

# Computational Semantics: Events

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# NL to FOL: Summary I

Syn Cat	NL example	FOL Cat	example
<b>proper noun</b>	Jane, Google, Mr. Smith	<b>constant</b>	<i>JANE</i> , <i>GOOG</i> , <i>SMITH432</i>

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<b>disjunction</b>	or, either...or	<b>logical disjunction</b>	$\vee$

# Today's lecture

## 1 NL to FOL: Loose ends

- Misc syn. categories
- VPs, Verbs
- Problems with verbs

## 2 Event semantics

- Semantic roles
- FrameNet

### NL to FOL: Loose ends

Misc syn. categories  
VPs, Verbs  
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### Event semantics

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## Universals

- *Every banker is a thief.*
- *Every politician is dishonest.*
- *All dogs are loyal.*

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*Everything is a dog and everything is loyal.*

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# Quantifier patterns

## Existentials

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**paraphrase:** there is something that satisfies the formula  $P(x) \rightarrow Q(x)$

$$\exists x (\neg P(x) \vee Q(x))$$

*Something is not a dog or something is a fish.* (Can be trivially True!)

## Does the universal imply existence?

All cats sleep a lot.

$\forall x (cat(x) \rightarrow sleep(x))$

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Negative markers are mapped to formulas with the negation symbol.

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What's wrong with this formula?

$\text{female}(x) \wedge \text{teacher}(x) \wedge \text{single}(x) = \text{oldmaid}(x) ???$

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Identity only holds between terms (variables and constants), not formulas.

# Mapping NL to FOL: Biconditional implication

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To represent definitional statements, such as:  
A female, unmarried teacher is an old maid.  
Use the **biconditional**,  $\leftrightarrow$ :

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$$\forall x \forall y(\text{person}(x) \wedge \text{race}(x, y) \wedge \text{horse}(y) \leftrightarrow \text{jockey}(x))$$

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- **That collection agency** called.  
(a specific individual of type collection agency)
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Similar examples:

- my father
- the woman's right hand
- Waldo's image

# Definite descriptions

## Definition

A **definite description** is any NP that picks out a single individual by means of a unique description. Definite descriptions are distinct from proper names.

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A **definite description** is any NP that picks out a single individual by means of a unique description. Definite descriptions are distinct from proper names.

To incorporate definite descriptions into FOL, for example, in *the car is red*, we can add a special uniqueness quantifier:

$$\exists!x (car(x) \wedge red(x))$$

Paraphrase: There is one and only one  $x$  such that  $x$  is a car and  $x$  is red.

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The formula makes three claims:

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The formula makes three claims:

- 1 There is a car. (an existence claim)
- 2 At most one thing is a car. (a uniqueness claim)
- 3 This car is red. (a claim of predication)

# Mapping NL to FOL: prepositions

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What do (most) prepositions refer to?

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# Mapping NL to FOL: prepositions

What do (most) prepositions refer to? ... some relation

Spatial prepositions, for instance, can be easily mapped onto binary predicates:

Joe is in Seattle, *in*(*JOE*, *SEATTLE*)

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# Mapping NL to FOL: prepositions

What do (most) prepositions refer to? ... some relation

Spatial prepositions, for instance, can be easily mapped onto binary predicates:

Joe is in Seattle,  $in(JOE, SEATTLE)$

We could then utilize some **spatial calculus** to reason about the locations of various objects:

$\forall x \forall y (in(x, y) \rightarrow near(x, y)),$

$\forall x \forall y (on(x, y) \leftrightarrow contact(x, y) \dots)$

## Definition

A **calculus** is a theory of some domain usually expressed in a formal logic (e.g., FOL). Some commonly used calculi in used to study NL semantics:

- spatial calculus: a theory of spatial objects/relations.
- temporal calculus: a theory of time points and durations. (cf. NL tense)
- agency calculus: a theory of agents and causation. (cf. NL voice)
- event calculus: a theory of events and participants. (cf. NL aspect)

Such calculi are part of the ontology of the underlying domain.

## NL to FOL: Summary II

Syn Cat	NL example	FOL Cat	example
<b>negation</b>	not, no, dis-, un-	<b>logical negation</b>	$\neg$ fish(x)
<b>various</b>	is, is the same as, equals	<b>identity</b>	<i>JOHN</i> = <i>SMITH</i>
<b>various</b>	is, is defined as, equals	<b>logical biconditional</b>	$\leftrightarrow$
<b>prepositions</b>	in, near, beside	<b>binary predicates</b>	<i>in</i> (x, y), <i>near</i> (a, b), <i>beside</i> (m, n)
<b>definites</b>	the house, my dog	<b>constant</b>	<i>HOUSE2</i> , <i>DOG13</i> or

$\exists x(\textit{house}(x) \wedge \neg \exists y(\textit{house}(y) \wedge x \neq y))$

# Mapping NL to FOL: Verbs

In most logic textbooks and some NL semantics works, the main verb is mapped to an  $n$ -ary predicate in FOL. Verb **valence** is transferred to the level of semantic representation.

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*swim*( $x$ )

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- Transitives can be represented as binary predicates.

*steal*( $x, y$ )

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*swim*( $x$ )
- Transitives can be represented as binary predicates.  
*steal*( $x, y$ )
- Ditransitives can be represented as ternary predicates.  
*give*( $x, y, z$ )

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But there are a few problems.

# Problem I: valence and arity

Consider this sentence:  
Sue bought the Honda.

*buy(SUE, HONDA321)*

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Consider this sentence:  
Sue bought the Honda.

*buy(SUE, HONDA321)*

Sue bought the Honda in Oregon.

*buy(SUE, HONDA321, OREGON)*

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## Problem I: valence and arity

Consider this sentence:  
Sue bought the Honda.

*buy(SUE, HONDA321)*

Sue bought the Honda in Oregon.

*buy(SUE, HONDA321, OREGON)*

Sue bought the car in Oregon for Sam.

*buy(SUE, HONDA321, OREGON, SAM)*

# Problem I: valence and arity

Sue bought the Honda in Oregon for Sam with a loan...

For a given verb, we would need a way to arbitrarily increase the predicate **arity** at the level of semantic representation. So, how to capture the common meaning among  $buy(x, y)$ ,  $buy(x, y, z)$ , etc.?

## Davidon's famous example

This was used in the original argument against allowing arbitrary arity of predicates:

- John buttered the toast.  
*Butter*(*JOHN*, *TOAST*)
- John buttered the toast at midnight.  
*Butter*(*JOHN*, *TOAST*, *MIDNIGHT*)
- John buttered the toast at midnight with a knife.  
*Butter*(*JOHN*, *TOAST*, *MIDNIGHT*, *KNIFE*)
- John buttered the toast at midnight with a knife before he went to bed.  
*Butter*(*JOHN*, *TOAST*, *MIDNIGHT*, *KNIFE*, ...)

# Problem 2: Tense

What do the tenses mean?

NL to FOL: Loose  
ends

Misc syn. categories

VPs, Verbs

Problems with verbs

Event semantics

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FrameNet

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### What do the tenses mean?

- Sue bought a car.
- Sue is buying a car. (present progressive)
- Sue will buy a car.
  
- The act of buying occurred before the time of speech.
- The act of buying is occurring at the time of speech.
- The act of buying will occur after the time of speech.

## Problem 2: Tense

Any reasonable account of the semantics of a tense system requires explicit reference to **temporal relations**: before, after, during, etc. The states and processes referred to by verbs are the arguments of such relations.

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$$before(buy(SUE, CAR1), T_1)$$

The above formula is incompatible with our logical machinery! A sentence cannot be the argument of a predicate.

# First- versus second-order logic

## Definition

A **second-order logic** is one in which predicates can be arguments of other predicates. A second-order logic allows quantification over subsets and relations, that is, over all predicates:

$$\forall buy \forall x (x \in buy \vee x \notin buy)$$

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By using a first-order logic, performance issues are already a problem. For example, FOL is **undecidable** which means that it is not possible to write a theorem prover which, when given an arbitrary formula as input, is guaranteed to halt in finitely many steps and correctly classify the input as consistent or not. For a second-order system, the problem is even worse.

# Today's lecture

## 1 NL to FOL: Loose ends

- Misc syn. categories
- VPs, Verbs
- Problems with verbs

## 2 Event semantics

- Semantic roles
- FrameNet

# Event semantics

One way to get around the need for second-order logic is to reify as **events** those entities referred to by verbs, and model those events as unary predicates:

*BuyingEvent(x)*, *VotingEvent(y)*, *BowlingEvent(z)*

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*BuyingEvent(x), VotingEvent(y), BowlingEvent(z)*

## Definition

**Event semantics** is an approach to modeling states and processes where the event is referred to directly such that individual events can be referred to in the universe of discourse. The study of the structure of events in linguistics was initiated by philosophers, cf. the work of Donald Davidson (d. 2003).

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# Event semantics

Furthermore, quantifiers can have scope over event variables, as in:

- $\forall e \text{ BuyingEvent}(e)$
- $\exists x \text{ SellingEvent}(x)$

But how are the NL subjects and objects (constants) then related to the event?

# Semantic roles

## Definition

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- **location, source, goal, path**: spatial individuals in relation to  $e$

## Mapping NL to FOL: VPs

- John buttered the toast.

$\text{ButteringEvent}(E_1) \wedge \text{agent}(E_1, \text{JOHN}) \wedge$   
 $\text{patient}(E_1, \text{TOAST1})$

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- John buttered the toast at midnight.  
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- John buttered the toast at midnight with a knife.  
 $\text{ButteringEvent}(E_3) \wedge \text{agent}(E_3, \text{JOHN}) \wedge \text{patient}(E_3, \text{TOAST1}) \wedge \text{time}(E_3, \text{MIDNIGHT}) \wedge \text{instrument}(E_3, k) \wedge \text{knife}(k)$

# Semantic role axioms

## axiom

All events take place in space:

$\forall e \exists x (Event(e) \rightarrow location(e, x))$

NL to FOL: Loose  
ends

Misc syn. categories  
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## axiom

If some individual is an agent of a cognition event (think, know, consider), then the individual is human.

$$\forall e \forall a (CognitionEvent(e) \wedge agent(e, a) \rightarrow human(a))$$

# Other examples: Process

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$$\exists p \text{ GivingEvent}(E_3) \wedge \text{Post}(p) \wedge \text{agent}(E_3, \text{OBAMA}) \\ \wedge \text{beneficiary}(E_3, \text{CLINTON}) \wedge \text{theme}(E_3, p)$$

# Other examples

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*If you work at a bank, then you're a banker.*

$$\forall e \forall b \forall x. [[\text{WorkingEvent}(e) \wedge \text{agent}(e, x) \wedge \text{loc}(e, b) \wedge \text{bank}(b)] \rightarrow \text{banker}(x)]$$

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### GOAL

*Bonnie is a banker.*

$$\text{banker}(\text{BONNIE})$$

# Other examples: States

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The market is weak.

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The market is weak.

$$\text{AttributeState}(E_4) \wedge \text{theme}(E_4, \text{MKT})$$

A **frame**, or a situation type, consists of a set of individuals and roles that the individuals play in a particular event type.

FrameNet is primarily set up to be a resource for shallow processing, in as much as deep processing involves the derivation of full semantic representation.

NL to FOL: Loose  
ends

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- With this, (El Cid<sub>Agent</sub>) at once avenged (the death of his son<sub>Injury</sub>).
- (Hook<sub>Avenger</sub>) tries to avenge (himself<sub>Injured\_party</sub>) (on Peter Pan<sub>Offender</sub>) (by becoming a second and better father<sub>Punishment</sub>).

There are **core roles** that are explicitly or implicitly present in any instance of a particular frame type. For the *avenge* frame, we can assume: an injured party, an avenger, an offender, etc.

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There are also peripheral roles that need not be present, not even implicitly:

- The bereaved family retaliated [immediately **Time**]
- Lee called the office [again **Iteration**].
- Abby went to Philadelphia [to study law **Purpose**].

“The distinction between core and peripheral frame elements on the one hand and extra-thematic frame elements on the other may be stated more appropriately as follows: events and participants that are included in the part of the causal chain that the target predicate designates are core or peripheral; and all other participants and events expressed are extra-thematic. ”