Semantic Theory
Week 4 – Event semantics

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A problem with verbs and adjuncts

(1) *The gardener killed the baron* $\mapsto$ $\mathrm{kill}_1(g',b')$ $\mathrm{kill}_1 :: \langle e,\langle e,t\rangle\rangle$

(2) *The gardener killed the baron in the park* $\mapsto$ $\mathrm{kill}_2(g',b',p')$ $\mathrm{kill}_2 :: \langle e,\langle e,\langle e,t\rangle\rangle$

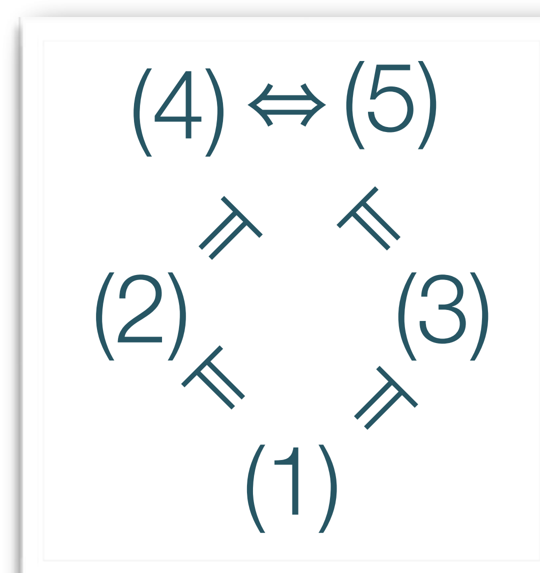
(3) *The gardener killed the baron at midnight* $\mapsto$ $\mathrm{kill}_3(g',b',m')$ $\mathrm{kill}_3 :: \langle e,\langle e,\langle e,t\rangle\rangle$

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

(5) *The gardener killed the baron in the park at midnight* $\mapsto$ $\mathrm{kill}_5(g',b',p',m')$ $\mathrm{kill}_5 :: \ldots$

Q: How to explain the systematic logical entailment relations between the different uses of "kill"?

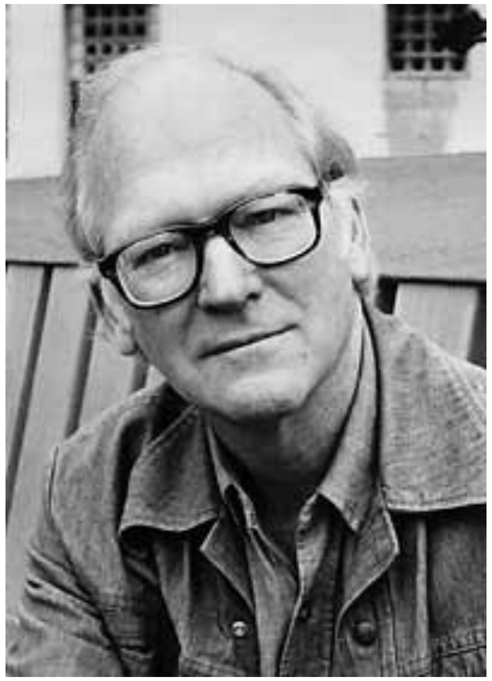
NB. We use the FOL syntax for predicates here, i.e., "kill(x,y)" — which is equivalent to the type theoretic expression "kill(y)(x)"



Davidson's solution: verbs introduce events.

Verbs expressing events have an additional event argument, which is not realised at linguistic surface:

- kill $\mapsto$ $\lambda y \lambda x \lambda e(\text{kill}'(e,x,y)) :: \langle e,\langle e,\langle e,t\rangle\rangle\rangle$ *arity = n+1*



Sentences denote sets of events:

- $\lambda y \lambda x \lambda e(\text{kill}'(e,x,y))(b')(g') \Rightarrow^{\beta} \lambda e(\text{kill}'(e, g', b')) :: \langle e,t\rangle$

Existential closure turns sets of events into truth conditions

- $\lambda P \exists e(P(e)) :: \langle\langle e,t\rangle,t\rangle$
- $\lambda P \exists e(P(e))(\lambda e(\text{kill}'(e,g',b'))) \Rightarrow^{\beta} \exists e(\text{kill}'(e,g',b')) :: t$

Davidson (1967, 1980)

Davisonian events and adjuncts

Adjuncts express two-place relations between events and the respective "circumstantial information": time, location, …

- at midnight $\mapsto \lambda P \lambda e(P(e) \wedge \mathrm{time}(e,m'))$ :: $\langle\langle e,t\rangle,\langle e,t\rangle\rangle$
- in the park $\mapsto \lambda P \lambda e(P(e) \wedge \mathrm{location}(e,p'))$ :: $\langle\langle e,t\rangle,\langle e,t\rangle\rangle$

The gardener killed the baron at midnight in the park

$$\left.\begin{array}{l} \mapsto \exists e\,(\mathrm{kill}(e, g', b') \wedge \mathrm{time}(e, m) \wedge \mathrm{location}(e, p')) \\ \\ \Leftrightarrow \exists e\,(\mathrm{kill}(e, g', b') \wedge \mathrm{location}(e, p) \wedge \mathrm{time}(e, m')) \end{array}\right\} \begin{array}{l} \models \exists e\,(\mathrm{kill}(e, g', b') \wedge \mathrm{time}(e, m')) \\ \models \exists e\,(\mathrm{kill}(e, g', b') \wedge \mathrm{location}(e, p')) \\ \models \exists e\,(\mathrm{kill}(e, g', b')) \end{array}$$

Compositional derivation of event-semantic representations

the gardener killed the baron

$\lambda x_e \lambda y_e \lambda e_e[\text{ kill}(e, y, x)](b')(g') \Rightarrow^{\beta} \lambda e [\text{ kill}(e, g', b')]$

α

… at midnight

$\lambda F_{\langle e,t \rangle} \lambda e_e [F(e) \wedge \text{time}(e, m')](\lambda e_1 [\text{ kill}(e_1, g', b')]) \Rightarrow^{\beta} \lambda e [\text{ kill}(e, g, b) \wedge \text{time}(e,m')]$

… in the park

$\lambda F_{\langle e,t \rangle} \lambda e_e [F(e) \wedge \text{location}(e, p')] (\lambda e_2 [\text{kill}(e_2, g', b') \wedge \text{time}(e_2, m')]) \Rightarrow^{\beta}$

$\lambda e [\text{kill}(e, g', b') \wedge \text{time}(e, m') \wedge \text{location}(e, p')]$

Existential closure

$\lambda P_{\langle e,t \rangle} \exists e(P(e))(\lambda e'(K \wedge T \wedge L) \Rightarrow^{\beta} \exists e [\text{ kill}(e, g', b') \wedge \text{time}(e, m') \wedge \text{location}(e, p')]$

Model structures with events

To interpret events, we need enriched *ontological* information

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

A model structure with events is a triple **$M = \langle U, E, V \rangle$**, where

- U is a set of “standard individuals” or “objects”
- E is a set of events
- $U \cap E = \varnothing$,
- V is an interpretation function like in first order logic

Sorted (first-order) logic

A variable assignment g assigns individuals (of the correct sort-specific domain) to variables:

- $g(x) \in U$ for $x \in VAR_U$ $\quad$ $VAR_U = \{ x, y, z, \ldots , x_1, x_2, \ldots \}$ (Object variables)
- $g(e) \in E$ for $e \in VAR_E$ $\quad$ $VAR_E = \{ e, e', e'', \ldots, e_1, e_2, \ldots \}$ (Event variables)

NB. variables from VAR_U and VAR_E are both of type e (in the formalization used here)

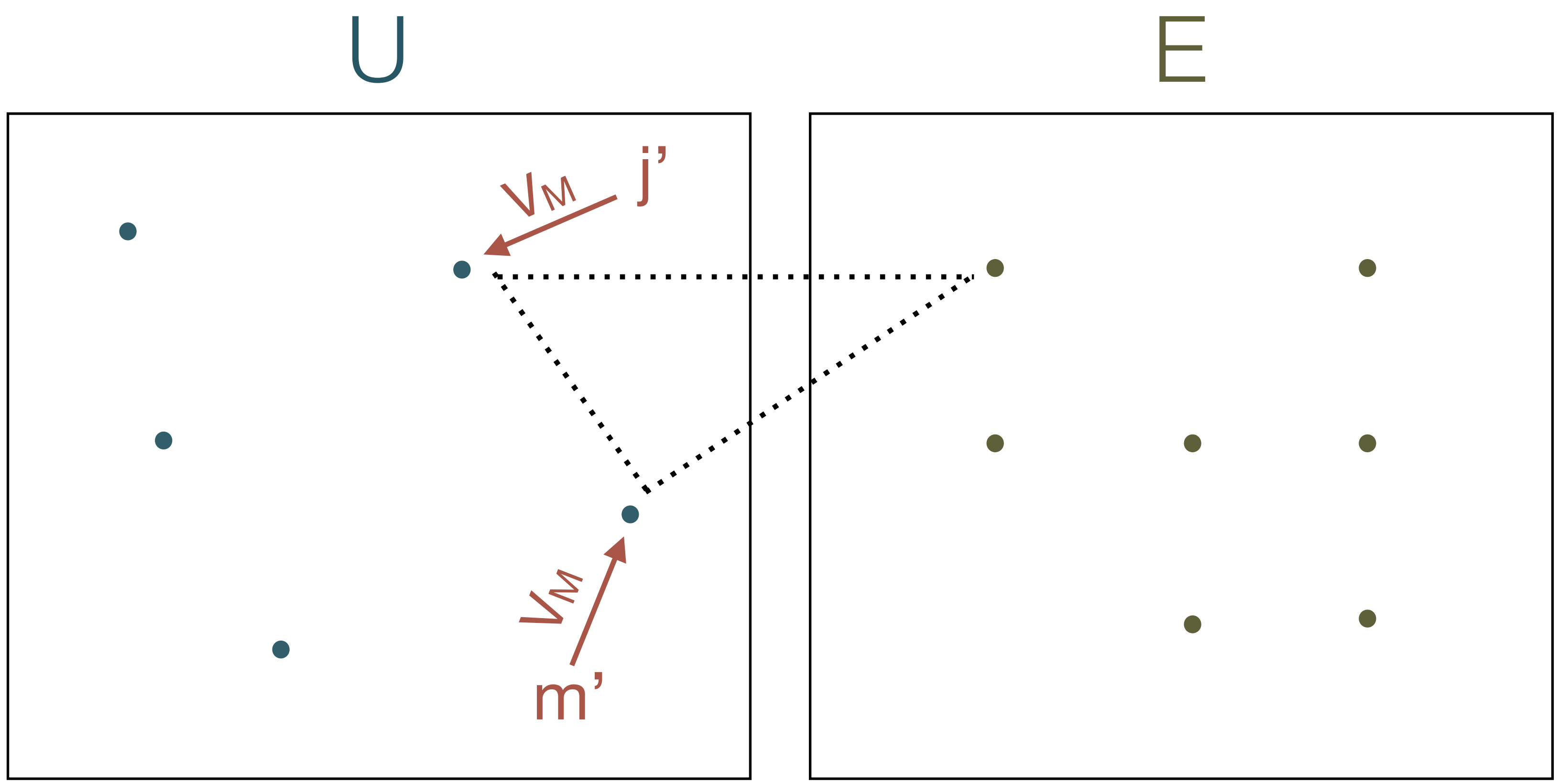
Quantification ranges over sort-specific domains:

- $[\![\exists x\ \Phi]\!]^{M,g} = 1$ 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 analogous)

Interpreting events

John kisses Mary $\mapsto \exists e\, (kiss(e, j', m'))$

$[\![\exists e\, (kiss(e, j', m'))]\!]^{M,g} = 1$
iff there is an $s \in E$ such that $[\![kiss(e, j', m')]\!]^{M,g[e/s]} = 1$
iff there is an $s \in E$ such that $\langle s, V_M(j'), V_M(m') \rangle \in V_M(kiss)$



Advantages of Davidsonian events

- ☑ Intuitive representation and semantic construction for adjuncts
- ☐ Uniform treatment of verb complements
- ☐ Uniform treatment of adjuncts and post-nominal modifiers
- ☐ Coherent treatment of tense information
- ☐ Highly compatible with analysis of semantic roles

Uniform treatment of verb complements

(1) *Bill saw an elephant*

↦ $\exists e\ \exists x\ (\text{see}(e, b', x) \wedge \text{elephant}(x))$

see :: $\langle e,\langle e,\langle e,t\rangle\rangle$

(2) *Bill saw an accident*

↦ $\exists e\ \exists e'\ (\text{see}(e, b, e') \wedge \text{accident}(e'))$

see :: $\langle e,\langle e,\langle e,t\rangle\rangle$

(3) *Bill saw the children play*

↦ $\exists e\ \exists e'\ (\text{see}(e, b, e') \wedge \text{play}(e', \text{the-children}))$

see :: $\langle e,\langle e,\langle e,t\rangle\rangle$

Uniform treatment of adjuncts and post-nominal modifiers

Treatment of adjuncts as predicate modifiers, analogous to attributive adjectives:

- red $\mapsto$ $\lambda F\ \lambda x\ [\ F(x) \wedge \text{red}^*(x)\ ]$ $\langle\langle e,t\rangle,\langle e,t\rangle\rangle$
- in the park $\mapsto$ $\lambda F\ \lambda e\ [\ F(e) \wedge \text{location}(e, \text{park})\ ]$ $\langle\langle e,t\rangle,\langle e,t\rangle\rangle$

(1) *The murder in the park…*

$\mapsto$ $\lambda F \lambda e[F(e) \wedge \text{location}(e, \text{park})]\ (\lambda e_1\ [\text{murder}(e_1)])$

(2) The fountain in the park ….

$\mapsto$ $\lambda F \lambda x[F(x) \wedge \text{location}(x, \text{park})]\ (\lambda y\ [\text{fountain}(y)])$

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Classical Tense Logic

- *John walks* walk(john)
- *John walked* P(walk(john))
- *John will walk* F(walk(john))

Φ has always been the case

Φ is always going to be the case

Syntax like in first-order logic, plus

- if Φ is a well-formed formula, then PΦ, FΦ, HΦ, GΦ are also well-formed formulae.

Φ happened in the past

Φ will happen in the future

Classical Tense Logic (cont.)

Tense model structures are quadruples $M = \langle U, T, <, V \rangle$ where

- U is a non-empty set of individuals (the “universe”)
- T is a non-empty sets of points in time
- $U \cap T = \varnothing$
- $<$ 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

$$[\![P\Phi]\!]^{M,\, t,\, g} = 1 \text{ iff there is a } t' < t \text{ such that } [\![\Phi]\!]^{M,\, t',\, g} = 1$$

$$[\![F\Phi]\!]^{M,\, t,\, g} = 1 \text{ iff there is a } t' > t \text{ such that } [\![\Phi]\!]^{M,\, t',\, g} = 1$$

Temporal Relations and Events

Observation: Event structure is inherently related to temporal structure.

(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.*

Q: How can we extend event-based models with a notion of *temporal order between events*?

Temporal Event Structure

A model structure with events and temporal precedence is defined as $M = \langle U, E, <, e_u, V \rangle$, where

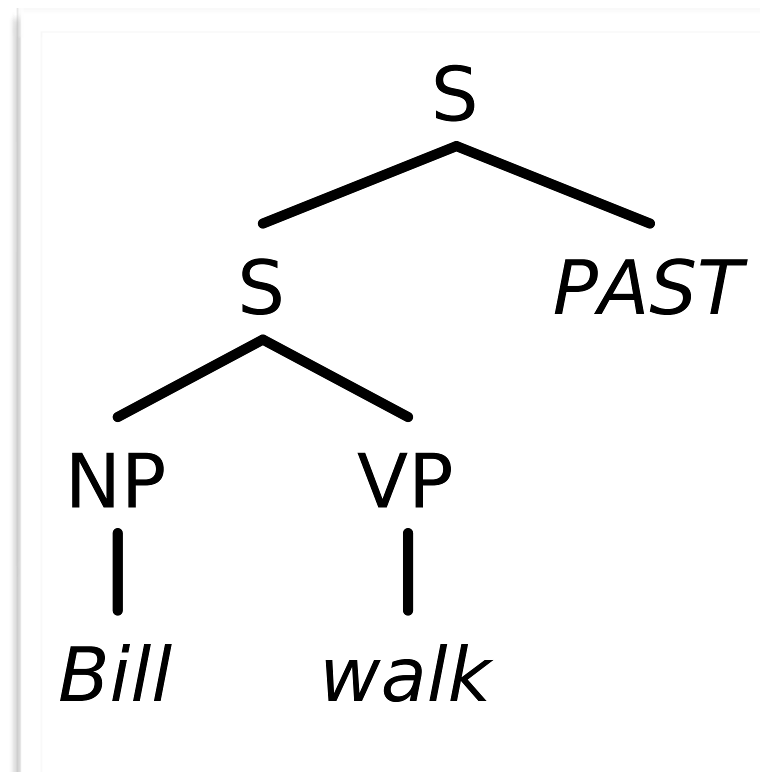
- $U \cap E = \varnothing$,
- $< \subseteq E \times E$ is an asymmetric relation (temporal precedence)
- $e_u \in E$ is the utterance event
- V is an interpretation function like in standard FOL
- Notation for overlapping events: $e \cdot e'$ iff neither $e < e'$ nor $e' < e$

Tense in Semantic Construction

We can represent tense inflection as an abstract tense operator reflecting the temporal location of the reported event relative to the utterance event.

$\text{PAST} \mapsto \lambda P.\exists e\ [P(e) \wedge e < e_u] : \langle\langle e, t\rangle, t\rangle$

$\text{PRES} \mapsto \lambda P.\exists e\ [P(e) \wedge e \cdot e_u] : \langle\langle e, t\rangle, t\rangle$

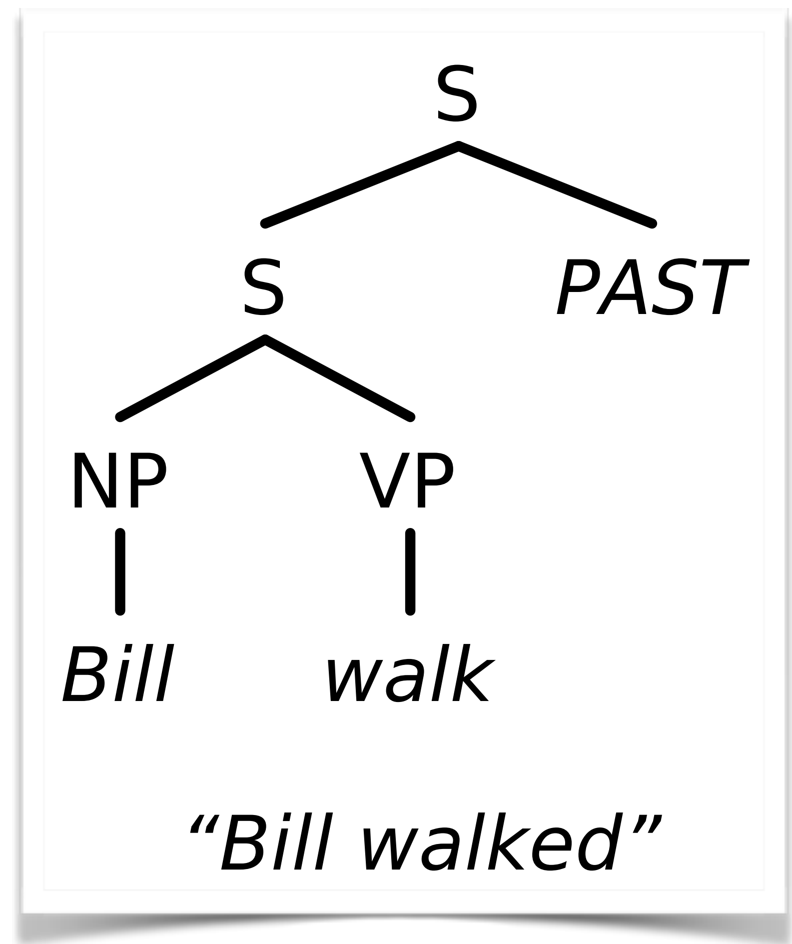


"Bill walked"

Tense in Semantic Construction (cont.)

Standard function application results in integration of temporal information and binding of the event variable (i.e., replacing E-CLOS):

- walk $\mapsto$ $\lambda x\ \lambda e\ [walk(e, x)]$
- Bill walk $\mapsto$ $\lambda x\ \lambda e\ [walk(e, x)](b') \Rightarrow^{\beta} \lambda e\ [walk(e, b')]$
- Bill walk PAST
  $\mapsto \lambda E\ \exists e\ [E(e) \wedge e < e_u](\lambda e'\ [walk(e', b)])$
  $\Rightarrow^{\beta} \exists e\ [\lambda e'\ [walk(e', b)](e) \wedge e < e_u]$
  $\Rightarrow^{\beta} \exists e\ [walk(e, b) \wedge e < e_u]$

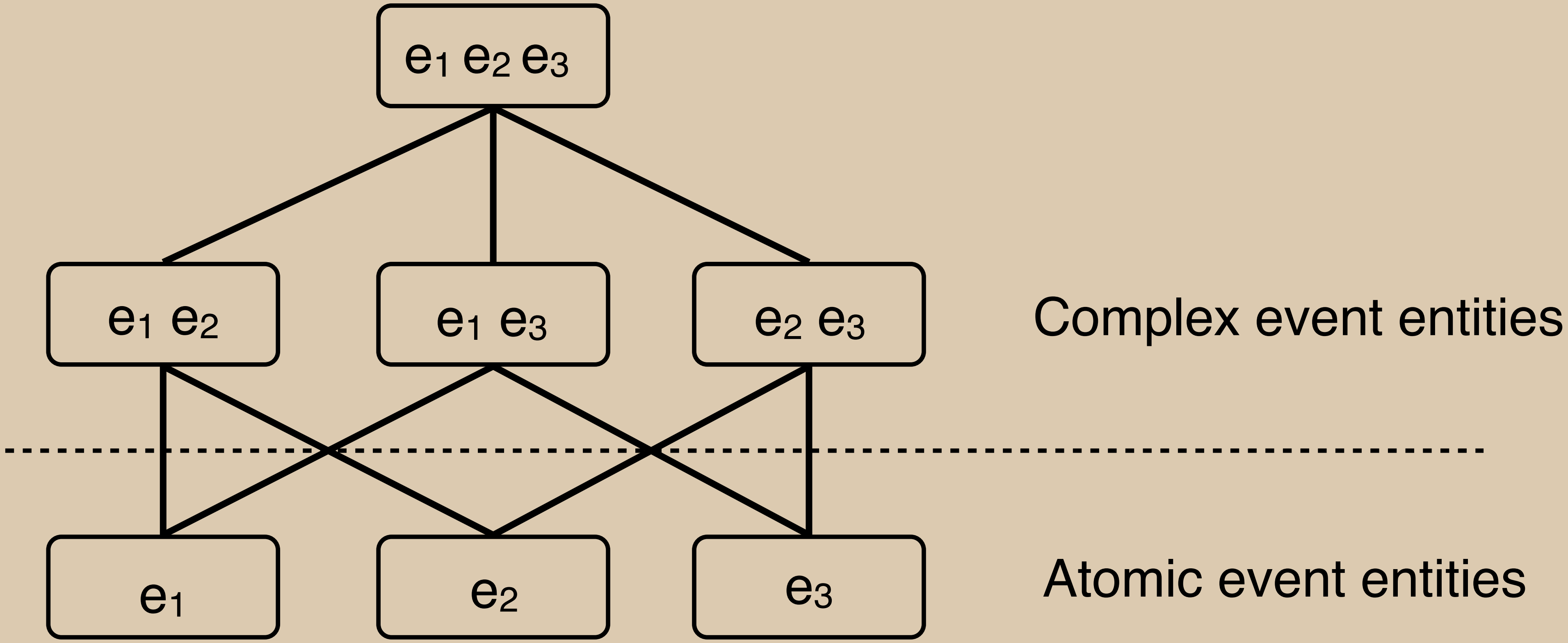


Event Structure

Observation: Events are generally constructs that consist of various (temporally ordered) sub-events

- E.g., "scripts": *visit a restaurant* or *shopping in the supermarket*

Idea: Induce structure into events universe



Lattices and Semi-lattices

A **partial order** is a structure $\langle A, \leq \rangle$ where $\leq$ is a reflexive, transitive, and antisymmetric relation over A.

- The **join** of a and b $\in$ A (Notation: $a \sqcup b$) is the lowest upper bound for a and b.
- The **meet** of a and b $\in$ A (Notation: $a \sqcap b$) is the highest lower bound for a and b.

A **lattice** is a partial order $\langle A, \leq \rangle$ that is closed under meet and join.

A **join semi-lattice** is a partial order $\langle A, \leq \rangle$ that is closed under join

Model Structure with Sub-Events

We can change the structure of the events universe to represent sub-event relations: $M = \langle U, \langle E, \leq_e \rangle, <, e_u, V \rangle$, where:

- $U \cap E = \varnothing$,
- $< \subseteq E \times E$ is an asymmetric relation (temporal precedence)
- $e_u \in E$ is the utterance event
- **$\langle E, \leq_e \rangle$ is a join semi-lattice**
- V is an interpretation function

Model Structure with Sub-Events (cont.)

The model structure $\mathbf{M} = \langle \mathbf{U}, \langle \mathbf{E}, \leq_e \rangle, <, \mathbf{e_u}, \mathbf{V} \rangle$ must observe some additional constraints on $<$ and $\leq_e$, for instance:

- If $e_1 < e_2$ and $e_1' \leq_e e_1$ and $e_2' \leq_e e_2$, then $e_1' < e_2'$
- If $e_1' \circ e_2'$ and $e_1' \leq_e e_1$ and $e_2' \leq_e e_2$, then $e_1 \circ e_2$

Sidenote: We could introduce a similar structuring of the universe of entities in order to capture *plurality* and other *composite entities*

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Verbal arguments; a related problem?

Verbal arguments with the same semantic “role” may syntactically appear in different positions.

(1) *John **broke** the window with a rock.*

(2) *A rock **broke** the window.*

(3) *The window **broke**.*

… and we’re back to the same entailment issue:

$\exists e(\text{break}_3(e, j, w, r)) \not\models \exists e(\text{break}_2(e, r, w)) \not\models \exists e(\text{break}_1(e, w))$

Semantic/Thematic roles

agent patient instrument

(1) *John* ***broke*** *the window with a rock.*

↦ ∃e [break(e) ∧ agent(e, j) ∧ patient(e, w) ∧ instrument(e, r)]

(2) *A rock* ***broke*** *the window.*

↦ ∃e [break(e) ∧ patient(e, w) ∧ instrument(e, r)]

(3) *The window* ***broke****.*

↦ ∃e [break(e) ∧ patient(e, w)]

In standard FOL & Type Theory: Thematic roles are implicitly represented by the canonical order of the arguments

In Neo-Davidsonian event semantics: Thematic roles are two-place relations between the event denoted by the verb, and an argument role filler.

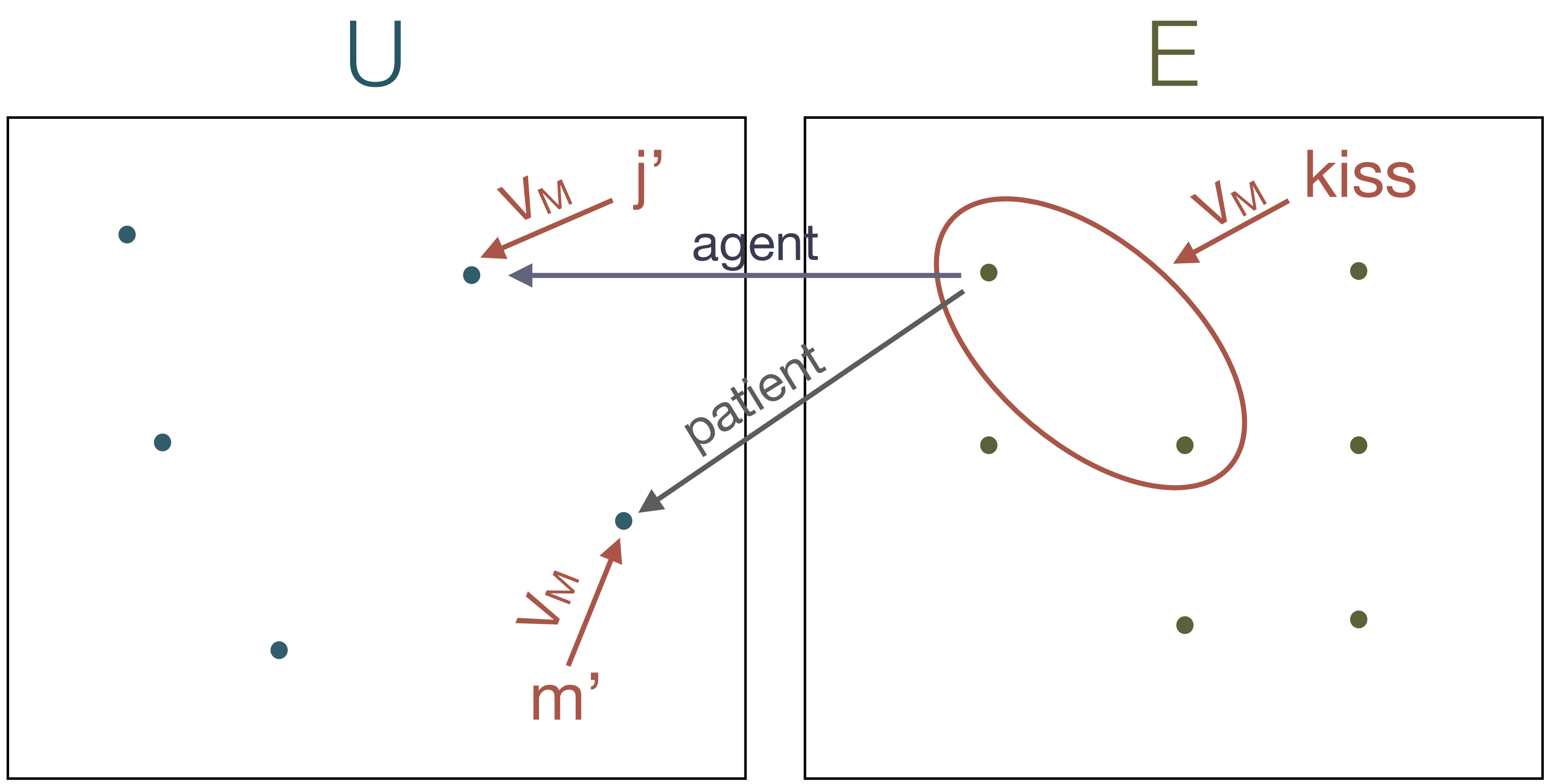
Interpretation of events with thematic roles

John kisses Mary ↦ $\exists e\,(kiss(e) \wedge agent(e, j') \wedge patient(e,m'))$

$[\![\ \exists e\,(kiss(e) \wedge agent(e, j') \wedge patient(e,m'))\ ]\!]^{M,g} = 1$

iff there is an $s \in E$ such that $[\![kiss(e)]\!]^{M,g[e/s]} = 1$ and $[\![\ agent(e, j')]\!]^{M,g[e/s]} = 1$ and $[\![patient(e,m')]\!]^{M,g[e/s]} = 1$

iff there is an $s \in E$ such that $s \in V_M(kiss)$ and $\langle s, V_M(j')\rangle \in V_M(agent)$ and $\langle s, V_M(m')\rangle \in V_M(patient)$



Thematic roles & verbal differences/similarities

Different verbs allow different thematic role configurations

(1) a. *John **broke** the window with a rock* → agent, patient, instrument
b. *John **smiled** at Mary* → agent, recipient

(2) a. *The window **broke*** → allows inanimate subject
b. **The bread **cut*** → does not allow inanimate subject

Thematic roles capture equivalences and entailment relations between different predicates

(3) a. *Mary **gave** Peter the book*
b. *Peter **received** the book from Mary*

$\forall e[give(e) \leftrightarrow receive(e)] \vDash (3a) \leftrightarrow (3b)$

Determining the role inventory

Fillmore (1968): “thematic roles form a small, closed, and universally applicable inventory conceptual argument types.”

A typical role inventory might consist of the roles:

- Agent, Patient, Theme, Recipient, Instrument, Source, Goal, Beneficiary, Experiencer.

But… there are some difficult cases:

(1) *Lufthansa is replacing its 737s with Airbus 320*

(2) *John sold the car to Bill for 3,000€*

(3) *Bill bought the car from John for 3,000€*

Semantic corpora with thematic roles

- PropBank: includes a separate role inventory for every lemma
- FrameNet: “Frame-based” role inventories

Frames are structured schemata representing complex prototypical situations, events, and actions

(1) *[$_{Agent}$ Lufthansa] is replacing$_{Frame:\ REPLACING}$ [$_{Old}$ its 737s] [$_{New}$ with Airbus A320s]*

(2) *[$_{Agent}$ Lufthansa] is substituting$_{Frame:\ REPLACING}$ [$_{New}$ Airbus A320s] [$_{Old}$ for its 737s]*

Semantic corpora with thematic roles (cont.)

PropBank (Palmer et al. 2005): Annotation of Penn TreeBank with predicate-argument structure.

(1) [$_{\text{Arg0}}$ Lufthansa] is replacing [$_{\text{Arg1}}$ its 737s] [$_{\text{Arg2}}$ with Airbus A320s]

Pred	replace
Arg0	Lufthansa
Arg1	its737s
Arg2	AirbusA320s

(2) [$_{\text{Arg0}}$ Lufthansa] is substituting [$_{\text{Arg1}}$ Airbus A320s] [$_{\text{Arg2}}$ for its 737s]

Pred	substitute
Arg0	Lufthansa
Arg1	AirbusA320s
Arg2	its737s

FrameNet (Baker et al. 1998): A database of frames and a lexicon with frame information

(3) [$_{\text{Agent}}$ Lufthansa] is replacing$_{\text{Frame: REPLACING}}$ [$_{\text{Old}}$ its 737s] [$_{\text{New}}$ with Airbus A320s]

(4) [$_{\text{Agent}}$ Lufthansa] is substituting$_{\text{Frame: REPLACING}}$ [$_{\text{New}}$ Airbus A320s] [$_{\text{Old}}$ for its 737s]

Frame	REPLACING
Agent	Lufthansa
Old	its737s
New	AirbusA320s

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… but how does it combine with other semantic constructs?

Note: The following slides present additional material for those of you interested in current issues in semantic theory. More details can be found in the referenced papers, and if time permits we can discuss during the Q&A session.

A problem with events and quantification

John kissed Mary

$\mapsto \lambda P.P(j') \; [\; \lambda P.P(m')(\lambda y \lambda x \lambda e \; [kiss(e) \wedge agent(e,x) \wedge patient(e,y)]) \;]$

$\Rightarrow^{\beta} \lambda e \; [kiss(e) \wedge agent(e,j') \wedge patient(e,m')]$

$\Rightarrow^{E\text{-}CLOS} \exists e \; [kiss(e) \wedge agent(e,j') \wedge patient(e,m')]$

John kissed every girl

$\mapsto \lambda P.P(j') \; [\; \lambda P.\forall x(girl'(x) \rightarrow P(x))(\lambda y \lambda x \lambda e \; [kiss(e) \wedge agent(e,x) \wedge patient(e,y)]) \;]$

$\Rightarrow^{\beta} \lambda e \; [\forall x(girl'(x) \rightarrow kiss(e) \wedge agent(e,j') \wedge patient(e,x)]$

$\Rightarrow^{E\text{-}CLOS} \exists e \; [\forall x(girl'(x) \rightarrow kiss(e) \wedge agent(e,j') \wedge patient(e,x)]$

Two solutions to the event quantification problem

Solution I

Interpret sentences as generalized quantifiers over events: $\langle\langle e,t\rangle,t\rangle$ instead of $\langle e,t\rangle$ (E-CLOS part of lexical semantics) (Champollion, 2010; 2015)

kiss $\mapsto \lambda F_{\langle v,t\rangle}.\exists e\,(\mathrm{kiss}(e) \wedge F(e)) :: \langle\langle v,t\rangle,t\rangle$ $\approx \{ F \mid F \cap \mathrm{KISS} \neq \varnothing \}$

separate type for events!

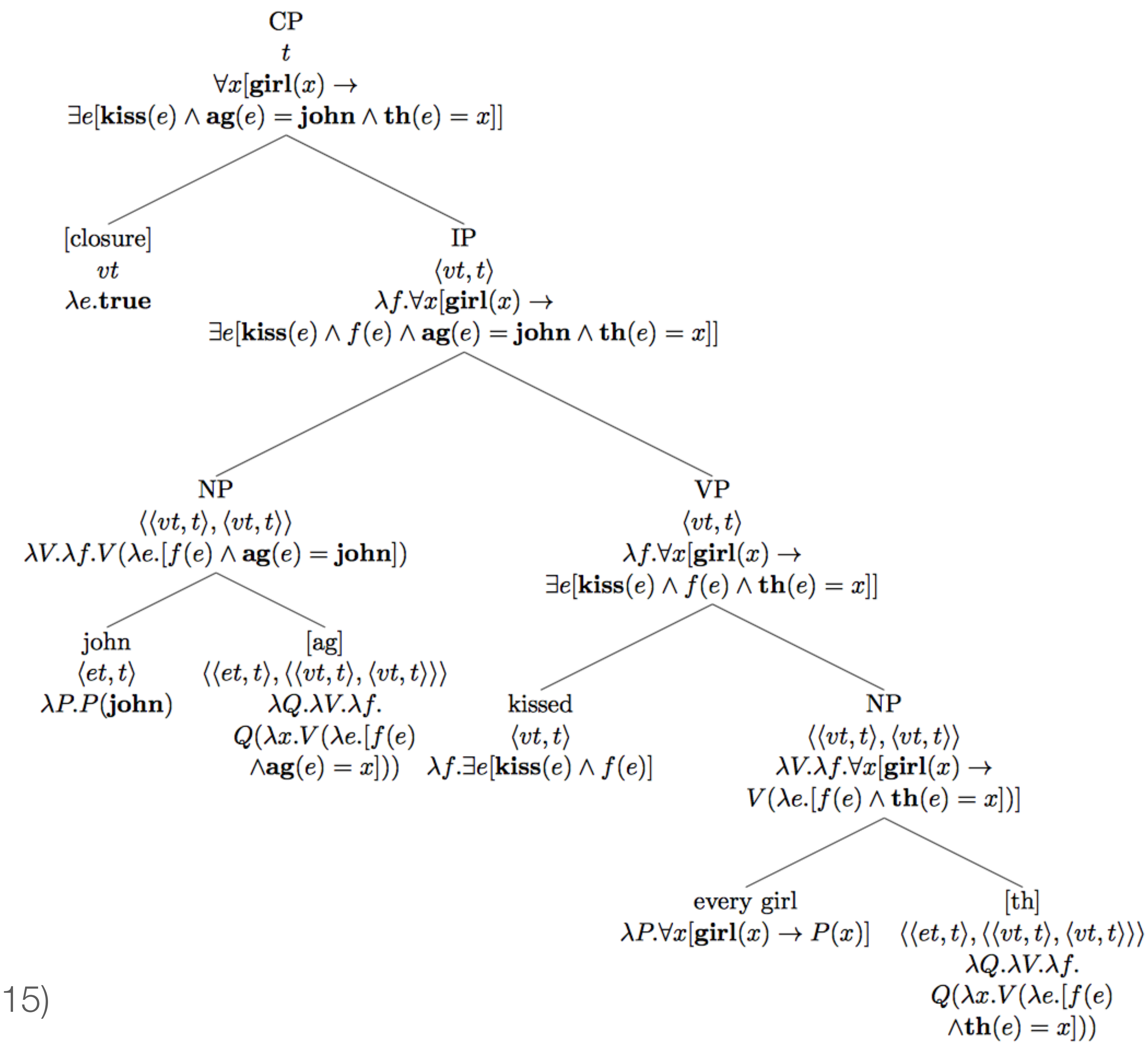
Solution II

Introduce separate types for regular NPs and quantified NPs, and restrict existential closure to regular NPs (Winter & Zwarts, 2011; de Groote & Winter, 2014)

john $\mapsto j :: e$
every girl $\mapsto \lambda Q.\forall x(\mathrm{girl}(x)\rightarrow Q(x)) :: \langle\langle e,t\rangle,t\rangle$
kiss $\mapsto \lambda x\lambda y\lambda e.\mathrm{kiss}(e,x,y) :: \langle e,\langle e,\langle v,t\rangle\rangle\rangle$
e-clos $\mapsto \lambda P.\exists e(P(e)) :: \langle\langle v,t\rangle,t\rangle$

separate type for events!

Solution I: Sentences as GQs over events



(Champollion, 2010; 2015)

Solution II: Type-restriction for existential closure

$$\frac{\vdash \textsc{every} : N \to (NP \to S) \to S \qquad \vdash \textsc{girl} : N}{\vdash \textsc{every girl} : (NP \to S) \to S}\ (1)$$

$$\frac{\dfrac{\vdash \textsc{kissed} : NP \to NP \to V \qquad x : NP \vdash x : NP}{x : NP \vdash \textsc{kissed}\, x : NP \to V} \qquad \vdash \textsc{john} : NP}{x : NP \vdash \textsc{kissed}\, x\, \textsc{john} : V}\ (2)$$

$$\frac{\dfrac{\vdash \textsc{e-clos} : V \to S \qquad \overset{\vdots\ (2)}{x : NP \vdash \textsc{kissed}\, x\, \textsc{john} : V}}{x : NP \vdash \textsc{e-clos}\,(\textsc{kissed}\, x\, \textsc{john}) : S}}{\vdash \lambda x.\, \textsc{e-clos}\,(\textsc{kissed}\, x\, \textsc{john}) : NP \to S}\ (3)$$

$$\frac{\overset{\vdots\ (1)}{\vdash \textsc{every girl} : (NP \to S) \to S} \qquad \overset{\vdots\ (3)}{\vdash \lambda x.\, \textsc{e-clos}\,(\textsc{kissed}\, x\, \textsc{john}) : NP \to S}}{\vdash \textsc{every girl}\,(\lambda x.\, \textsc{e-clos}\,(\textsc{kissed}\, x\, \textsc{john})) : S}$$

(Winter & Zwarts, 2011; de Groote & Winter, 2014)

Reading Material & Links

- Overview paper: Lasersohn (2012) Event-Based Semantics: https://semanticsarchive.net/Archive/jFhNWM2M/eventbasedsemantics.pdf
- PropBank: http://propbank.github.io/
- FrameNet: https://framenet.icsi.berkeley.edu/fndrupal/