Semantic Theory

Lexical Semantics I

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The meaning of content words

- *John loves Mary*
- *Mary kicked John*
- *Bill is coughing*

- *Bill saw an elephant*
- *Bill saw an accident*

- *Bill travelled to Paris*
- *Bill's travel started in Paris*

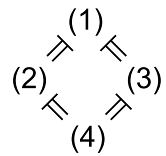
Davidson's problem

Interpretation of adjunct constructions:

(1) *The gardener killed the baron at midnight in the park*
$\Rightarrow \text{kill}_4(g, b, m, p)$
(2) *The gardener killed the baron at midnight*
$\Rightarrow \text{kill}_3(g, b, m)$
(3) *The gardener killed the baron in the park*
$\Rightarrow \text{kill}_2(g, b, p)$
(4) *The gardener killed the baron*
$\Rightarrow \text{kill}_1(g, b)$

Davidson's Problem

- Problem: How can the systematic logical entailment relations between the different uses of *kill* be explained?



- Naïve FOL interpretation does not solve the problem:
  - $\text{kill}_4(g, b, m, p) \not\models \text{kill}_3(g, b, m)$
  - $\text{kill}_3(g, b, m) \not\models \text{kill}_1(g, b)$
  - etc.

An Interpretation Alternative

- 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.

(1) ⇒ kill(g, b, m, p)
(2) ⇒ ∃y kill(g, b, m, y)
(3) ⇒ ∃x kill(g, b, x, p)
(4) ⇒ ∃x∃y kill(g, b, x, y)

- Problem: What is the maximum arity of a predicate?
The gardener killed the baron at midnight in the park under cover of absolute darkness with a gun …

Davidson's Proposal

- Standard FOL-Semantics: two-place verbs denote sets of pairs of individuals.
- Davidson: Verbs denote events.
- More precisely: Verbs expressing events have an additional event argument, which is not realised at linguistic surface:

  λyλxλe. kill(e,x,y)
- In general, n-place event verbs are represented by relations of arity n+1.
- Adjuncts express two-place relations between events and the respective "circumstantial information" (a time, a 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

- Semantic representation of verbs using events allows an arbitrary number of adjuncts.
- Since adjunct information is attached through conjunction, the entailment problem finds a trivial solution:

∃e[kill(e,g,b) ∧ time(e, m) ∧ location(e, p)]

|= ∃e[kill(e,g,b) ∧ time(e, m)]

|= ∃e[kill(e,g,b)]

Model structure 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”.
- We assume two disjoint classes, or kinds, or sorts of entities:
  - A set of “standard individuals” or “objects” U
  - A set of events E
- A model structure is defined as

  M = (U, E, V),
  with U∩E = ∅,
  V interpretation function like in standard FOL

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: $Var_E = e, e', e'', \ldots, e_1, e_2, \ldots$
- Variable assignment functions g assign 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 $a \in U$ s.t. $[[\Phi]]^{M,g[x/a]} = 1$
  - $[[\exists e\, \Phi]]^{M,g} = 1$ iff there is an $a \in E$ s.t. $[[\Phi]]^{M,g[e/a]} = 1$

Added value of event semantics

Events as "first-class citizens" enable

- the natural representation of adjunct information
- a natural and uniform interpretation of event verbs and nominal event predicates
- a uniform treatment of NPs and infinitive constructions as verb complements
- an intuitive semantic construction for adjuncts
- a uniform treatment of noun modifiers (adjectives, post-nominal PPs) and adjuncts
- the plausible integration of tense

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Uniform treatment of verb complements

- *Bill saw an elephant.*
  $\exists e \exists x\, [\,\text{see}(e, b, x) \wedge \text{elephant}(x)]$
- *Bill saw an accident.*
  $\exists e \exists e'\, [\,\text{see}(e, b, e') \wedge \text{accident}(e')]$
- *Bill saw the children play*
  $\exists e \exists e'\, [\,\text{see}(e, b, e') \wedge \text{play}(e', \text{the-children})]$

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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 (represented by a common noun:
  - Representation of the intersective adjective *red:*
    red $\Rightarrow \lambda F \lambda x[F(x) \wedge \text{red}^*(x)]$,
    modifying, e.g., $\lambda x[\text{book}(x)]$
- Adjuncts modify event predicates, represented by the sentence (more precise description follows):
  - *at midnight* $\Rightarrow \lambda E \lambda e[E(e) \wedge \text{time}(e, \text{midnight})]$,
    modifying, e.g., $\lambda e[\text{it\_rains}(e)]$

Compositional derivation of event-semantic representations

- *kill* $\Rightarrow \lambda y \lambda x \lambda e.\text{kill}(e,x,y) : (e,(e,(e,t)))$
- *baron* $\Rightarrow$ b : e
- *gardener* $\Rightarrow$ g : e
- *at midnight* $\Rightarrow \lambda E \lambda e[E(e) \wedge \text{time}(e, \text{midnight})] : ((e,t),(e,t))$
- *in the park* $\Rightarrow \lambda E \lambda e[E(e) \wedge \text{location}(e, \text{park})] : ((e,t),(e,t))$

$\lambda y \lambda x \lambda e.\text{kill}(e,x,y) \quad g \quad b$

$\lambda E \lambda e[E(e) \wedge \text{time}(e, \text{midnight})] \qquad \lambda e.\text{kill}(e, g, b) : (e,t)$

$\lambda E \lambda e[E(e) \wedge \text{location}(e, \text{park})] \qquad \lambda e[\text{kill}(e, g, b) \wedge \text{time}(e, \text{midnight})] : (e,t)$

$\lambda e[\text{kill}(e, g, b) \wedge \text{time}(e, \text{midnight}) \wedge \text{location}(e, \text{park})] : (e,t)$

Existential closure:

$\exists e[\text{kill}(e, g, b) \wedge \text{time}(e, \text{midnight}) \wedge \text{location}(e, \text{park})] : t$

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Adjuncts and modifiers

Uniform semantic representation for adjuncts and post-nominal modifiers:

in the park ⇒ λFλx[F(x) ∧ location(x, park)]

- Local adjunct:
  [[The gardener killed the baron] in the park]
  ⇒ λEλe[E(e) ∧ location(e, park)](λe.kill(e, g, b))
  ⇔ λe[kill(e, g, b) ∧ location(e, park)]
- Post-nominal modifier of event noun:
  The [[murder] in the park]
  ⇒ λEλe[E(e) ∧ location(e, park)](λe.murder(e))
  ⇔ λe[murder(e) ∧ location(e, park)]
- Post-nominal modifier of standard noun:
  The [[fountain] in the park]
  ⇒ λFλx[E(x) ∧ location(x, park)](λy.fountain(y))
  ⇔ λx[fountain(x) ∧ location(x, 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)
  P*walk(john)*
  F*walk(john)*

Classical tense Logic

- Representation of tense with tense operators **P** and **F**:
  walk(john) **P***walk(john)* **F***walk(john)*
- Tense-logical model structure: M = <U, T, <, V>
  - $U \cap T = \varnothing$
  - < a linear ordering on T
  - V a value assignment function, which assigns to every non-logical constant α a function from T to appropriate denotations of α
- Interpretation of tense operators:
  $[\![PA]\!]^{M,t} = 1$ iff $[\![A]\!]^{M,t'} = 1$ for at least one $t' < t$
  $[\![FA]\!]^{M,t} = 1$ iff $[\![A]\!]^{M,t'} = 1$ for at least one $t' > t$

Temporal Relations

- The door opened, and Mary entered the room.
- John arrived. Then Mary left.
- Mary left, before John arrived.
- John arrived. Mary had left already.

Temporal Event Structure

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

Time expressions

- John arrived at 9 p.m.
- The lecture is on Tuesday.
- Mozart was born in 1756.
- Mary had left two hours, before John arrived.

Temporal Event Structure II

- An alternative model structure with points and intervals of time:

  M = (U, E , T, <, t_u, tl, V),

  with U, E, and T mutually disjoint,

  < 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 $t \in tl(e)$, $t' \in tl(e')$: $t < t'$
- Overlapping events:

  $e \circ e'$ iff $tl(e) \cap tl(e') \neq \varnothing$

Tense in Semantic Construction

- Tense is encoded in the verb inflection.
- There are reasons to give stem and inflection of the verb distinct syntactic representations, where inflection is represented as an abstract tense operator commanding the untensed rest of the sentence:

  Bill walked : $[_S [_S \text{ Bill } [_{VP} \text{ walk}]] \text{ PAST }]$

- Semantic representation of tense operators expresses temporal location of reported event w.r.to utterance event:

  PAST $\Rightarrow \lambda E \exists e(E(e) \wedge e < e_u)$: ((e,t),t)

  PRES $\Rightarrow \lambda E \exists e(E(e) \wedge e \circ e_u)$: ((e,t),t)
- Standard function application effects integration of temporal information and binding of the event variable:

$$\frac{\lambda E \exists e(E(e) \wedge e < e_u) \qquad \lambda e.walk(e, b)}{\exists e[walk(e, b) \wedge e < e_u]}$$

Stative and non-stative verbs

- *Mary kicked John* : "there is a kicking event, in which Mary and John are involved"
- *John knew the answer:* "there is a knowing event, in which John and the answer are involved" (?)
- There are verbs expressing states and verbs expressing events (which we call non-stative for the time being)
  - States: *know, believe, have, desire, love*
  - Events: *run, walk, kick, kill, build a house*
- Only non-stative verbs come with an extra argument:
  - kick(e, x, y)
  - know(x, y)