)$  is a (possibly empty) set of **discourse referents**, also: "universe of  $K$ ", and
2.  $con(K)$  a set of **conditions**. Those may contain atomic predicates over discourse referents as well as further DRSs.

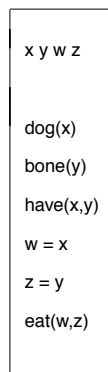
**Example:** "A dog has a bone."



For **pronouns**, a new discourse referent is introduced and set equal to an already present one.

**Example:** Reference resolution beyond the sentence limit.

"A dog has a bone. He eats it."



**Operators** on DRSs:  $\neg, \Rightarrow, \vee$

Accessibility: Similar to block structured programming languages (exceptions: " $\Rightarrow$ ").

## Context in DRT (Knott)

In DRT, a sentence's meaning is taken to be an update operation on a context: Each sentence is interpreted in a context. The result of interpretation is a new context: **Merging**.

A sentence can also make **presuppositions** about the kinds of context in which it can be interpreted:

"The dog barks" presupposes that there is a dog in the discourse context.

Each presupposition can also be represented as a DRS, so in general a sentence is represented by an assertion DRS and a set of presupposition DRSs.

A presupposition is basically a simple query to execute on the discourse context.

A presupposition is **resolved**, if the query is successful:

- Any variable bindings returned by the query are carried over to the assertion DRS.
- The assertion DRS is then merged with the context DRS.

### Indefinite NPs in DRT (Knott)

DRT provides a representation of indefinite NPs which shows how they sometimes introduce new discourse referents, and sometimes behave like quantifiers.

Therefore, the idea of **Sub-DRSs** is introduced:

- Sub-DRSs are created by scope elements such as quantifiers and negation.
- When we process a phrase inside a scope element, we add discourse referents and conditions to the sub-DRS.

Indefinites in the scope of negation can't be used to resolve presuppositions, e.g.

A dog did not bark. ??The dog was big.

⇒ **Accessibility relation:** In DRT, discourse referents and conditions within sub-DRSs are inaccessible to presuppositions.

This extends to dealing with indefinites in conjunction with quantifiers (see following example!).

### DRT and λ-Calculus

Composition procedure conformant with Frege's compositionality principle:

Meaning of a sentence results from word meanings and grammatical structure.

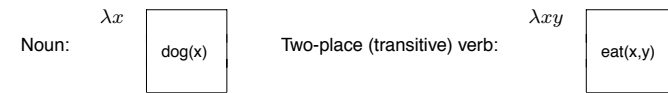
Use of λ-calculus as a systematic combination method:

Semantic composition as function application.

In principle, basic DRSes are retrieved from the lexicon and combined according to semantic composition schemata, which are attached to grammar rules.

Distinction of predicative and partial DRSes.

#### Predicative DRS:



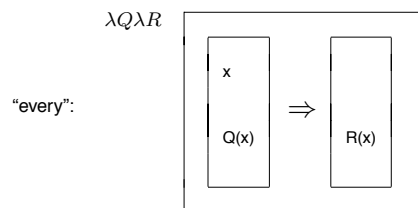
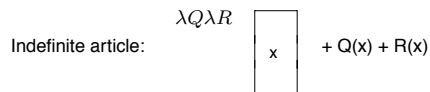
#### Partial DRS:

If  $K$  is a variable over DRSes, then

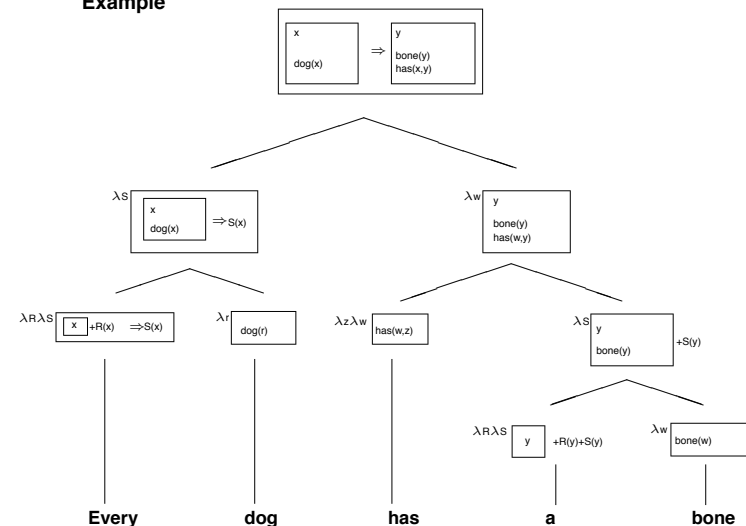
$$\lambda K \langle u(K), con(K) \rangle + K$$

is a **partial DRS**.

Examples:

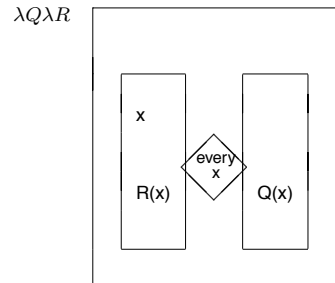


#### Example

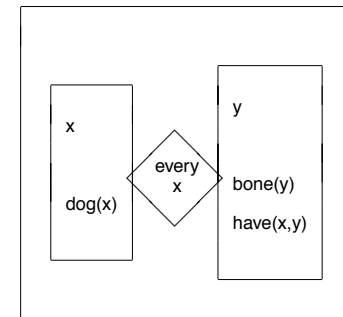


### Generalized Quantifiers

“Duplex” condition: New representation of “every”:



Example: “Every dog has a bone.”



### Tense in DRT

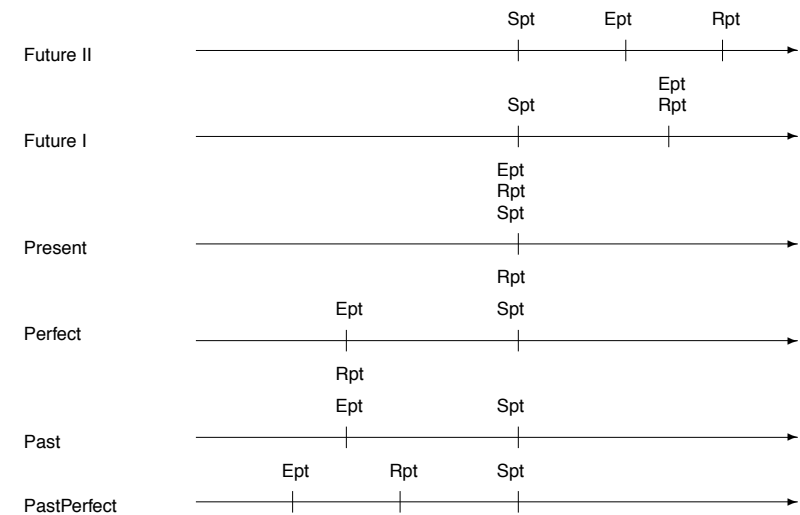
Reminder: Temporal (modal) logic

#### Representation of tense:

Introduction of three different time points — according to Reichenbach — as discourse referents:

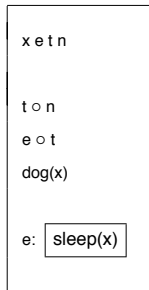
- Event time (point)
- Reference time (point)
- Speaking time (point)

Representation of tenses:



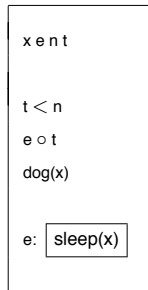
**Present:**

"A dog sleeps."



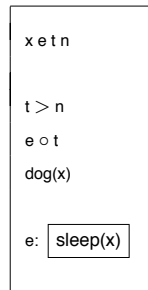
**Past:**

"A dog slept."



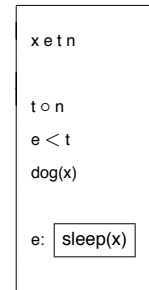
**Future I:**

"A dog will sleep."



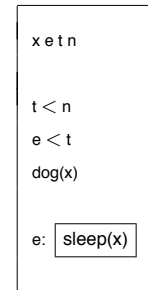
**Perfect:**

"A dog has slept."



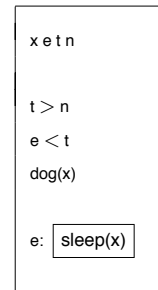
**PastPerfect**

"A dog had slept."

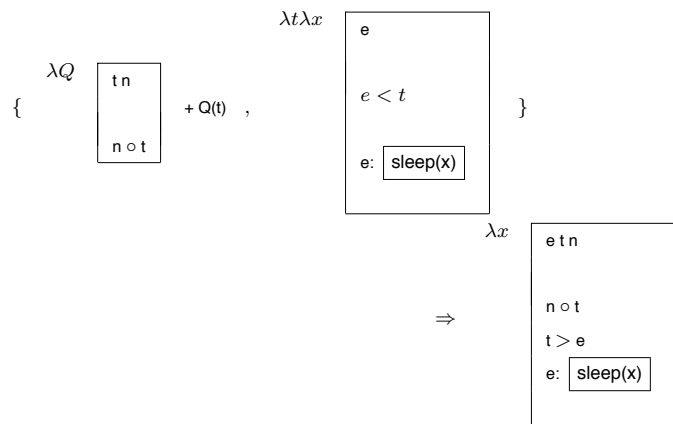


**Future II:**

"A dog will have slept."



Translation into  $\lambda$ -DRT, e.g. **Perfect**: "has slept" (also PastPerfect "had slept")

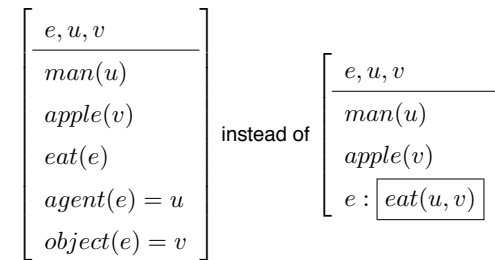


**Events Reified in DRT**

Davidsonian approach to the representation of events:

Events are reified, i.e. treated as a kind of object.

$\Rightarrow$  Unary event predicate and a number of thematic roles instead of an event description by an n-ary event predicate:



### Events Reified in DRT (cont.)

Closer to a description logic representation, we would write

$$\left[ \begin{array}{c} e, u, v \\ \hline man(u) \\ apple(v) \\ eat(e) \\ agent(e, u) \\ object(e, v) \end{array} \right] \text{ instead of } \left[ \begin{array}{c} e, u, v \\ \hline man(u) \\ apple(v) \\ eat(e) \\ agent(e) = u \\ object(e) = v \end{array} \right]$$

### Final Remarks on Inference

#### Dealing with ambiguities

- Quantification (scope): First attempt with a quantifier store mechanism which can generate all readings (Cooper);  
now superseded by **underspecification**
- Reference: Anaphoric resolution, i.e. identifying the appropriate discourse referents for anaphoric expressions (heuristics combining aspects from various linguistic levels);  
⇒ DRS with explicit representation of **presupposition** information

**Inference:** Determining consistency and informativeness

Extraction of first order formulae from DRSs and application of

- Theorem proving
- Model generation