

# Semantic Theory

## Week 7 – Event semantics

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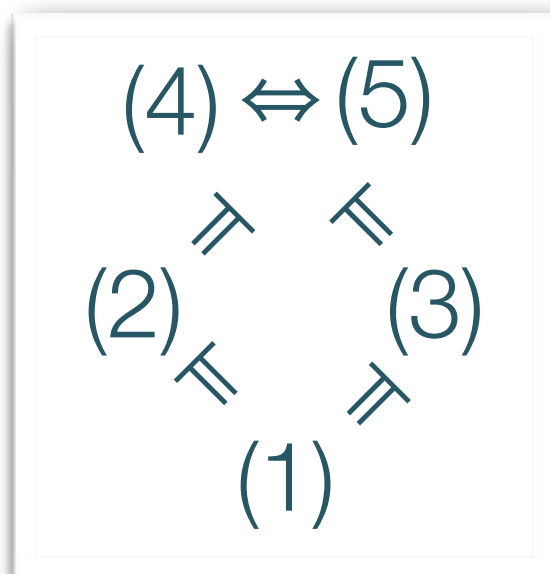
Universität des Saarlandes

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# A problem with verbs and adjuncts

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- (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*  $\mapsto \text{kill}_4(g', b', m', p')$   $\text{kill}_4 :: \dots$
- (5) *The gardener killed the baron in the park at midnight*  $\mapsto \text{kill}_5(g', b', p', m')$   $\text{kill}_5 :: \dots$



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:

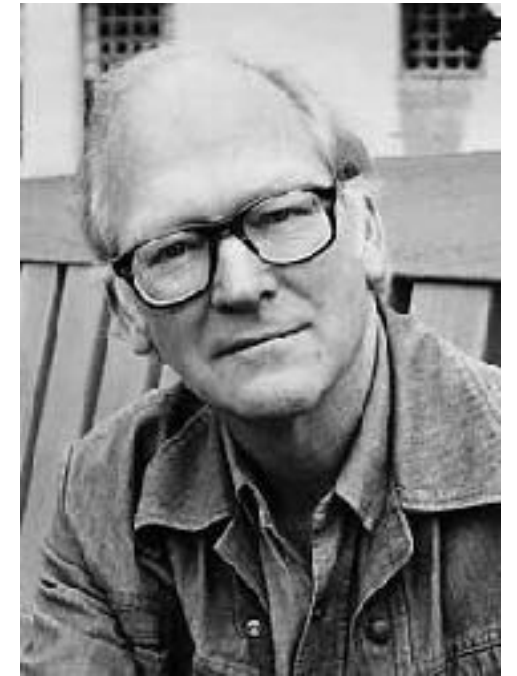
- $\text{kill} \mapsto \lambda y \lambda x \lambda e (\text{kill}'(e, x, y)) :: \langle e, \langle e, \langle e, t \rangle \rangle \rangle$  *arity = n+1*

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

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

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

*The gardener killed the baron at midnight in the park*

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

# Compositional derivation of event-semantic representations

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*the gardener killed the baron*

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

*... 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

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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
- $U \cap E = \emptyset$ ,
- $V$  is an interpretation function like in first order logic

# Sorted (first-order) logic

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

- $g(x) \in U$  for  $x \in \text{VAR}_U$        $\text{VAR}_U = \{ x, y, z, \dots, x_1, x_2, \dots \}$  (Object variables)
- $g(e) \in E$  for  $e \in \text{VAR}_E$        $\text{VAR}_E = \{ e, e', e'', \dots, e_1, e_2, \dots \}$  (Event variables)

Quantification ranges over sort-specific domains:

- $\llbracket \exists x \Phi \rrbracket^{M,g} = 1$       iff there is an  $a \in U$  such that  $\llbracket \Phi \rrbracket^{M,g[x/a]} = 1$
- $\llbracket \exists e \Phi \rrbracket^{M,g} = 1$       iff there is an  $a \in E$  such that  $\llbracket \Phi \rrbracket^{M,g[e/a]} = 1$
- (universal quantification analogous)

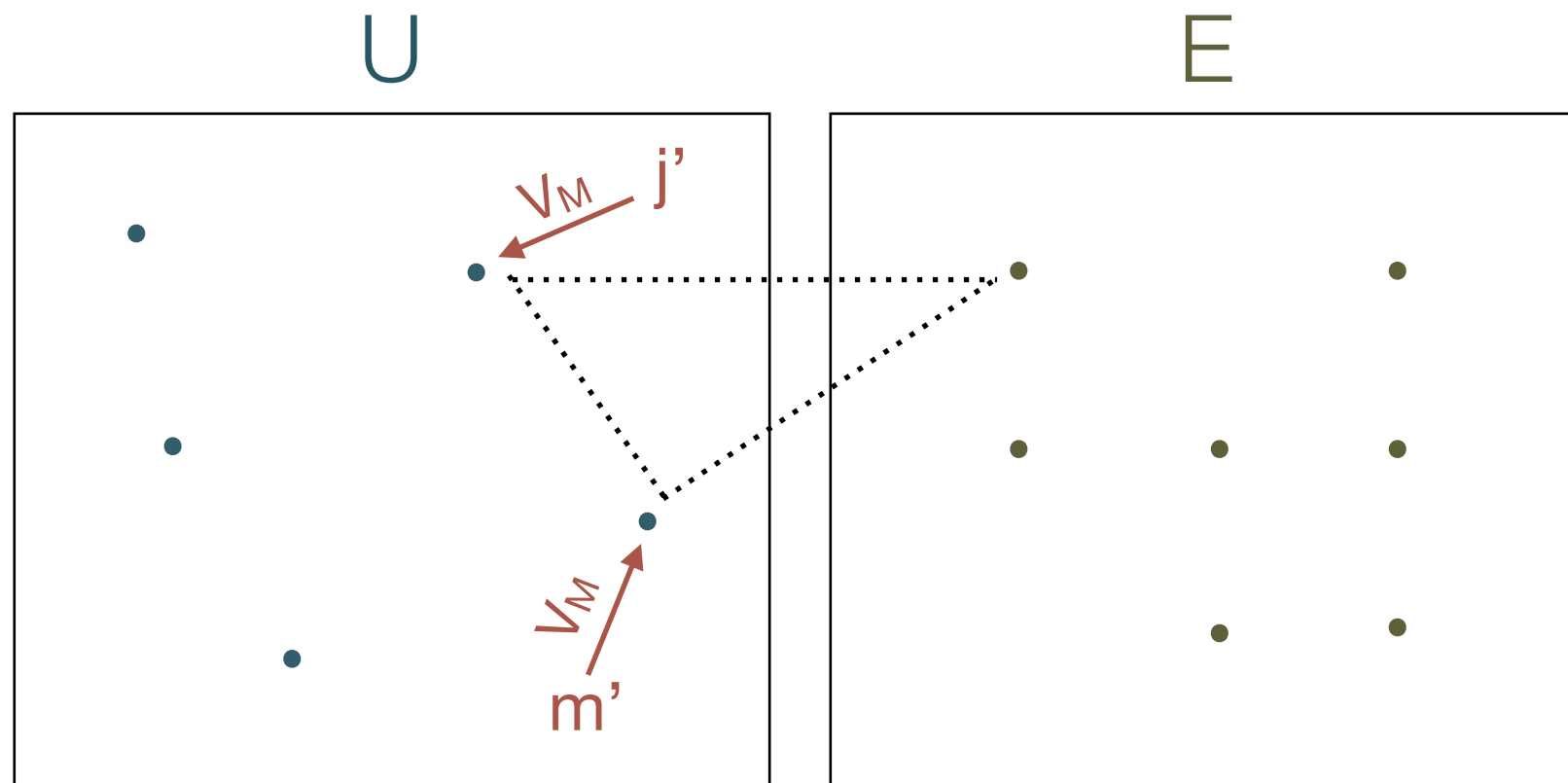
# Interpreting events

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

$\llbracket \exists e (\text{kiss}(e, j', m')) \rrbracket^{M,g} = 1$

*iff* there is an  $s \in E$  such that  $\llbracket \text{kiss}(e, j', m') \rrbracket^{M,g[e/s]} = 1$

*iff* there is an  $s \in E$  such that  $\langle s, V_M(j'), V_M(m') \rangle \in V_M(\text{kiss})$





# Advantages of Davidsonian events

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- ☑ 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

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(1) *Bill saw an elephant*

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

$\text{see} :: \langle e, \langle e, \langle e, t \rangle \rangle$

(2) *Bill saw an accident*

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

$\text{see} :: \langle e, \langle e, \langle e, t \rangle \rangle$

(3) *Bill saw the children play*

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

$\text{see} :: \langle e, \langle e, \langle e, t \rangle \rangle$

# Uniform treatment of adjuncts and post-nominal modifiers

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

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

(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

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- *John walks*             $\text{walk}(\text{john})$
- *John walked*         $P(\text{walk}(\text{john}))$
- *John will walk*       $F(\text{walk}(\text{john}))$

Syntax like in first-order logic, plus

- if  $\Phi$  is a well-formed formula, then  $P\Phi$ ,  $F\Phi$ ,  $H\Phi$ ,  $G\Phi$  are also well-formed formulae.

$\Phi$  has always  
been the case

$\Phi$  is always  
going to be  
the case

$\Phi$  happened in the past

$\Phi$  will happen  
in the future

# Classical Tense Logic (cont.)

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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
- $U \cap T = \emptyset$
- $<$  is a linear order on  $T$
- $V$  is a value assignment function, which assigns to every non-logical constant  $\alpha$  a function from  $T$  to appropriate denotations of  $\alpha$

$\llbracket P\Phi \rrbracket^{M, t, g} = 1$  iff there is a  $t' < t$  such that  $\llbracket \Phi \rrbracket^{M, t', g} = 1$

$\llbracket F\Phi \rrbracket^{M, t, g} = 1$  iff there is a  $t' > t$  such that  $\llbracket \Phi \rrbracket^{M, t', g} = 1$

# Temporal Relations and Events

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- (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

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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:  $e \cdot e'$  iff neither  $e < e'$  nor  $e' < e$

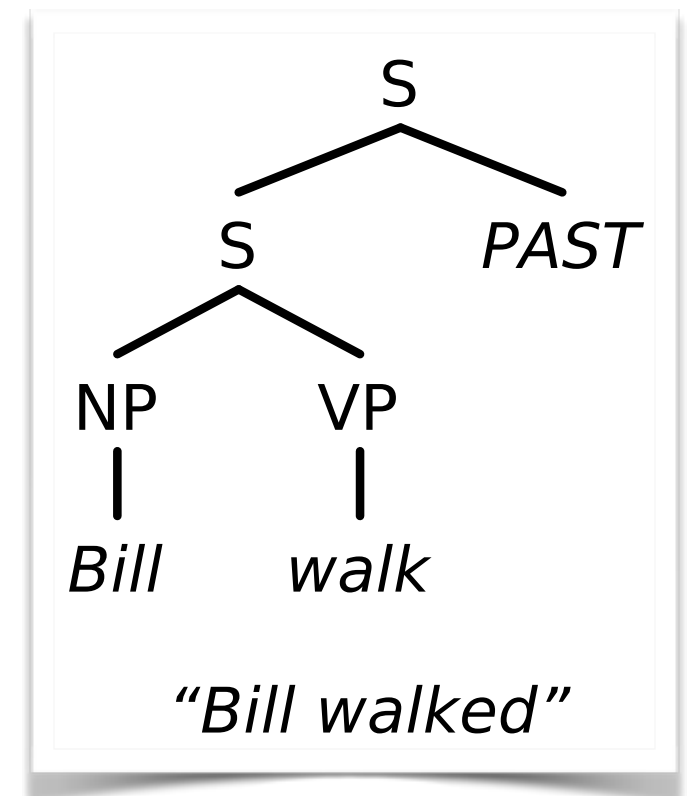


# Tense in Semantic Construction

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

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

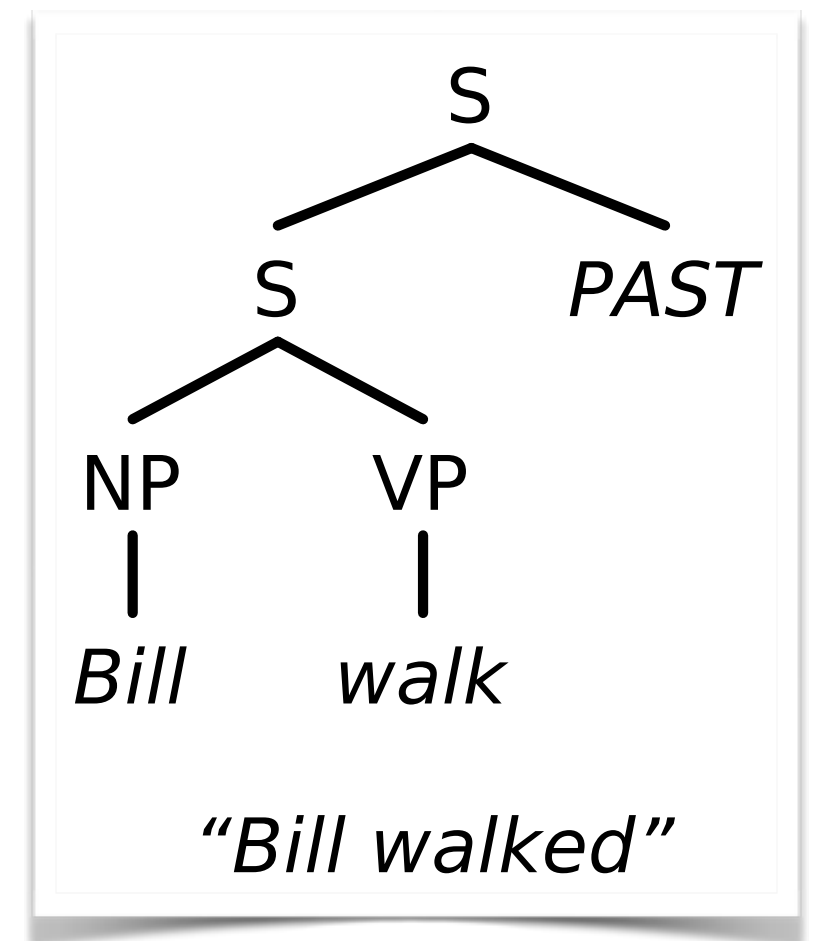
$PRES \mapsto \lambda P. \exists e [P(e) \wedge e \cdot e_u] : \langle \langle e, t \rangle, t \rangle$



# Tense in Semantic Construction

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

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



# Advantages of Davidsonian events

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- ☑ Intuitive representation and semantic construction for adjuncts
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# Verbal arguments; a related problem?

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(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

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agent

patient

instrument

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

$\mapsto \exists e [\text{break}(e) \wedge \text{agent}(e, j) \wedge \text{patient}(e, w) \wedge \text{instrument}(e, r)]$

(2) *A rock broke the window.*

$\mapsto \exists e [\text{break}(e) \wedge \text{patient}(e, w) \wedge \text{instrument}(e, r)]$

(3) *The window broke.*

$\mapsto \exists e [\text{break}(e) \wedge \text{patient}(e, w)]$

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.

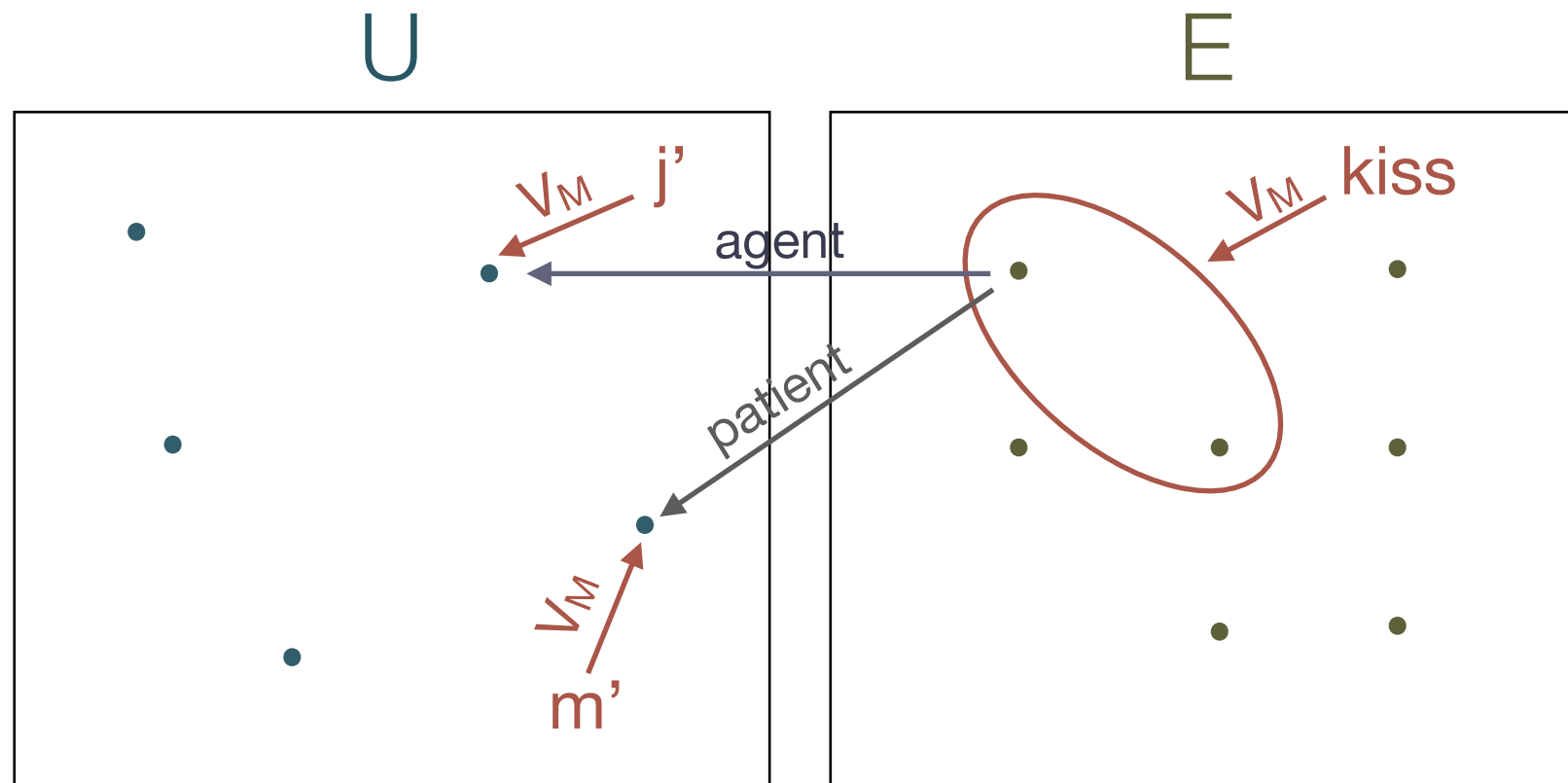
# Interpretation of events with thematic roles

John kisses Mary  $\mapsto \exists e (\text{kiss}(e) \wedge \text{agent}(e, j') \wedge \text{patient}(e, m'))$

$\llbracket \exists e (\text{kiss}(e) \wedge \text{agent}(e, j') \wedge \text{patient}(e, m')) \rrbracket^{M,g} = 1$

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

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



# Thematic roles & verbal differences/similarities

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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
- $\forall e[\text{give}(e) \leftrightarrow \text{receive}(e)] \models (3a) \leftrightarrow (3b)$

# Determining the role inventory

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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

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- 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*<sub>Frame: REPLACING</sub> *[Old its 737s] [New with Airbus A320s]*
- (2) *[Agent Lufthansa] is substituting*<sub>Frame: REPLACING</sub> *[New Airbus A320s] [Old for its 737s]*

# Semantic corpora with thematic roles (cont.)

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

(1) [Arg0 Lufthansa] is replacing [Arg1 its 737s]  
[Arg2 with Airbus A320s]

Pred	replace
Arg0	Lufthansa
Arg1	its737s
Arg2	AirbusA320s

(2) [Arg0 Lufthansa] is substituting  
[Arg1 Airbus A320s] [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) [Agent Lufthansa] is replacing<sub>Frame: REPLACING</sub>  
[Old its 737s] [New with Airbus A320s]

Frame	REPLACING
Agent	Lufthansa
Old	its737s
New	AirbusA320s

(4) [Agent Lufthansa] is substituting<sub>Frame: REPLACING</sub>  
[New Airbus A320s] [Old for its 737s]

# Links

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- 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/>