Computational Models of Events

Lecture 2: Atomic Theories of Events

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Basic Aspectual Properties

- **Durativity**: Does the event last for some time (e.g., *Mike built the house*) or is it instantaneous (e.g., *Mike exploded the balloon*)?
- **Boundedness**: Does the event come to an end (e.g., *Mike built the house/ Mike built the house for two years*) or does it last indefinitely within the relevant time period (*Mike was building the house/ Mike is in Boston*)?
- **Dynamicity**: Does the event involve some kind of change or not? *Stative events* do not involve change, e.g., *know*, *love*, *be tall*, *be sick*. *Dynamic* events, on the other hand, are perceived and described as changing in time: e.g., *John* {*ran/was running*} (John's location in time changes), *John is working*, etc.

Basic Aspectual Properties

- **Telicity**: Does the event reach a natural culmination? Events that involve change may have a built-in endpoint (their *telos*) or not. For instance, the event denoted by *John read* does not have a natural result (i.e., is *atelic*), but that denoted by *John read the book* does (i.e., when the book has been read through) and it is therefore *telic*.
- **Iteration**: Is the event composed of several distinct events (e.g., *The ball bounced along the road* or *Mike visited his parents every Sunday*) or just one single event (e.g., *The baby sneezed once*)?
- **Intensity**: What degree of force does the event have? For instance, if we compare *He burned himself* and *The building burned down*, the latter expresses a higher intensity event: the building was completely destroyed by burning.

Grammatical Aspect

(1) a. PERFECTIVE: Mike built the house.
b. IMPERFECTIVE: Mike was building the house

(2) a. PERFECTIVE: **vybrosit'**^{P} 'throw away'
IMPERFECTIVE: **vybras-yva-t'**^{I} 'be in the process of throwing away repeatedly or habitually'
b. PERFECTIVE: **dat'**^{P} 'give'
IMPERFECTIVE: **da-va-t'** ^{I} 'be giving, give repeatedly or habitually'

Grammatical Aspect

The Spanish past imperfect inflection (the *-aba* ending of 'trabajaba' encodes both the past tense and the imperfective aspect, and the simple past perfect inflection (the *-ó* ending of 'trabajó' in (3b)) amalgamates past tense and perfective aspect.

(3) a. Juan trabaj-a-ba en el campo.
'Juan was working the land.'

b. Juan trabaj-ó en el campo.
'Juan worked the land.'

The Davidson Event Argument

Events are concrete entities, which can be perceived, located in space and time and, moreover, that they are linguistically real. In (4b), for example, both instances of the pronoun *it* refer to the event 'Brutus stabbed Caesar', while the verb *witness* selects this event as one of its complements. In (4a), the PPs 'in the back', 'in the Forum' and 'with a knife' can be seen as modifying this event.

(4) a. **He stabbed Caesar** *in the back*, *in the Forum*, *with a knife*.

b. Brutus did **it** and everyone witnessed **it**.

Composition

(5) a. John feeds Fido.
b. $[_S\ [_{DP}$ John$]\ [_{VP}\ [_V$ feeds $][_{DP}$ Fido $]\ ]\ ]$

(6) a. A boy feeds Fido.
b. $[_S\ [_{DP}$ A $[_{NP}\ [_N$ boy$]]]\ [_{VP}\ [_V$ feeds $]\ [_{DP}$ Fido $]]]$

(7) a. feed(arg_1, arg_2)
b. APPLY feed(arg_1, arg_2) to 'Fido' $\Rightarrow$ feed(arg_1, Fido)
c. APPLY feed(arg_1, Fido) to 'John' $\Rightarrow$ feed(John, Fido)
c'. APPLY feed(arg_1, Fido) to 'a_boy' $\Rightarrow$ feed(a_boy, Fido)

Function Application

(8) FUNCTION APPLICATION:

a. INFORMAL: A predicate β is an unsaturated expression, which, when combined with its argument, α, becomes a saturated expression, $\beta(\alpha)$;

b. FORMAL: If the argument α is of type *a*, and the function β is of type $a \rightarrow b$ (i.e., if β maps expressions of type *a* into expressions of type *b*), then $\beta(\alpha)$ is of type *b*.

Function Application

(9) a. John feeds Fido.
$\text{feed}(j, f)$

b. A boy feeds Fido.
$\exists x[\text{boy}(x) \wedge \text{feed}(x, f)]$

(10) a. PREDICATE-ARGUMENT NOTATION: $\text{feed}(\text{arg}_1, \text{arg}_2)$

b. λ-NOTATION: $\lambda y \lambda x[\text{feed}(x, y)]$

(11) a. Mary sleeps.

b. $\text{sleep}(m)$

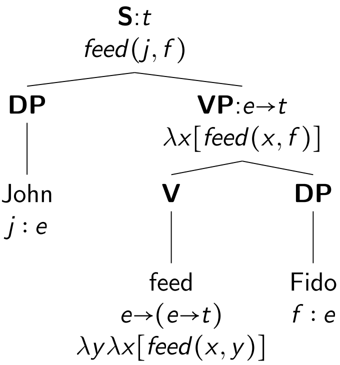
Function Application

(12) a. **Mary**, $m : e$

b. **sleep**, $\lambda x[\text{sleep}(x)] : e \rightarrow t$

c. APPLY $\lambda x[\text{sleep}(x)](m) \Rightarrow \text{sleep}(m) : t$

(13)



Translations

SYNTACTIC TYPE	SEMANTIC TYPE	SEMANTIC EXPRESSION
Proper Name	e	individuals (*Mary*)
Sentence	t	propositions
Intransitive Verb	$e \to t$	$\lambda x[\text{Verb}'(x)]$
Transitive Verb	$e \to (e \to t)$	$\lambda y \lambda x[\text{Verb}'(x, y)]$
Noun	$e \to t$	$\lambda x[\text{Noun}'(x)]$
Adjective	$e \to t$	$\lambda x[\text{Adj}'(x)]$
DP (referential)	e	individuals (*my oldest daughter*, *the sun*)
VP	$e \to t$	$\lambda x[\text{VP}'(x)]$

Table: *Syntactic Categories and their Semantic Types (Part A)*

Quantifiers

(14) a. A woman sleeps.

b. $\exists x[\text{woman}(x) \wedge \text{sleep}(x)]$

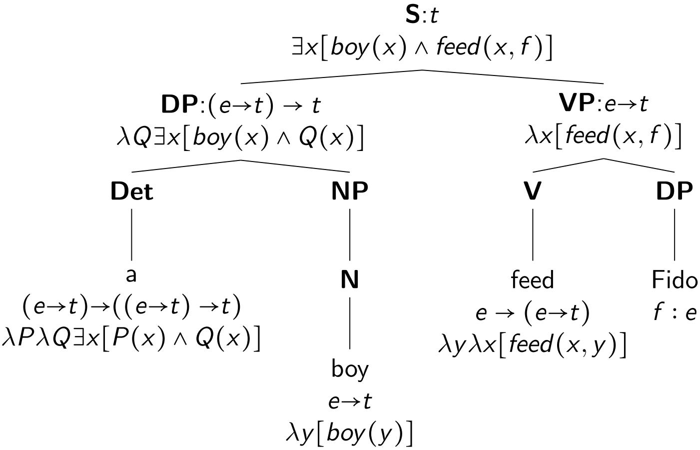
(15)

$$[[A \overbrace{woman}^{e \to t}]_{DP} [\ \overbrace{sleeps}^{e \to t}]_{VP}]_S$$

(16) a. $[\![\text{a}]\!] = \lambda P \lambda Q \exists x[P(x) \wedge Q(x)]$

b. $[\![\text{every}]\!] = \lambda P \lambda Q \forall x[P(x) \to Q(x)]$

(17)


S:t
$\exists x[boy(x) \wedge feed(x, f)]$
DP:$(e \to t) \to t$
$\lambda Q \exists x[boy(x) \wedge Q(x)]$
VP:$e \to t$
$\lambda x[feed(x, f)]$
Det
NP
V
DP
a
$(e \to t) \to ((e \to t) \to t)$
$\lambda P \lambda Q \exists x[P(x) \wedge Q(x)]$
N
feed
$e \to (e \to t)$
$\lambda y \lambda x[feed(x, y)]$
Fido
$f : e$
boy
$e \to t$
$\lambda y[boy(y)]$

Event Argument

Table 1.1: Approaches to verbal denotations

truerule Position	Verbal denotation	Example: Brutus stabbed Caesar
Traditional	$\lambda y \lambda x[\mathbf{stab}(x,y)]$	$\mathbf{stab}(b,c)$
Classical Davidsonian	$\lambda y \lambda x \lambda e[\mathbf{stab}(e,x,y)]$	$\exists e[\mathbf{stab}(e,b,c)]$
Neo-Davidsonian	$\lambda e[\mathbf{stab}(e)]$	$\exists e[\mathbf{stab}(e) \wedge \mathbf{ag}(e,b) \wedge \mathbf{th}(e,c)]$
Landman (1996)	$\lambda y \lambda x \lambda e[\mathbf{stab}(e) \wedge \mathbf{ag}(e,x) \wedge \mathbf{th}(e,y)]$	$\exists e[\mathbf{stab}(e,b,c)]$
Kratzer (2000)	$\lambda y \lambda e[\mathbf{stab}(e,y)]$	$\exists e[\mathbf{ag}(e,b) \wedge \mathbf{stab}(e,c)]$

Event Argument

- Verbs have an implicit event argument

(1) $[\![\text{stab}]\!] = \lambda y \lambda x \lambda e[\mathbf{stab}(e, x, y)]$

- Verbal modifiers apply to the same event variable

(2) a. $[\![\text{at noon}]\!] = \lambda e[\mathbf{time}(e, \mathbf{noon})]$
b. $[\![\text{in the forum}]\!] = \lambda e[\mathbf{loc}(e, \iota x.\mathbf{forum}(x))]$

- The event argument is bound by existential closure

(3) $[\![\text{Brutus stabbed Caesar}]\!] = \exists e[\mathbf{stab}(e, \mathbf{brutus}, \mathbf{caesar})]$

- (Arguments and) modifiers are additional conjuncts

(4) $[\![\text{Brutus stabbed Caesar at noon}]\!] = \exists e[\mathbf{stab}(e, \mathbf{brutus}, \mathbf{caesar}) \wedge \mathbf{time}(e, \mathbf{noon})]$

Davidson (1967)

Notice that adverbial and prepositional modifiers add complementary information to this core event.

(18) a. Brutus stabbed Caesar in the Forum with a knife.
b. $\exists e \exists x[\text{stab}(\textit{Brutus}, \textit{Caesar}, e) \wedge \text{in}(e, \textit{Forum}) \wedge \text{knife}(x) \wedge \text{with}(e, x)]$

(19) $\exists e \exists x[\text{stab}(e) \wedge \textsc{ag}(e, \textit{Brutus}) \wedge \textsc{pat}(e, \textit{Caesar}) \wedge \textsc{loc}(e, \textit{Forum}) \wedge \text{knife}(x) \wedge \textsc{inst}(e, x)]$

Parsons (1990)

Parsons develops an interpretation of events that introduces a distinction between an event *culminating* (*Cul*) versus an event *holding* (*Hold*). This makes it possible to distinguish the telicity associated with a sentence. Hence, for an event, e, and a temporal interval, t, the following relations hold:

(20) a. TELIC EVENTS (achievements, accomplishments): $Cul(e, t)$
b. ATELIC EVENTS (processes, states): $Hold(e, t)$

Returning to the sentence in (18a), we now modify the logical form in (19) to that below in (21).

(21) $\exists e \exists t \exists x[\text{stab}(e) \wedge \textsc{ag}(e, Brutus) \wedge \textsc{pat}(e, Caesar) \wedge \textsc{loc}(e, Forum) \wedge \text{knife}(x) \wedge \textsc{inst}(e, x) \wedge Cul(e, t)]$

Function Application

With event argument: $\mathcal{E}$ stands for type $v \to t$.

(22) a. **Mary**, $m : e$

b. **sleep**, $\lambda x \lambda e[\text{sleep}(e, x)] : e \to (v \to t)$

c. APPLY $\lambda x \lambda e[\text{sleep}(e, x)](m) \Rightarrow \lambda e[\text{sleep}](e, m) : \mathcal{E}$

Events and Thematic Roles

(5) a. $[\![[\text{agent}]]\!] = \lambda x \lambda e[\mathbf{ag}(e) = x]$
b. $[\![[\text{theme}]]\!] = \lambda x \lambda e[\mathbf{th}(e) = x]$
c. $[\![\text{stab}]\!] = \lambda e[\mathbf{stab}(e)]$

Applying the thematic roles gives:

d. $[\![[\text{ag}]\ \text{Brutus}]\!] = \lambda e[\mathbf{ag}(e) = \mathbf{brutus}]$
e. $[\![[\text{th}]\ \text{Caesar}]\!] = \lambda e[\mathbf{ag}(e) = \mathbf{caesar}]$
f. $[\![\text{Brutus stab Caesar}]\!] = (5c) \cap (5d) \cap (5e)$ (sentence radical)
g. $[\![\text{Brutus stabbed Caesar}]\!] = \exists e.e \in (5c) \cap (5d) \cap (5e)$ (full sentence)

- The event quantifier always takes the lowest scope relative to other quantifiers.

(1) No dog barks.

(2) a. $\neg\exists x[\mathbf{dog}(x) \wedge \exists e[\mathbf{bark}(e) \wedge \mathbf{ag}(e,x)]]$ — No $>>$ $\exists e$
"There is no barking event that is done by a dog"

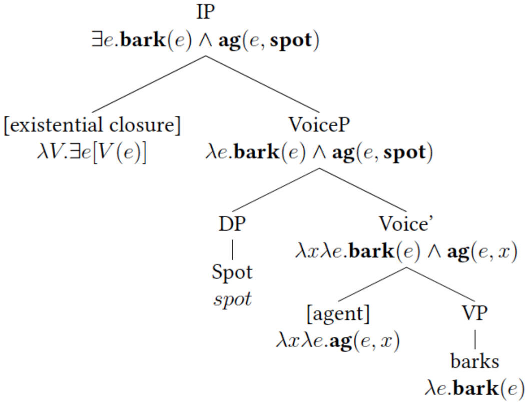
b. $^*\exists e[\neg\exists x[\mathbf{dog}(x) \wedge \mathbf{bark}(e) \wedge \mathbf{ag}(e,x)]]$ — $^*\exists e$ $>>$ No
"There is an event that is not a barking by a dog"

(4) Every dog barks.

(5) a. $\forall x[\mathbf{dog}(x) \rightarrow \exists e[\mathbf{bark}(e) \wedge \mathbf{ag}(e) = x]]$ — Every $>>$ $\exists e$
"For every dog there is a barking event that it did"

b. $^*\exists e \forall x[\mathbf{dog}(x) \rightarrow [\mathbf{bark}(e) \wedge \mathbf{ag}(e) = x]]$ — $^*\exists e$ $>>$ Every
"There is a barking event that was done by every dog"

- Spot barks.


IP
∃e.bark(e) ∧ ag(e, spot)
[existential closure]
λV.∃e[V(e)]
VoiceP
λe.bark(e) ∧ ag(e, spot)
DP
Spot
spot
Voice'
λxλe.bark(e) ∧ ag(e, x)
[agent]
λxλe.ag(e, x)
VP
barks
λe.bark(e)

Kratzer

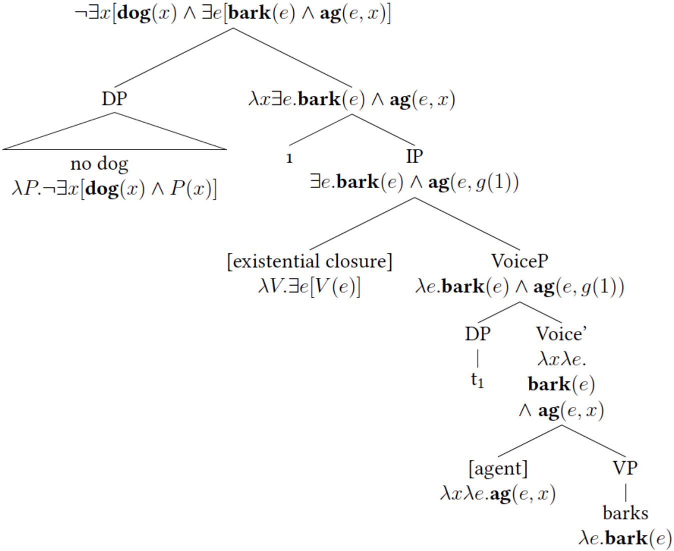
Kratzer (1996) invents an "event identification" rule that combines the Voice head (*agent*) with the VP.

(6) f: $\langle e, vt\rangle$ g: $\langle vt\rangle$ $\Rightarrow$ h : $\langle e, vt\rangle$

$\lambda x \lambda e.\mathbf{ag}(e, x)$ $\lambda e.\mathbf{bark}(e)$ $\lambda x \lambda e.\mathbf{ag}(e, x) \wedge \mathbf{bark}(e)$

(Kratzer's event identification rule)

Negation



$\neg\exists x[\mathbf{dog}(x) \wedge \exists e[\mathbf{bark}(e) \wedge \mathbf{ag}(e,x)]$
DP
no dog
$\lambda P.\neg\exists x[\mathbf{dog}(x) \wedge P(x)]$
$\lambda x\exists e.\mathbf{bark}(e) \wedge \mathbf{ag}(e,x)$
1
IP
$\exists e.\mathbf{bark}(e) \wedge \mathbf{ag}(e,g(1))$
[existential closure]
$\lambda V.\exists e[V(e)]$
VoiceP
$\lambda e.\mathbf{bark}(e) \wedge \mathbf{ag}(e,g(1))$
DP
t_1
Voice'
$\lambda x\lambda e.$
$\mathbf{bark}(e)$
$\wedge\ \mathbf{ag}(e,x)$
[agent]
$\lambda x\lambda e.\mathbf{ag}(e,x)$
VP
barks
$\lambda e.\mathbf{bark}(e)$

Champollion (2015)

(8) a. Old Neo-Davidsonian approach: $[\![\text{kiss}]\!] = \lambda e.\mathbf{kiss}(e)$

b. This approach: $[\![\text{kiss}]\!] = \lambda f_{\langle vt \rangle}.\exists e.\mathbf{kiss}(e) \wedge f(e)$
(derivable from (8a) by Partee (1987)'s type-shifting principle A; other inspirations: existential closure, bare plurals, continuation semantics)

- Start with a verb and successively apply its arguments and adjuncts to it, as in event semantics. But the verb is now of type $\langle vt, t \rangle$ (where v is the type of events)
- Compared to syntactic approaches, putting existential closure into the lexical entry of the verb will automatically derive the fact that all other quantifiers always have to take scope above existential closure.
- Every argument/adjunct is a function from $\langle vt, t \rangle$ to $\langle vt, t \rangle$.

(9) $[\![\text{kiss Mary}]\!] = \lambda f.\exists e.\mathbf{kiss}(e) \wedge f(e) \wedge \mathbf{th}(e) = \mathbf{mary}$

Champollion (2015)

- On the old approach, a verb phrase had to apply to an event, but there was no single event to which a verb phrase like "kiss every girl" could apply. Now, "kiss every girl" applies to any set of events that contains a potentially different kissing event for every girl. Noun phrases can retain their usual analysis as quantifiers over individuals.

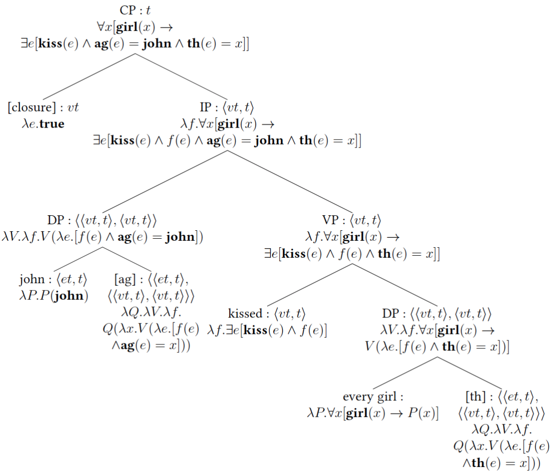
(10) $[\![\text{kiss every girl}]\!] = \lambda f.\forall x.\mathbf{girl}(x) \rightarrow \exists e.\mathbf{kiss}(e) \wedge f(e) \wedge \mathbf{th}(e) = x$

- Noun phrases can retain their usual analysis as quantifiers over individuals. I assume that proper names are Montague-lifted to that type.

(11) a. $[\![\text{every girl}]\!] = \lambda P.\forall x.\mathbf{girl}(x) \rightarrow P(x)$
b. $[\![\text{John}]\!] = \lambda P.P(\mathbf{john})$

Champollion (2015)

- John kissed every girl.



Negation and Adverbials

- Like other verbal modifiers, we can give negation the semantic type $\langle\langle vt, t\rangle, \langle vt, t\rangle\rangle$.
- Negation has been considered particularly difficult for event semantics because it leads to apparent scope paradoxes (Krifka 1989).

For-adverbials can take scope both above negation and below it (Smith 1975):

- John did not laugh for two hours.
  - For two hours, it was not the case that John laughed.
  - It was not the case that John laughed for two hours.

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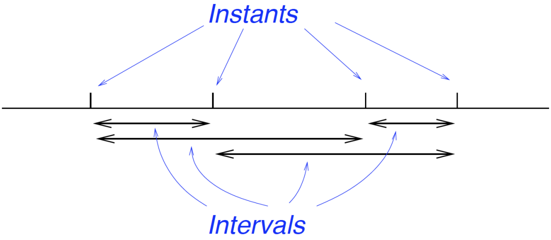
Events as Instants or Intervals

- Instants are durationless. They represent the meeting-points of contiguous intervals. E.g., “2.45 p.m. exactly”.
- Intervals have duration. An interval is bounded by instants at the beginning and end. Instants may be
  - “Standard”: 1812, June 1812, 24th June 1812.
  - “Arbitrary”: from 4 p.m. to 5.30 p.m. on 24th June 1812.
  - Defined by events: The reign of Louis XIV.



Events as Instants or Intervals

Which is more fundamental, the instant or the interval?

If instants are fundamental, then an interval can be specified by means of its beginning and end points:

$$i = \langle t_1, t_2 \rangle \quad \text{(where } t_1 \prec t_2\text{)}$$

where $x \prec y$ is read 'x precedes y'.

You might (but don't have to) then identify the interval with the *set* of instants falling between the two ends:

$$i = \{t \mid t_1 \prec t \prec t_2\}$$

where $x \prec y \prec z$ is short for $(x \prec y) \wedge (y \prec z)$.

Events as Instants or Intervals

If intervals are fundamental, then an instant can be specified by means of a pair of intervals:

$$\langle i_1, i_2 \rangle \quad (\text{where } i_1 \mid i_2)$$

($x \mid y$ is read 'x meets y').

Then we define equality for instants by

$$\langle i_1, i_2 \rangle = \langle j_1, j_2 \rangle =_{\text{def}} i_1 \mid j_2 \wedge j_1 \mid i_2.$$

In effect, we are defining an instant as an equivalence class of interval-interval pairs.

Events as Instants or Intervals

Primitive relation: $t \prec t'$
Interpretation: Instant t precedes (i.e., is earlier than) instant t'.

A **predecessor** of instant t is any instant t' such that $t' \prec t$.
A **successor** of instant t is any instant t' such that $t \prec t'$.

The formal properties of the ordering of the instants are expressed by means of *axioms* written as first-order formulae.

In any application context, the axioms should be chosen to capture the properties of the temporal ordering that are required for reasoning within that context. In principle, different applications may require different models of time (there is not "one true model" for time — probably).

Note: We use the convention that unless otherwise indicated, all individual variables are understood as universally quantified.

- **Irreflexive**:

TI $$\neg(t \prec t)$$

- **Transitive**:

TT $$(t \prec t') \wedge (t' \prec t'') \rightarrow t \prec t''$$

From TI and TT we can infer [Exercise!]

- **Asymmetric**:

TA $$t \prec t' \rightarrow \neg(t' \prec t)$$