From NL to FOL

Scott Farrar
CLMA, University of Washington
farrar@u.washington.edu

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Today's lecture

1. Review
2. From NL to Logic
3. Semantics and the NLTK

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

ForAllX

What is/are:

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review

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Semantics and the NLTK

ForAllX

What is/are:

- the **three main problems** associated with computational semantics?

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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What is/are:

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Scott Farrar
CLMA, University of Washington far-rar@u.washington.ed

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ForAllX

What is/are:

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- some logics we've talked about ?

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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What is/are:

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- a **logical sentence**?

Scott Farrar
CLMA, University of Washington far-rar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

ForAllX

What is/are:

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- a **logical sentence**?
- the **logical connectives** of sentential logical?

Scott Farrar
CLMA, University of Washington far-rar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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- a logical **argument**?

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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Semantics and the NLTK

ForAllX

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- some logics we've talked about ?
- a **logical sentence**?
- the **logical connectives** of sentential logical?
- a logical **argument**?
- a **tautology**?

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

What is meaning, really?

An example:

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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Semantics and the NLTK

What is meaning, really?

An example:

1. English: *Horatio bakes me a cake* **or** *Horatio bakes you a cake.*

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

What is meaning, really?

An example:

1. English: *Horatio bakes me a cake* **or** *Horatio bakes you a cake.*
2. Sentential Logic: $P \vee Q$ (just a symbolic translation)

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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Intuitive approach to meaning

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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Intuitive approach to meaning

- Intuitively we say that (1)'s meaning depends on whether Horatio bakes a cake, and whether it's for you or me.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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- Intuitively we say that (1)'s meaning depends on whether Horatio bakes a cake, and whether it's for you or me.
- That is, depending on the state of the world.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

What is meaning, really?

An example:

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Intuitive approach to meaning

- Intuitively we say that (1)'s meaning depends on whether Horatio bakes a cake, and whether it's for you or me.
- That is, depending on the state of the world.
- Not very satisfying!

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Slightly more formal account

What about assigning a value to meaning?

Something like the meaning of *Horatio bakes me a cake.* is:

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic

Semantics and the NLTK

Slightly more formal account

What about assigning a value to meaning?

Something like the meaning of *Horatio bakes me a cake.* is:

- **True**

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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Semantics and the NLTK

Slightly more formal account

What about assigning a value to meaning?

Something like the meaning of *Horatio bakes me a cake.* is:

- **True**
- 0.43

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Slightly more formal account

What about assigning a value to meaning?

Something like the meaning of *Horatio bakes me a cake.* is:

- **True**
- 0.43

Truth values

In fact, we can say that the atomic sentences of our logic P, Q, ..., X can either be **True** or **False** depending on the state of the world. This is called a **truth functional logic**.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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Something like the meaning of *Horatio bakes me a cake.* is:

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Complex sentences

What about $P \vee Q$? When is it **True** or **False**?

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Truth table for 'inclusive or', $\vee$

P	Q	$P \vee Q$
T	T	T
T	F	T
F	T	T
F	F	F

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review

From NL to Logic

Semantics and the NLTK

Truth table for 'exclusive or', $\oplus$

P	Q	$P \oplus Q$
T	T	F
T	F	T
F	T	T
F	F	F

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CLMA, University of Washington farrar@u.washington.ed

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Semantics and the NLTK

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CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Methodology

Semantic analysis is the mapping of NL utterances onto some logic. In traditional logic classes, the mapping is usually done from logic to NL:

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

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Semantic analysis is the mapping of NL utterances onto some logic. In traditional logic classes, the mapping is usually done from logic to NL:

Example

$\exists x\ (dog(x) \wedge disappear(x))$
At least one entity is a dog and disappeared.
Some dog disappeared.
A dog disappeared.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Methodology

Semantic analysis is the mapping of NL utterances onto some logic. In traditional logic classes, the mapping is usually done from logic to NL:

Example

$\exists x\ (dog(x) \wedge disappear(x))$
At least one entity is a dog and disappeared.
Some dog disappeared.
A dog disappeared.

Our methodology: start with structures in NL and find appropriate logical formulas. This makes the logic work for NL, not the other way around.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Nouns

What do **nouns** usually denote?

Scott Farrar
CLMA, University of Washington far-rar@u.washington.ed

Review

From NL to Logic

Semantics and the NLTK

Mapping NL to FOL: Nouns

What do **nouns** usually denote?

- **physical objects**, ones that exist in time and space
- fish, dogs, hat, leg

Scott Farrar
CLMA, University of Washington far-rar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Nouns

What do **nouns** usually denote?

- **physical objects**, ones that exist in time and space
- **abstract objects**, ones that may persist in time, but not space

- fish, dogs, hat, leg
- value, politics, mathematics, scorn

Scott Farrar
CLMA, University of Washington far-rar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Nouns

What do **nouns** usually denote?

- **physical objects**, ones that exist in time and space
- **abstract objects**, ones that may persist in time, but not space
- **events**, ones that exist in time and space, but not as long as objects

- fish, dogs, hat, leg
- value, politics, mathematics, scorn
- destruction, creation, movement

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Nouns

Unary predicates, those with a single argument, are often used to represent the semantics of nouns.

$fish(FLIPPER)$, $dog(FRITZ)$, $hat(HAT234)$
$value(V1)$, $politics(P1)$, $scorn(S1)$
$destroyingEvent(D1)$, $movementEvent(M1)$

In fact the unary predicate is naming the **type** of whatever the argument may be. There can be many, many types wrt the semantics of natural language.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

NL semantics and ontology

Definition

Our FOL approach requires a rich **ontology**, or a theory of existence and how the elements of the world relate.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

NL semantics and ontology

Definition

Our FOL approach requires a rich **ontology**, or a theory of existence and how the elements of the world relate.

Modeling NL meaning is an exercise in 'natural language' metaphysics.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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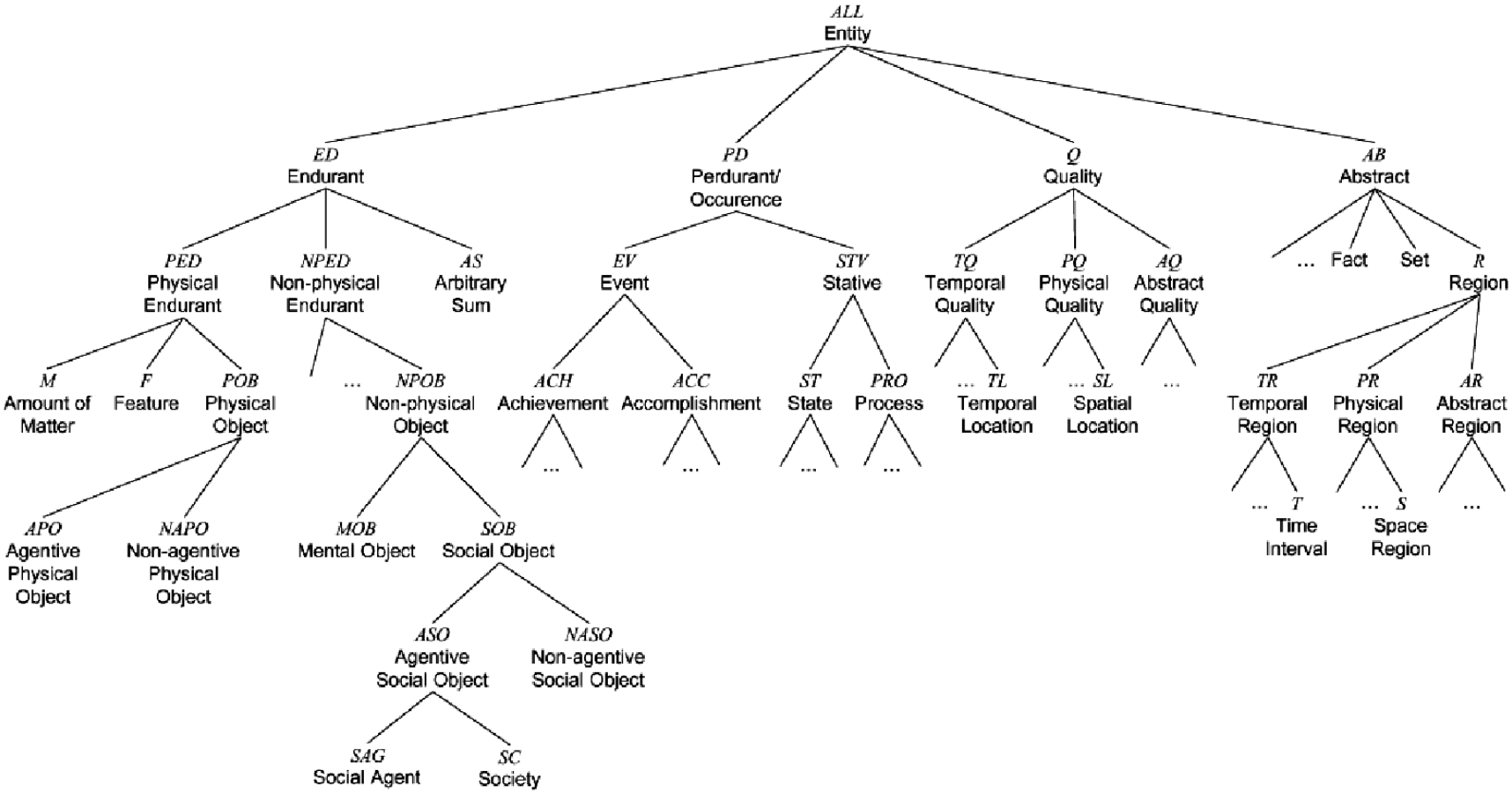
From NL to Logic
Semantics and the NLTK

DOLCE upper categories



Mapping NL to FOL: PNs

Constants are used to represent the semantics of proper nouns.

- Queen Elizabeth II, *ELIZII*
- Barack Obama, *BARACK*
- John, *JOHN*432

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: NPs

A modified NP is an NP of the form: $NP \rightarrow X\ NN$, where X can be one of a number of syntactic categories: determiner, quantity, adjective, etc.

- a dog, some dog
- all cats
- 3 fish
- several elephants
- a bunch of rats

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Quantificational modifiers

Quantificational modifiers of the type **a** or **some** are modeled using the existential quantifier, $\exists$.

- a dog, $\exists x\ dog(x)$
- some person, $\exists x\ person(x)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Quantificational modifiers

And the quantificational modifier of the type **all**, **every**, etc. can be modeled using the universal $\forall$:

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Quantificational modifiers

And the quantificational modifier of the type **all**, **every**, etc. can be modeled using the universal $\forall$:

- all fish, $\forall f \ \mathit{fish}(f)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Quantificational modifiers

And the quantificational modifier of the type **all**, **every**, etc. can be modeled using the universal $\forall$:

- all fish, $\forall f \ \mathit{fish}(f)$
- every man, $\forall m \ \mathit{man}(m)$

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CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

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And the quantificational modifier of the type **all**, **every**, etc. can be modeled using the universal $\forall$:

- all fish, $\forall f \ \mathit{fish}(f)$
- every man, $\forall m \ \mathit{man}(m)$
- each and every member, $\forall m \ \mathit{member}(m)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Quantificational modifiers

In reality quantification in languages is often difficult to describe given the standard logical machinery of FOL: $\exists$ and $\forall$.

Scott Farrar
CLMA, University of Washington far-rar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Quantificational modifiers

In reality quantification in languages is often difficult to describe given the standard logical machinery of FOL: $\exists$ and $\forall$.

Semanticists are often forced to come up with new logical quantifiers to discuss natural language quantification.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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Semantics and the NLTK

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Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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- Just **a few** biscuits please, with **a lot** of gravy!

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Quantificational modifiers

In reality quantification in languages is often difficult to describe given the standard logical machinery of FOL: $\exists$ and $\forall$.

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- Just **a few** biscuits please, with **a lot** of gravy!
- He'll take **several** doses to be cured.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Quantificational modifiers

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- He'll take **several** doses to be cured.
- A **couple** of slices.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

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In reality quantification in languages is often difficult to describe given the standard logical machinery of FOL: $\exists$ and $\forall$.

Semanticists are often forced to come up with new logical quantifiers to discuss natural language quantification.

- Just **a few** biscuits please, with **a lot** of gravy!
- He'll take **several** doses to be cured.
- A **couple** of slices.
- Simply **scads** of weapons of mass destruction.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Adjectives

Just as with nouns, adjectives say something about the type of entity being referred to; accordingly, they can be modeled as unary predicates at the semantic level.

Scott Farrar
CLMA, University of Washington far-rar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

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Just as with nouns, adjectives say something about the type of entity being referred to; accordingly, they can be modeled as unary predicates at the semantic level.

- broken leg, $broken(x) \wedge leg(x)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

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- broken leg, $broken(x) \wedge leg(x)$
- red rooster, $red(y) \wedge rooster(y)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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- red rooster, $red(y) \wedge rooster(y)$
- jagged white pill, $jagged(z) \wedge white(z) \wedge pill(z)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

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- broken leg, $broken(x) \wedge leg(x)$
- red rooster, $red(y) \wedge rooster(y)$
- jagged white pill, $jagged(z) \wedge white(z) \wedge pill(z)$

Some adjectives are more problematic and require more elaborate semantic machinery: *small solar system*, *large mouse*, *grande latte*

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Conjunctions

Conjunctions such as **and**, **as well as**, **or**, **either...or...** are mapped to logical connectives.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

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- fish and chips, $fish(f) \wedge chip(c)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

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- fish and chips, $fish(f) \wedge chip(c)$
- ham as well as eggs, $ham(h) \wedge egg(e)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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- coffee or tea, $coffee(c) \vee tea(t)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

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- fish and chips, $fish(f) \wedge chip(c)$
- ham as well as eggs, $ham(h) \wedge egg(e)$
- coffee or tea, $coffee(c) \vee tea(t)$
- either red or green, $red(x) \oplus green(x)$ (XOR)

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: misc

Negative markers are mapped to formulas with the negation symbol.
not pumpkin, $\neg pumpkin(p)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: misc

Negative markers are mapped to formulas with the negation symbol.
not pumpkin, $\neg pumpkin(p)$

Some prepositions are mapped to binary predicates.
Joe is in Seattle, $in(JOE, SEATTLE)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: misc

Negative markers are mapped to formulas with the negation symbol.
not pumpkin, $\neg pumpkin(p)$

Some prepositions are mapped to binary predicates.
Joe is in Seattle, $in(JOE, SEATTLE)$

Copulas (certain occurrences of *be*) are mapped to equality.
Fred is the killer, $FRED = KILLER123$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Verbs

The main verb is mapped to an n-ary predicate in FOL. It indicates a property or relation.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Verbs

The main verb is mapped to an n-ary predicate in FOL. It indicates a property or relation.

- Intransitives can be represented as unary predicates. $swim(x)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Verbs

The main verb is mapped to an n-ary predicate in FOL. It indicates a property or relation.

- Intransitives can be represented as unary predicates. $swim(x)$
- Transitives can be represented as binary predicates. $steal(x, y)$

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: Verbs

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- Intransitives can be represented as unary predicates. $swim(x)$
- 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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CLMA, University of Washington farrar@u.washington.ed

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Semantics and the NLTK

Mapping NL to FOL: Verbs

The main verb is mapped to an n-ary predicate in FOL. It indicates a property or relation.

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- Ditransitives can be represented as ternary predicates. $give(x, y, z)$

But there's a problem.

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

Mapping NL to FOL: VPs

- John buttered the toast.
  $Butter(JOHN, TOAST)$

Mapping NL to FOL: VPs

- John buttered the toast.
  $Butter(JOHN, TOAST)$
- John buttered the toast at midnight.
  $Butter(JOHN, TOAST, MIDNIGHT)$

Mapping NL to FOL: VPs

- 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.
  $Butter(JOHN, TOAST, MIDNIGHT, KNIFE)$

Mapping NL to FOL: VPs

- 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.
  $Butter(JOHN, TOAST, MIDNIGHT, KNIFE, ...)$

Today's lecture

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Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

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From NL to Logic
Semantics and the NLTK

Packages

- `nltk.sem.logic`: A version of first order logic, built on top of the untyped lambda calculus.
- `nltk.sem.logic.Expression` is the base class for all kinds of logical formulas.
- `nltk.sem.LogicParser`: A parser that reads semantic representations and creates logic objects.
- `nltk.sem.util`: Utility functions for batch-processing sentences: parsing and extraction of the semantic representation of the root node of the the syntax tree, followed by evaluation of the semantic representation in a first-order model.
- `Prover9`: a supplemental theorem prover callable from the NLTK

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
Semantics and the NLTK

FOL in the NLTK

The `nltk.sem.logic` package contains the tools necessary for representing FOL.
Boolean operators:

`negation`	`-`	`(the hyphen)`
`conjunction`	`&`	
`disjunction`	`|`	
`implication`	`->`	
`equivalence`	`<->`	

Scott Farrar
CLMA, University of Washington farrar@u.washington.ed

Review
From NL to Logic
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Equality predicates:

`equality`	`=`
`inequality`	`!=`

Quantifiers:

`existential`	`exists`
`universal`	`all`
`lambda`	`\`

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