Semantic Theory
Week 6 – Event semantics

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A problem with verbs and adjuncts

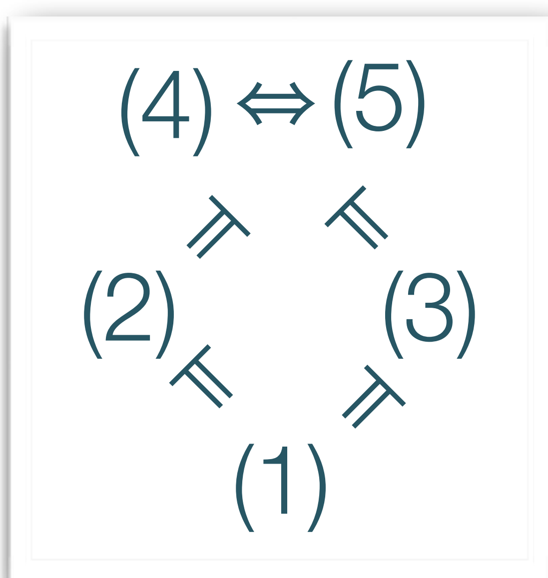
(1) *The gardener killed the baron* $\mapsto \text{kill}_1(g',b')$ $\text{kill}_1 :: \langle e,\langle e,t\rangle\rangle$

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

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

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

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

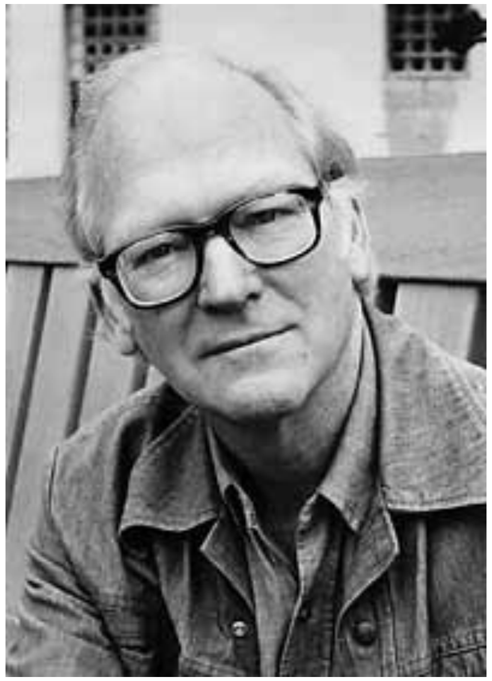


Q: How to explain the systematic logical entailment relations between the different uses of “kill”?

Davidson's solution: verbs introduce events.

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

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



Sentences denote sets of events:

- $\lambda y \lambda x \lambda e(kill'(e,x,y))(b')(g') \Rightarrow_\beta \lambda e(kill'(e, g', b'))$ :: $\langle e,t\rangle$

Existential closure turns sets of events into truth conditions

- $\lambda P \exists e(P(e))$ :: $\langle\langle e,t\rangle,t\rangle$
- $\lambda P \exists e(P(e))(\lambda e(kill'(e,g',b'))) \Rightarrow_\beta \exists e(kill'(e,g',b'))$ :: t

Davidson (1967, 1980)

Davisonian events and adjuncts

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

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

The gardener killed the baron at midnight in the park

$\mapsto \exists e\,(\text{kill}(e, g', b') \wedge \text{time}(e, m) \wedge \text{location}(e, p'))$

$\Leftrightarrow \exists e\,(\text{kill}(e, g', b') \wedge \text{location}(e, p) \wedge \text{time}(e, m'))$

} $\models \exists e\,(\text{kill}(e, g', b') \wedge \text{time}(e, m'))$

$\models \exists e\,(\text{kill}(e, g', b') \wedge \text{location}(e, p'))$

$\models \exists e\,(\text{kill}(e, g', b'))$

Compositional derivation of event-semantic representations

the gardener killed the baron

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

… at midnight

α

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

… in the park

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

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

Existential closure

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

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

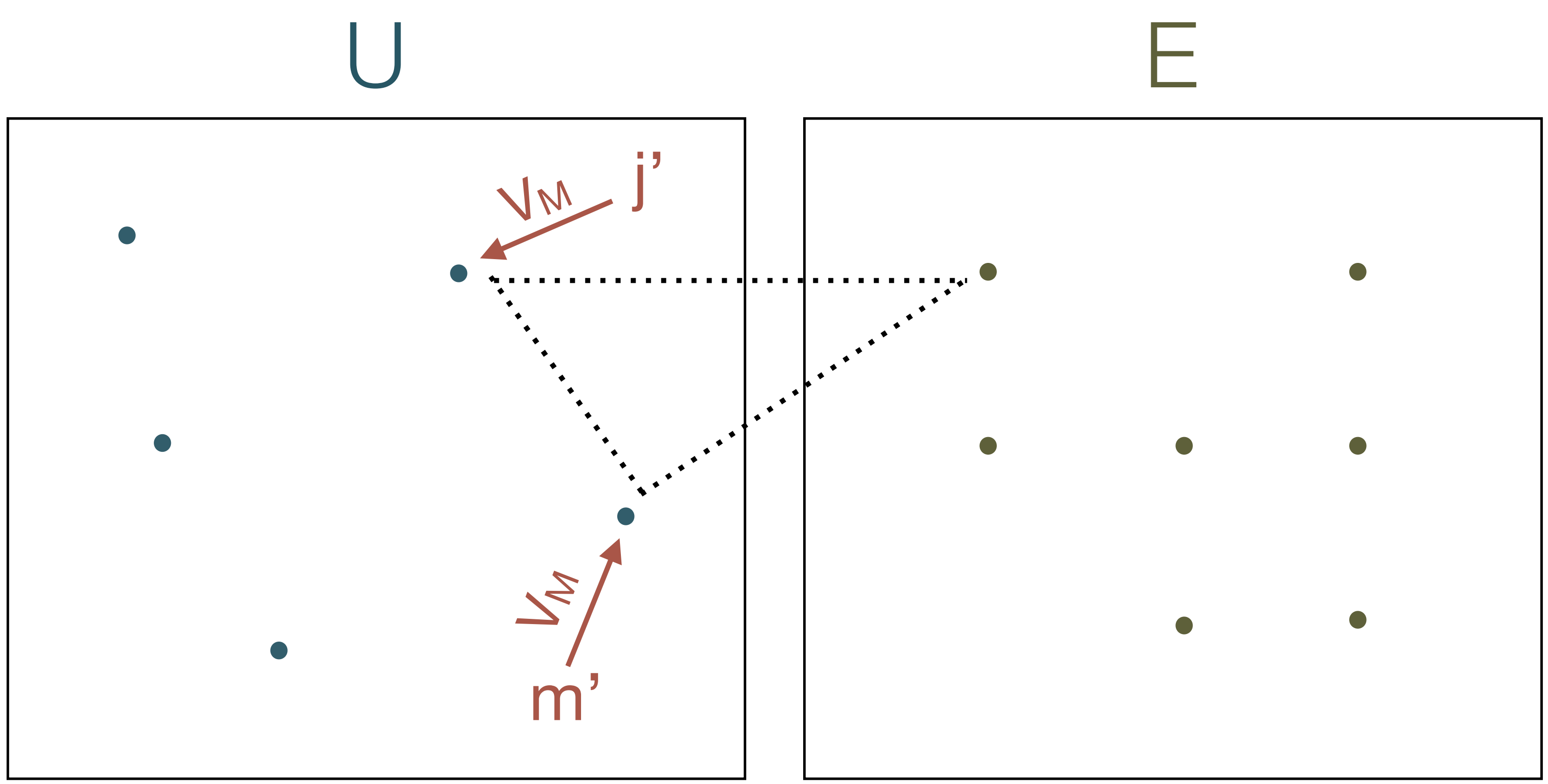
Quantification ranges over sort-specific domains:

- $[\![\exists x\, \Phi]\!]^{M,g} = 1$ 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 ↦ ∃e (kiss(e, j', m'))

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



Advantages of Davidsonian events

- [x] 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*

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

see :: ⟨e,⟨e,⟨e,t⟩⟩

(2) *Bill saw an accident*

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

see :: ⟨e,⟨e,⟨e,t⟩⟩

(3) *Bill saw the children play*

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

see :: ⟨e,⟨e,⟨e,t⟩⟩

Uniform treatment of adjuncts and post-nominal modifiers

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

- red $\mapsto$ λF λx [F(x) ∧ red*(x)] ⟨⟨e,t⟩,⟨e,t⟩⟩
- in the park $\mapsto$ λF λe [F(e) ∧ location(e, park)] ⟨⟨e,t⟩,⟨e,t⟩⟩

(1) *The murder in the park…*

$\mapsto$ λFλe[F(e) ∧ location(e, park)] (λe_1 [murder(e_1)])

(2) The fountain in the park ….

$\mapsto$ λFλx[F(x) ∧ location(x, park)] (λy [fountain(y)])

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THE PAST, PRESENT
& FUTURE WALK
INTO A BAR
IT WAS TENSE
WallingfordSign.com

Classical Tense Logic

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

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

Φ has always been the case

Φ is always going to be the case

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

(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 to formalize temporal relations *between events*?

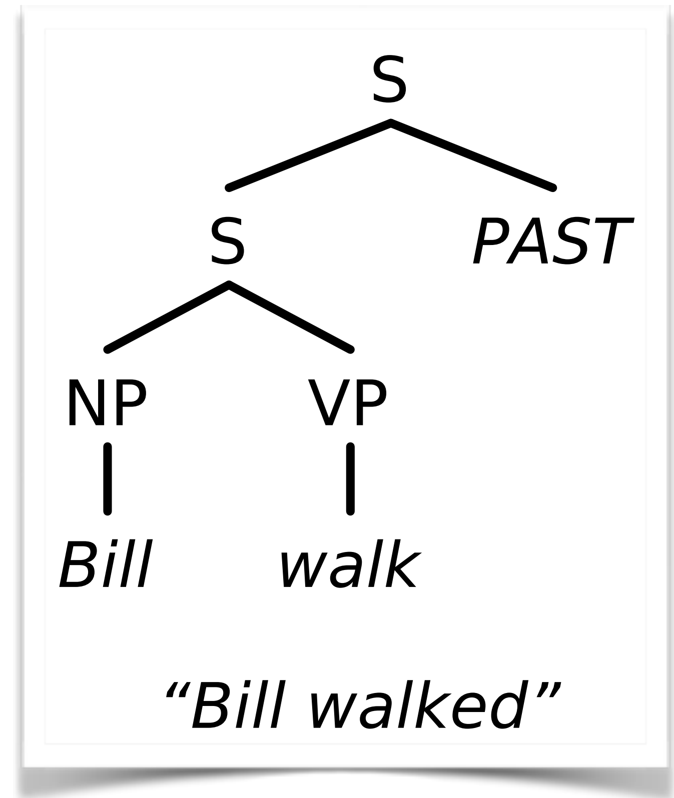
Temporal Event Structure

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
- Overlapping events: $e \cdot e'$ iff neither $e < e'$ nor $e' < e$

Tense in Semantic Construction

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



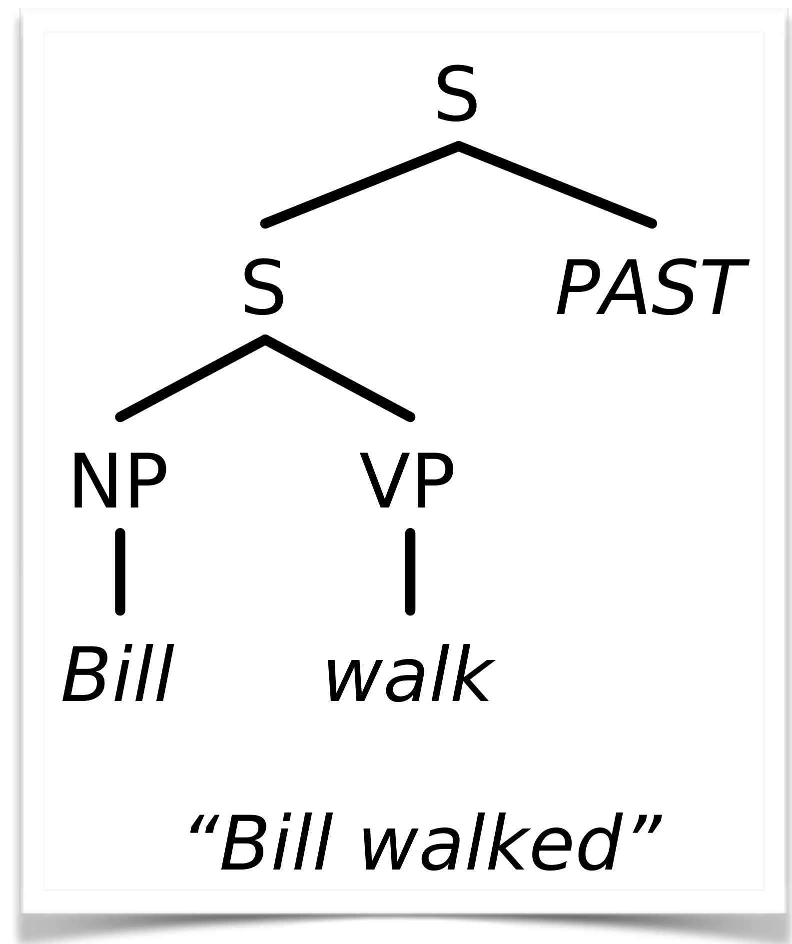
$\text{PAST} \mapsto \lambda P.\exists e\, [P(e) \wedge e < e_u] : \langle\langle e, t\rangle, t\rangle$

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

Tense in Semantic Construction

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

- walk ↦ λx λe [walk(e, x)]
- Bill walk ↦ λx λe [walk(e, x)](b') $\Rightarrow^{\beta}$ λe [walk(e, b')]
- Bill walk PAST
  ↦ λE ∃e [E(e) ∧ e < e_u](λe' [walk(e', b)])
  $\Rightarrow^{\beta}$ ∃e [λe' [walk(e', b)](e) ∧ e < e_u]
  $\Rightarrow^{\beta}$ ∃e [walk(e, b) ∧ e < e_u]

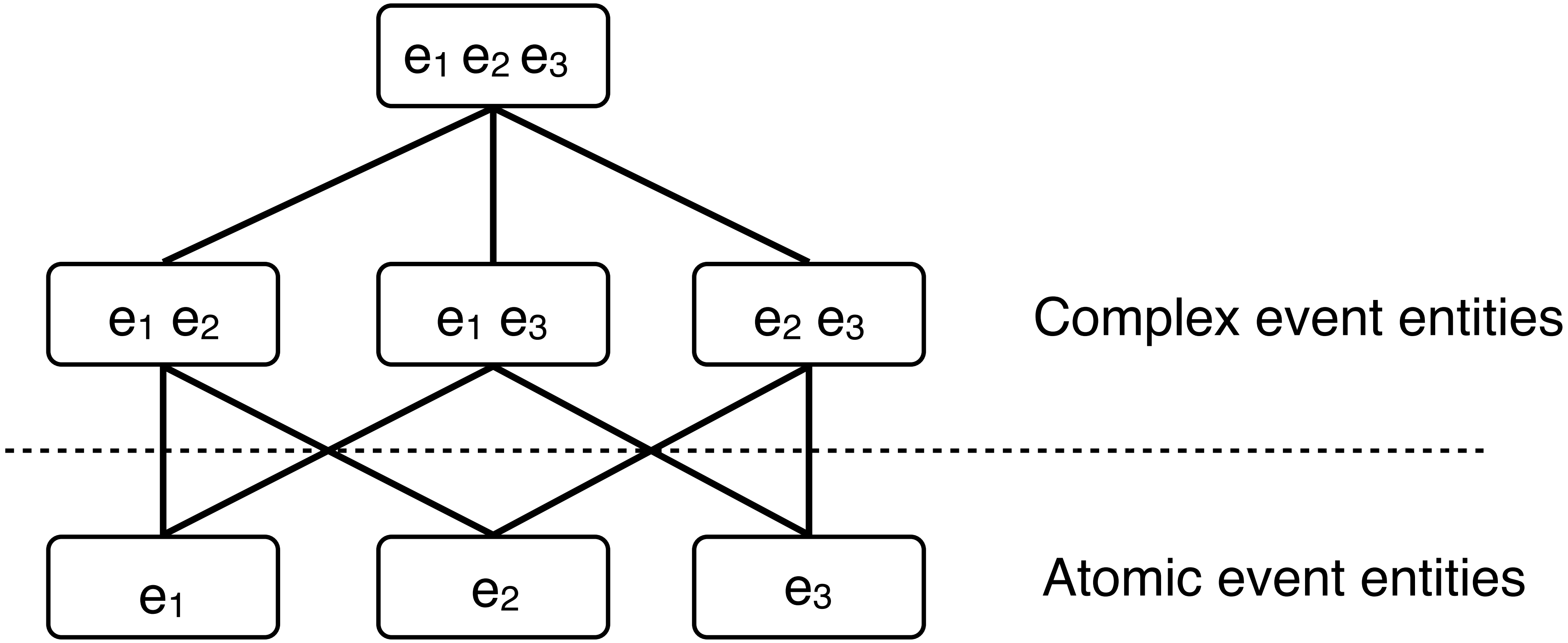


Event Structure

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 ⟨A, ≤⟩ where ≤ is a reflexive, transitive, and antisymmetric relation over A.

- The **join** of a and b ∈ A (Notation: $a \sqcup b$) is the lowest upper bound for a and b.

- The **meet** of a and b ∈ A (Notation: $a \sqcap b$) is the highest lower bound for a and b.

A **lattice** is a partial order ⟨A, ≤⟩ that is closed under meet and join.

A **join semi-lattice** is a partial order ⟨A, ≤⟩ 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 $M = \langle U, \langle E, \leq_e \rangle, <, e_u, V \rangle$ 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?

(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: Thematic roles are implicitly represented by the canonical order of the arguments

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

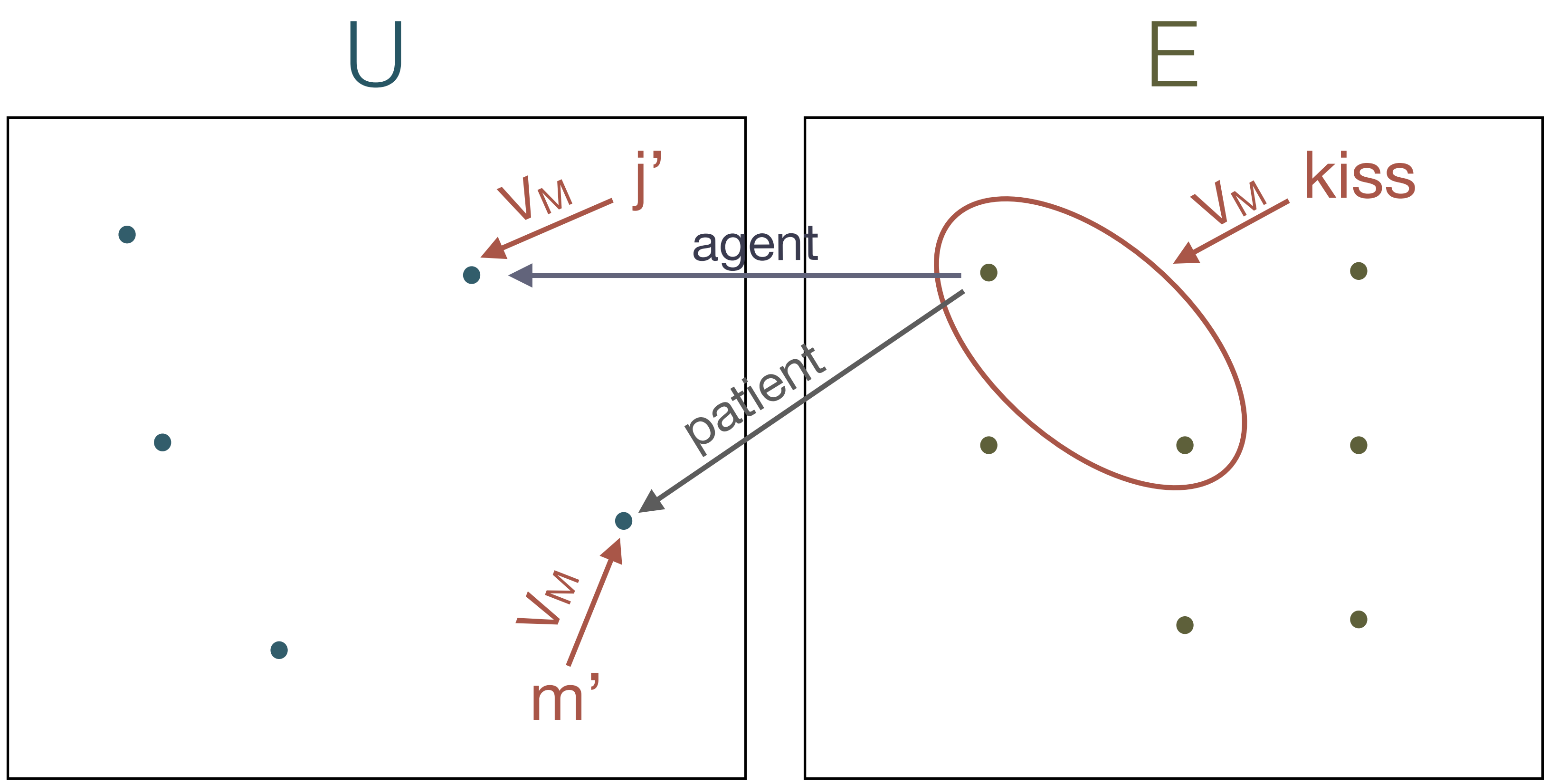
Interpretation of events with thematic roles

John kisses Mary $\mapsto$ $\exists e$ (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*

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

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

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

Advantages of Davidsonian events

- ☑ Intuitive representation and semantic construction for adjuncts
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… but how does it combine with other semantic constructs?

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

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

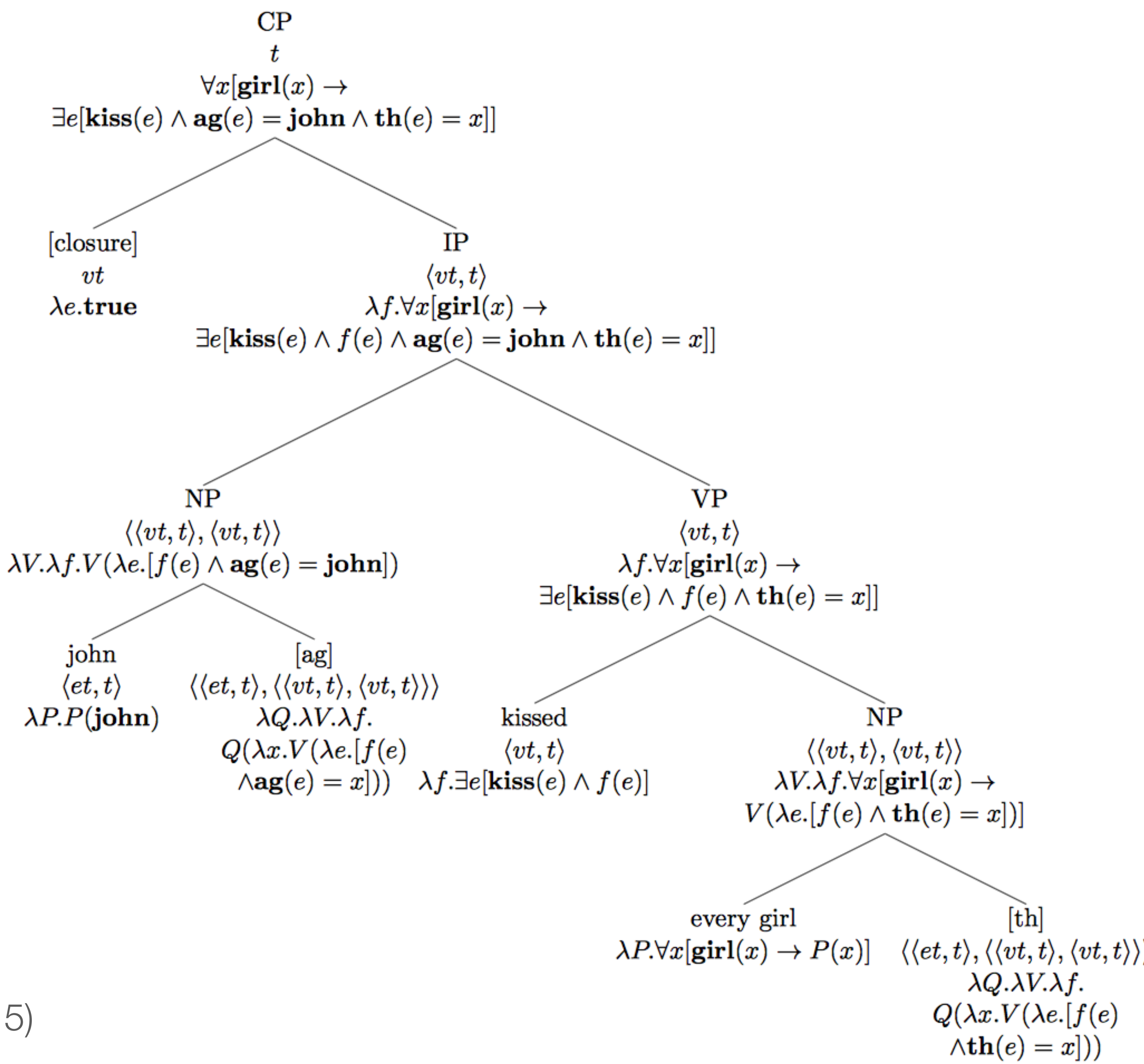
every girl $\mapsto \lambda Q.\forall x(\text{girl}(x)\rightarrow Q(x)) :: \langle\langle e,t\rangle,t\rangle$

kiss $\mapsto \lambda x\lambda y\lambda e.\text{kiss}(e,x,y) :: \langle e,\langle e,\langle v,t\rangle\rangle\rangle$

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)

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/