Semantic Theory

Lecture 10 – Event Semantics

Stefan Thater
FR 4.7 Allgemeine Linguistik (Computerlinguistik)
Universität des Saarlandes

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The meaning of content words

(1) *John loves Mary*

(2) *Mary kicked John*

(3) *Bill is coughing*

(4) *Bill saw an elephant*

(5) *Bill saw an accident*

(6) *Bill travelled to Paris*

(7) *Bill’s travel started in Paris*

Davidson’s Problem

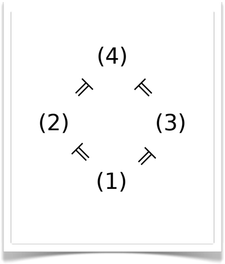
(1) *The gardener killed the baron*
⇒ $\mathrm{kill}_1(g, b)$

(2) *The gardener killed the baron in the park*
⇒ $\mathrm{kill}_2(g, b, p)$

(3) *The gardener killed the baron at midnight*
⇒ $\mathrm{kill}_3(g, b, m)$

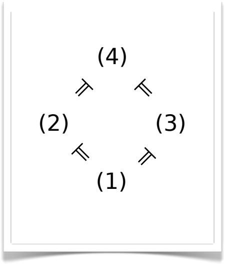
(4) *The gardener killed the baron at midnight in the park*
⇒ $\mathrm{kill}_4(g, b, m, p)$

Davidson’s Problem



- **The problem:** How can the systematic logical entailment relations between the different uses of kill be explained?
- The naïve approach does not solve the problem:
  - kill$_4$(g, b, m, p) $\not\models$ kill$_3$(g, b, m)
  - kill$_3$(g, b, m) $\not\models$ kill$_1$(g, b)
  - etc.

A Solution?



- Determine the maximum arity n of the predicate
- Take n to be the arity of the predicate
- Bind syntactically empty argument positions with existential quantifier
  - (4) ⇒ kill(g, b, m, p)
  - (3) ⇒ $\exists y$ kill(g, b, m, y)
  - (2) ⇒ $\exists x$ kill(g, b, x, p)
  - (1) ⇒ $\exists x \exists y$ kill(g, b, x, y)
- **Problem:** What is the maximum arity of a predicate?

Davidson’s Proposal

- So far, we made the assumption that two-place verbs denote sets of pairs of individuals: $V(R^2) \subseteq U \times U$
- **Davidson’s proposal**
  - Verbs denote events.
- More precisely
  - Verbs expressing events have an additional event argument, which is not realized at linguistic surface
  - *kill* ⇒ $\lambda y \lambda x \lambda e$[kill(e, x, y)]

Davidson’s Proposal

- n-place event verbs denote (n+1)-ary relations
- Adjuncts express two-place relations between events and the respective “circumstantial information”
  - time, location, …
- The event variable is existentially bound:
  - *The gardener killed the baron at midnight in the park*
  - ⇒ ∃e[kill(e, g, b) ∧ time(e, m) ∧ location(e, p)]

Davidson’s Problem Solved

- Using events within the semantic representations of verbs allows for an arbitrary number of adjuncts
- The entailment problem is solved in a trivial way since adjunct information is attached by conjunction
- ∃e[kill(e, g, b) ∧ time(e, m) ∧ location(e, p)]
  - ⊨ ∃e[kill(e, g, b) ∧ time(e, m)]
  - ⊨ ∃e[kill(e, g, b) ∧ location(e, p)]
  - ⊨ ∃e[kill(e, g, b)]

Model structures with events

- We enrich model structures with ontological information in the traditional Aristotelian sense of ontology:

  The area of philosophy identifying and describing the basic “categories of being and their relations.”

Model structures with events

- We assume two disjoint kinds, or sorts of entities:
  - U – a set of “standard individuals” or “objects”
  - E – a set of events
- A model structure is a triple $M = \langle U, E, V \rangle$ where
  - $U \cap E = \emptyset$,
  - V is an interpretation function like in first order logic

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Sorted (first-order) logic

- We assume a separate inventory of variables for each sort of individuals:
- **Standard object variables**
  - $VAR_U = \{ x, y, z, \ldots, x_1, x_2, \ldots \}$
- **Event variables**
  - $VAR_E = \{ e, e', e'', \ldots, , e_1, e_2, \ldots \}$

Sorted (first-order) logic

- A variable assignment g assigns object and event variables individuals of the respective sort-specific domain:
  - $g(x) \in U$ for $x \in VAR_U$
  - $g(e) \in E$ for $e \in VAR_E$
- Quantification ranges over sort-specific domains:
  - $[\![\exists x \Phi]\!]^{M,g} = 1$ iff there is an $a \in U$ such that $[\![\Phi]\!]^{M,g[x/a]} = 1$
  - $[\![\exists e \Phi]\!]^{M,g} = 1$ iff there is an $a \in E$ such that $[\![\Phi]\!]^{M,g[e/a]} = 1$
  - (universal quantification analogously)

The added value of events as “first class citizens”

- a natural representation of adjunct information
- a natural and uniform interpretation of event verbs and nominal event predicates
- a uniform treatment of noun phrases and infinitive constructions as verb complements
- an intuitive semantic construction for adjuncts
- a uniform treatment of noun modifiers and adjuncts
- a plausible treatment of tense information

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Uniform treatment of verb complements

(1) *Bill saw an elephant*
$\exists e \exists x [\, \text{see}(e, b, x) \land \text{elephant}(x) \,]$

(2) *Bill saw an accident*
$\exists e \exists e' [\, \text{see}(e, b, e') \land \text{accident}(e') \,]$

(3) *Bill saw the children play*
$\exists e \exists e' [\, \text{see}(e, b, e') \land \text{play}(e', \text{the-children}) \,]$

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Compositional derivation of event-semantic representations

kill $\Rightarrow \lambda y \lambda x \lambda e[\mathrm{kill}(e, x, y)] : \langle e,\langle e,\langle e,t\rangle\rangle\rangle$

the baron $\Rightarrow b : e$

the gardener $\Rightarrow g : e$

at midnight $\Rightarrow \lambda F \lambda e[F(e) \wedge \mathrm{time}(e, \mathrm{midnight})] : \langle\langle e,t\rangle,\langle e,t\rangle\rangle$

in the park $\Rightarrow \lambda F \lambda e[F(e) \wedge \mathrm{location}(e, \mathrm{park})] : \langle\langle e,t\rangle,\langle e,t\rangle\rangle$

Compositional derivation of event-semantic representations

- *the gardener killed the baron*
  $\Rightarrow \lambda y \lambda x \lambda e[\mathrm{kill}(e, x, y)](g)(b)$
- *… at midnight*
  $\Rightarrow \lambda F \lambda e[F(e) \wedge \mathrm{time}(e, \mathrm{midnight})](\lambda e[\mathrm{kill}(e, g, b)])$
  $\Leftrightarrow \lambda e[\mathrm{kill}(e, g, b) \wedge \mathrm{time}(e, \mathrm{midnight})]$
- *… in the park*
  $\Rightarrow \lambda F \lambda e[F(e) \wedge \mathrm{location}(e, \mathrm{park})](\lambda e[\mathrm{kill}(e, g, b) \wedge \ldots])$
  $\Leftrightarrow \lambda e[\mathrm{kill}(e, g, b) \wedge \mathrm{time}(e, \mathrm{midnight}) \wedge \mathrm{location}(e, \mathrm{park})]$
- Existential closure
  $\Rightarrow \exists e[\mathrm{kill}(e, g, b) \wedge \mathrm{time}(e, \mathrm{midnight}) \wedge \mathrm{location}(e, \mathrm{park})]$

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Adjuncts as modifiers

- Treatment of adjuncts as predicate modifiers, in analogy to attributive adjectives (type ⟨⟨e,t⟩,⟨e,t⟩⟩):
- Adjectives modify a predicate over standard objects denoted by a common noun:
  - *red* ⇒ λFλx[F(x) ∧ red*(x)]
- Adjuncts modify event predicates, represented by the sentence:
  - *at midnight* ⇒ λFλe[F(e) ∧ time(e, midnight)]

Adjuncts and modifiers

- Uniform semantic representation for adjuncts and post-nominal modifiers:
  - *in the park* ⇒ λFλx[F(x) ∧ location(x, park)]
- **Local adjunct**
  - [$_S$ [$_S$ *The gardener killed the baron*] [$_{PP}$ *in the park*]]
  - ⇒ λFλe[F(e) ∧ location(e, park)](λe[kill(e, g, b)])
  - ⇔ λe[kill(e, g, b) ∧ location(e, park)]

Adjuncts and modifiers

- Uniform semantic representation for adjuncts and post-nominal modifiers:
  - *in the park* $\Rightarrow \lambda F \lambda x[\,F(x) \wedge \text{location}(x, \text{park})\,]$
- **Post-nominal modifier of event noun**
  - $[_{N}\ [_{N}$ *murder* $]\ [_{PP}$ *in the park* $]\ ]$
  - $\Rightarrow \lambda F \lambda e[\,F(e) \wedge \text{location}(e, \text{park})\,](\lambda e[\,\text{murder}(e)\,])$
  - $\Leftrightarrow \lambda e[\,\text{murder}(e) \wedge \text{location}(e, \text{park})\,]$

Adjuncts and modifiers

- Uniform semantic representation for adjuncts and post-nominal modifiers:
  - *in the park* $\Rightarrow \lambda F \lambda x[\,F(x) \wedge \text{location}(x, \text{park})\,]$
- **Post-nominal modifier of standard noun**
  - $[_{N}\ [_{N}$ *fountain* $]\ [_{PP}$ *in the park* $]\ ]$
  - $\Rightarrow \lambda F \lambda x[\,F(x) \wedge \text{location}(x, \text{park})\,](\lambda y[\,\text{fountain}(y)\,])$
  - $\Leftrightarrow \lambda x[\,\text{fountain}(x) \wedge \text{location}(x, \text{park})\,]$

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Tense

- Natural-language sentences are tensed:
  - *John is walking*
  - *John walked*
  - *John will walk*
- Representation of tense in conventional tense logic:
  - walk(john) – *John walks*
  - **P**walk(john) – *John walked*
  - **F**walk(john) – *John will walk*

Classical Tense Logic

- Syntax like in first-order logic, plus
  - if Φ is a well-formed formula, then **P**Φ, **F**Φ, **H**Φ, **G**Φ are also well-formed formulae.
- We focus on **P** and **F** here:
  - **P**Φ – Φ happened in the past
  - **F**Φ – Φ will happen

Classical Tense Logic

- Model structures are quadruples M = ⟨U, T, <, V⟩ where
  - U is a non-empty set of individuals (the “universe”)
  - T is a non-empty sets of points in time
  - U ∩ T = ∅
  - < is a linear order on T
  - V is a value assignment function, which assigns to every non-logical constant α a function from T to appropriate denotations of α

Classical Tense Logic

- Interpretation of tense operators
  - $[\![\mathbf{P}\Phi]\!]^{M,t,h} = 1$ iff there is a $t' < t$ such that $[\![\Phi]\!]^{M,t',h} = 1$
  - $[\![\mathbf{F}\Phi]\!]^{M,t,h} = 1$ iff there is a $t' > t$ such that $[\![\Phi]\!]^{M,t',h} = 1$

Temporal Relations

(1) *The door opened, and Mary entered the room.*

(2) *John arrived. Then Mary left.*

(3) *Mary left, before John arrived.*

(4) *John arrived. Mary had left already.*

Temporal Event Structure

- A model structure with events and temporal precedence is defined as $M = \langle U, E, <, e_u, V\rangle$, where
  - $U \cap E = \emptyset$,
  - $< \subseteq E\times E$ is an asymmetric relation (temporal precedence)
  - $e_u \in E$ is the utterance event
  - V is an interpretation function like in standard FOL
- Overlapping events
  - $e \circ e'$ iff neither $e < e'$ nor $e' < e$

Time expressions

(1) *John arrived at 9 p.m.*

(2) *The lecture is on Tuesday.*

(3) *Mozart was born in 1756.*

(4) *Mary had left two hours, before John arrived.*

Temporal Event Structure II

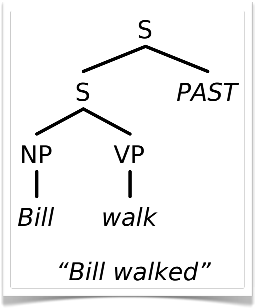
- An alternative model structure with points and intervals of time:
- **M = $\langle U, E, T, <, t_u, tl, V\rangle$**, where
  - U, E, and T are mutually disjoint,
  - $<$ is a linear ordering on T
  - $t_u \in T$ is the utterance time
  - tl a function from E to intervals of T
  - V an interpretation function like in standard FOL

Temporal Event Structure II

- **M = $\langle U, E, T, <, t_u, tl, V\rangle$**, where
  - U, E, and T are mutually disjoint,
  - $<$ is a linear ordering on T
  - $t_u \in T$ is the utterance time
  - tl a function from E to intervals of T
  - V an interpretation function like in standard FOL
- **Precedence of events:**
  - $e < e'$ iff for all $t \in tl(e)$ and $t' \in tl(e')$, $t < t'$
- **Overlapping events:**
  - $e \circ e'$ iff $tl(e) \cap tl(e') \neq \emptyset$

Tense in Semantic Construction

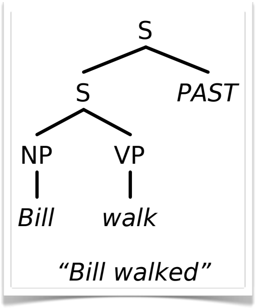
- We can represent inflection as an abstract tense operator commanding the untensed rest of the sentence
- The semantic representation of the tense operators expresses temporal location of the reported event with respect to the utterance event:
- PAST ⇒ $\lambda E\,\exists e[E(e) \wedge e < e_u] : \langle\langle e, t\rangle, t\rangle$
- PRES ⇒ $\lambda E\,\exists e[E(e) \wedge e \circ e_u] : \langle\langle e, t\rangle, t\rangle$



"Bill walked"

Tense in Semantic Construction

- Standard function application effects integration of temporal information and binding of the event variable:
- *walk* ⇒ $\lambda x \lambda e[\text{walk}(e, x)]$
- *Bill walk* ⇒ $\lambda x \lambda e[\text{walk}(e, x)](b)$
  ⇔ $\lambda e[\text{walk}(e, b)]$
- *Bill walk PAST*
  ⇒ $\lambda E\,\exists e[E(e) \wedge e < e_u](\lambda e[\text{walk}(e, b)])$
  ⇔ $\exists e[\lambda e[\text{walk}(e, b)](e) \wedge e < e_u]$
  ⇔ $\exists e[\text{walk}(e, b) \wedge e < e_u]$



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