Semantic Theory
Week 6 – Event semantics

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A problem with verbs and adjuncts

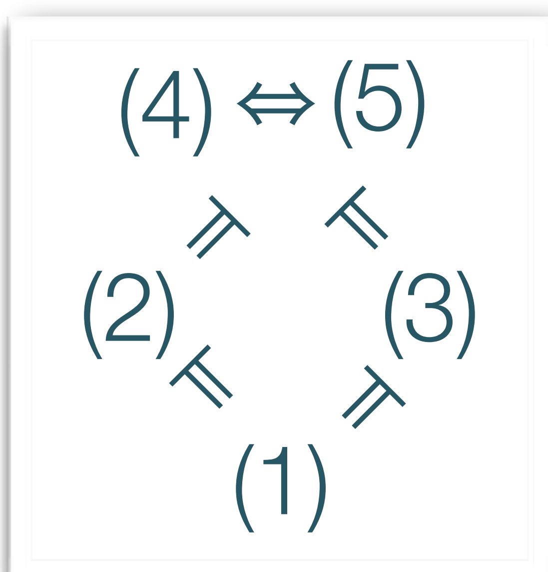
(1) *The gardener killed the baron* $\mapsto$ $\mathrm{kill}_1(g',b')$ $\mathrm{kill}_1 :: \langle e,\langle e,t\rangle\rangle$

(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* $\mapsto$ $\mathrm{kill}_5(g',b',p',m')$ $\mathrm{kill}_5 :: \ldots$

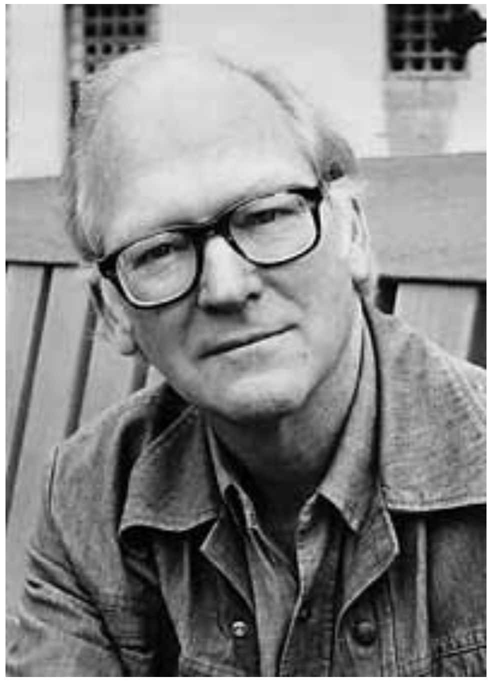


Q: How to explain the systematic logical entailment relations between the different uses of "kill"?

Davidson’s solution: verbs introduce events.

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

- kill $\mapsto$ $\lambda y \lambda x \lambda e(kill'(e,x,y)) :: \langle e,\langle e,\langle e,t\rangle\rangle\rangle$ *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 $\mapsto$ λPλe(P(e) ∧ time(e,m’)) :: ⟨⟨e,t⟩,⟨e,t⟩⟩
- in the park $\mapsto$ λPλe(P(e) ∧ location(e,p’)) :: ⟨⟨e,t⟩,⟨e,t⟩⟩

The gardener killed the baron at midnight in the park

$\mapsto$ ∃e (kill(e, g’, b’) ∧ time(e, m) ∧ location(e, p’))

$\Leftrightarrow$ ∃e (kill(e, g’, b’) ∧ location(e, p) ∧ time(e, m’))

$\models$ ∃e (kill(e, g’, b’) ∧ time(e, m’))

$\models$ ∃e (kill(e, g’, b’) ∧ location(e, p’))

$\models$ ∃e (kill(e, g’, b’))

Compositional derivation of event-semantic representations

the gardener killed the baron

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

… at midnight

α

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

… in the park

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

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

Existential closure

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

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

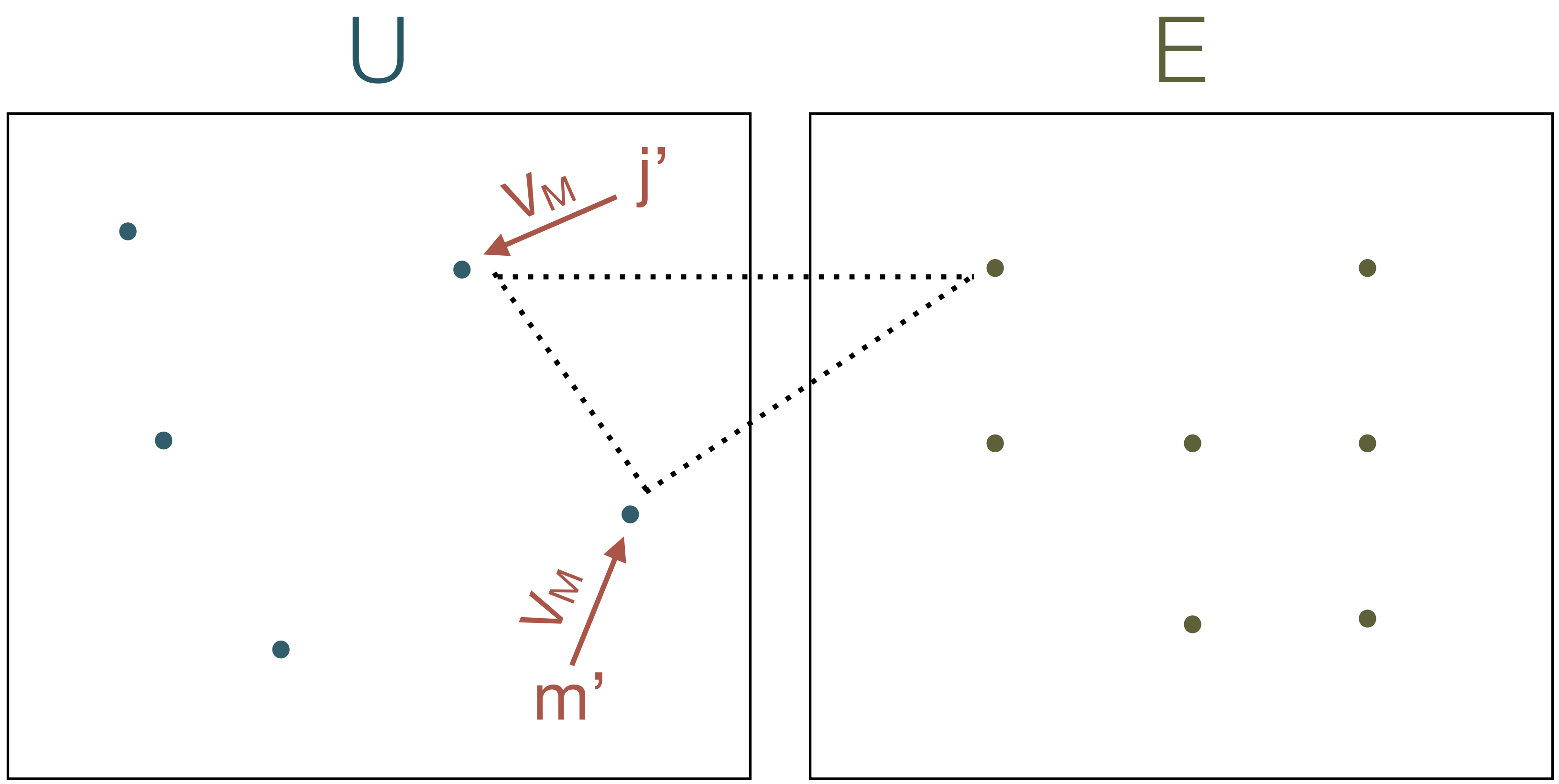
Interpreting events

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

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

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

- [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*

↦ $\exists e\ \exists x\ (\text{see}(e, b', x) \wedge \text{elephant}(x))$ 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 $\mapsto$ $\lambda F\ \lambda x\ [\ F(x) \wedge red^*(x)\ ]$ $\langle\langle e,t\rangle,\langle e,t\rangle\rangle$
- in the park $\mapsto$ $\lambda F\ \lambda e\ [\ F(e) \wedge location(e, park)\ ]$ $\langle\langle e,t\rangle,\langle e,t\rangle\rangle$

(1) *The murder in the park…*

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

(2) The fountain in the park ….

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

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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 has always been the case

Φ is always going to be the case

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

(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*?

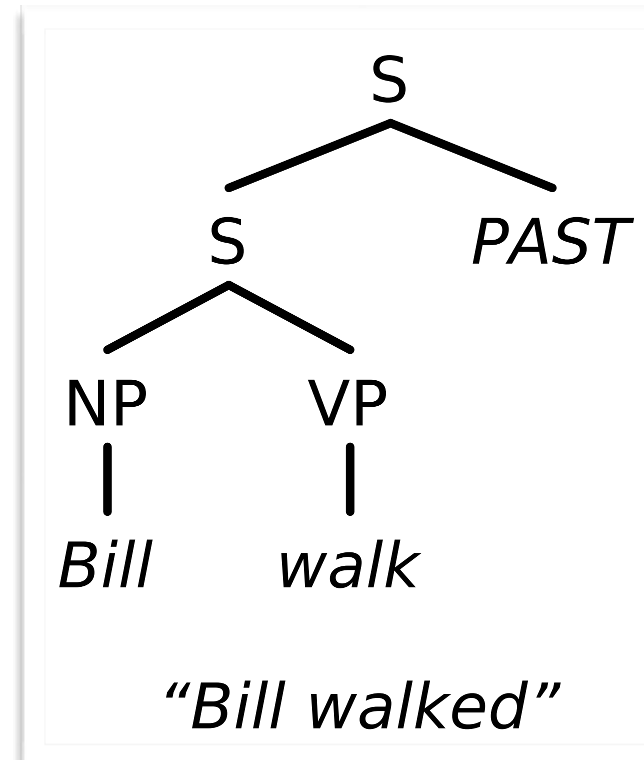
Temporal Event Structure

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.



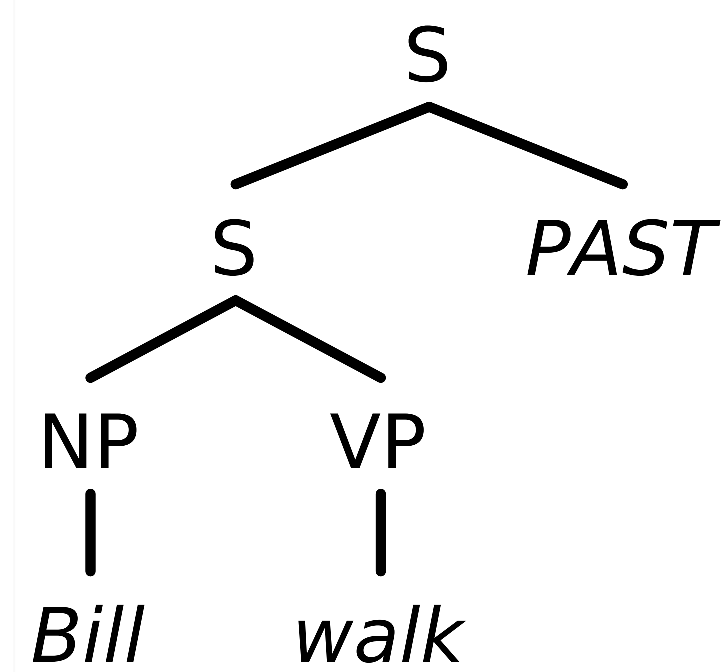
PAST $\mapsto \lambda P.\exists e\, [P(e) \wedge e < e_u] : \langle\langle e, t\rangle, t\rangle$

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



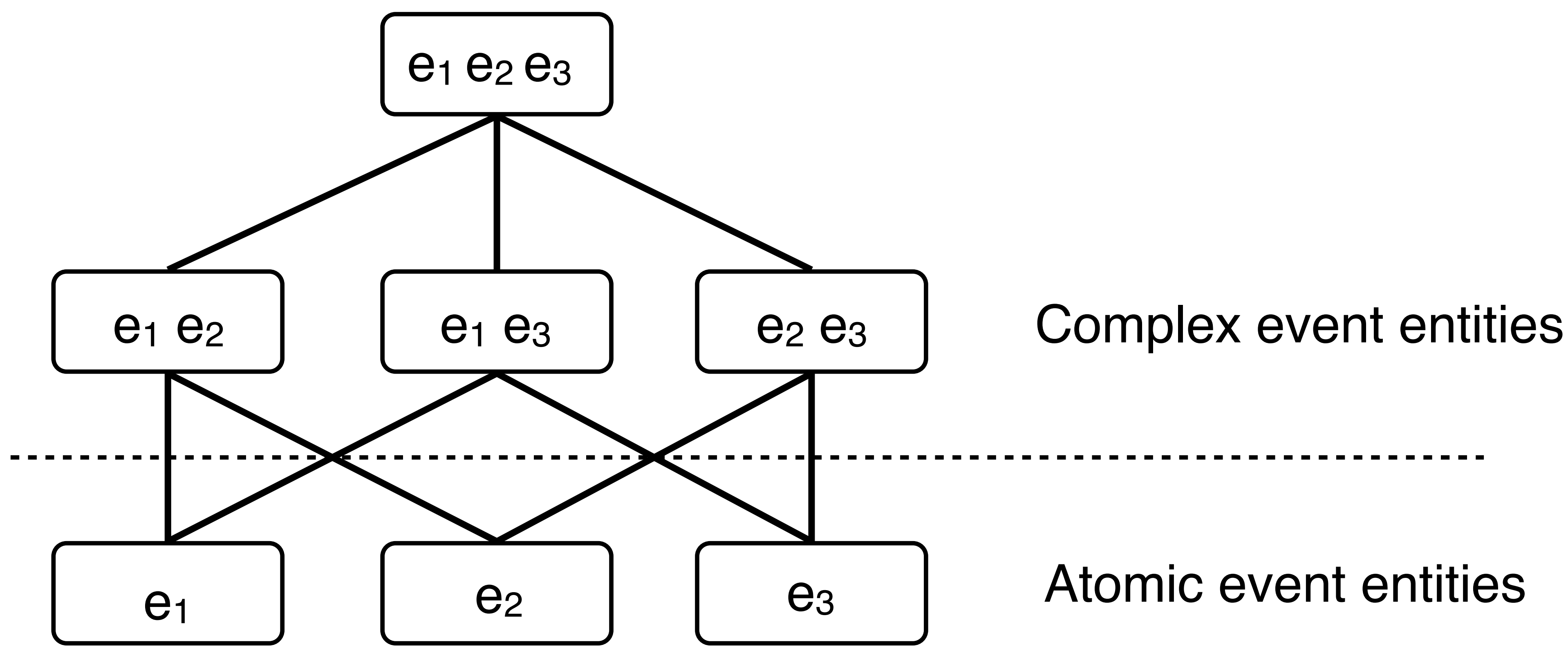
"Bill walked"

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 $M = \langle U, \langle E, \leq_e \rangle, <, e_u, V \rangle$ 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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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/