# Developing and Applying
# An Integrated Semantic Framework
## for Natural Language Understanding

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# Problems

## Observation

We have a lot of text.

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- At least 30 million digitalised (Google Books, 2010)
- At least 4.65 billion pages indexed (`http://http://www.worldwidewebsize.com/`)

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## Solutions

Information Systems

# Branches of Research

- Information Retrieval Systems (e.g. Search engines, e-dictionaries, etc.)

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# Popular Systems

## Successful Stories

- Question Answering (e.g. Wolfram Alpha, Siri)
- Machine Translation (e.g. Google Translate)
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## Approaches

- Question classification & answer ranking
- Statistical phrase mapping
- Deep linguistic analysis

# My Research

## Research Gap

- How deep is deep linguistic analysis?
- Pipeline: Tokenizer $\rightarrow$ Syntactic Parser $\rightarrow$ Semantic Parser $\rightarrow$ Named Entity Recognition, Co-reference Resolution, etc.
- Statistical methods? Manual analyses?

# My Research

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- Statistical methods? Manual analyses?

## Integrated Semantic Framework

- Construction Grammar
- Integrated Semantic Representation
- Hybrid model (statistical and manual analyses)

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# Linguistic Analysis

## Main aspects of linguistic analysis considered

- Morphosyntactic theory
- Semantic theory

These two are perspectives for looking at a single phenomenon rather than independent components.

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- Semantic theory

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## Implementation

- A grammar (actual analysis of a language)
- Semantic Representation (i.e. how to "capture" and "store" semantics)

# Morphosyntactic Analysis

## Aspects

- We do not remember all possible sentences
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## Construction Grammar

- Basic units are grammatical constructions
- A construction is a form-function pair
- Constructions can be used to form more complex constructions
- Chosen formalism: Sign-Based Construction Grammar (Boas & Sag, 2012)

# Sign Representation

$$\begin{bmatrix} \text{sign} & \\ \text{PHON/ORTH} & \text{phon/orth-obj} \\ \text{FORM} & \text{morph-obj} \\ \text{SYN} & \text{syn-obj} \\ \text{SEM} & \text{sem-obj} \\ \text{CNTXT} & \text{context-obj} \end{bmatrix}$$

# Example *Dogs sleep.*: Atomic constructions

$$
\begin{bmatrix}
\text{dog-1} & \\
\text{PHON} & [\ldots] \\
\text{FORM} & \begin{bmatrix} \text{LEMMA} & \text{dog} \\ \text{FORM} & \text{dogs} \\ \ldots & \end{bmatrix} \\
\text{SYN} & \begin{bmatrix} \text{noun} & \\ \text{NUM} & \text{pl} \\ \text{COUNTABLE} & + \\ \ldots & \end{bmatrix} \\
\text{SEM} & \begin{bmatrix} \text{IND} & x \\ \text{DOG} & x \\ \ldots & \end{bmatrix} \\
\text{CNTXT} & [\ldots]
\end{bmatrix}
$$

$$
\begin{bmatrix}
\text{sleep-1} & \\
\text{PHON} & [\ldots] \\
\text{FORM} & \begin{bmatrix} \text{LEMMA} & \text{sleep} \\ \text{FORM} & \text{sleep} \\ \ldots & \end{bmatrix} \\
\text{SYN} & \begin{bmatrix} \text{verb-i} & \\ \text{NUM} & \text{non-3sg} \\ \text{SUBJ} & \textbf{subj-constraint} \end{bmatrix} \\
\text{SEM} & \begin{bmatrix} \text{IND} & x \\ \text{SLEEP-ER} & x \\ \ldots & \end{bmatrix} \\
\text{CNTXT} & [\ldots]
\end{bmatrix}
$$

# Example *Dogs sleep.*: Sentence construction

$$
\begin{bmatrix}
\text{dog-sleep-1} & \\
\text{PHON} & [\ldots] \\
\text{FORM} & \begin{bmatrix} \text{FORM} & \text{“dogs sleep”} \\ \ldots & \end{bmatrix} \\
\text{SYN} & \begin{bmatrix} \text{sentence} \\ \\ \ldots \end{bmatrix} \\
\text{SEM} & \begin{bmatrix} \text{IND} & x \\ \text{DOG} & x \\ \text{SLEEP-ER} & x \\ \ldots & \end{bmatrix} \\
\text{CNTXT} & [\ldots]
\end{bmatrix}
$$

# Aspects of meanings

## What is meaning?

Linguistic meaning is the relation between linguistic signs and the things being denoted.

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Linguistic meaning is the relation between linguistic signs and the things being denoted.

## Difficulties

**Circularity in definition** What is the foundation of meanings? Words?

**Exact definition** Is *whale* a *mammal* or a *fish*?

**Meaning in context** Pragmatic aspect of meaning

# Formal Semantics

## Main Ideas

- Objectivist semantics: meaning is independent from human mental processes.
- Main theoretician: Richard Montague (1970)

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## Formalism

- SYN = { whale, dog, cat, . . . }
- SEM = { WHALE, DOG, CAT, . . . }
- $f = [\![]\!] = \{$ whale $\rightarrow$ WHALE; dog $\rightarrow$ DOG; cat $\rightarrow$ CAT, . . . $\}$

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## Formalism

- SYN = { whale, dog, cat, . . . }
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- $f = [\![\,]\!] = \{$ whale $\rightarrow$ WHALE; dog $\rightarrow$ DOG; cat $\rightarrow$ CAT, . . . $\}$

## Example

- $[\![whale]\!]$ = WHALE
- $[\![S]\!] = [\![NP \backslash dog]\!]\ [\![VP \backslash bark]\!] = [\![BARK(DOG)]\!] = 1$
- How about $[\![bank]\!]$ = BANK-1 or BANK-2 ???

# Cognitive Semantics

## Main Ideas

- Subjective Semantics: Meanings are created in the human mind
- Guessing game: Speakers try to constrain possible interpretations while hearers try to guess

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Subjectivism only captures idiolects (does not capture generalisations)

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## Critiques

Subjectivism only captures idiolects (does not capture generalisations)

## Arguments

- An idiolect is a generalised version of language.
- Everything is subjective, even corpus linguistics.

# Frame Semantics

## Main Ideas

Grammatical constructions such as words, phrases, sentences, etc. have meaning because they are linked into conceptual structures in minds. (C. J. Fillmore, 2006)

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## Motivation

1. *Jim's only spent two hours on land today.*
2. *Jim's only spent two hours on the ground today.*
3. *Jim's only spent a few years on this Earth.*

# "Research" Frame

A $\left[Researcher_{(INHERITANCE)}\right]$ (an individual a group or institution) attempts to answer a $\left[Question_{(SUBFRAME)}\right]$ by means of consulting literature, observation, or conducting experiments in a particular $\left[Field_{(SUBFRAME)}\right]$ pertinent to the $\left[Question_{(SUBFRAME)}\right]$. The $\left[Question_{(SUBFRAME)}\right]$ may be underspecified in the form of a $\left[Topic_{(SEE-ALSO)}\right]$.

# Abstract Meaning Representation

## Main Ideas

- Paraphrases have the same semantics

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## Example

- *The man described the mission as a disaster.*
- *The man's description of the mission: disaster.*
- *As the man described it, the mission was a disaster.*

# Abstract Meaning Representation

## Main Ideas

- Paraphrases have the same semantics

## Example

- *The man described the mission as a disaster.*
- *The man's description of the mission: disaster.*
- *As the man described it, the mission was a disaster.*

## Outputs

```
( d / describe-01
:  arg0 ( m / man )
:  arg1 ( m2 / mission )
:  arg2 ( d / disaster ) )
```

## Problems

Too vague, too abstract, not consistent, ...

# Minimal Recursion Semantics

## Main Ideas

Primary units are **elementary predications** (EP) which are relations and associated arguments.

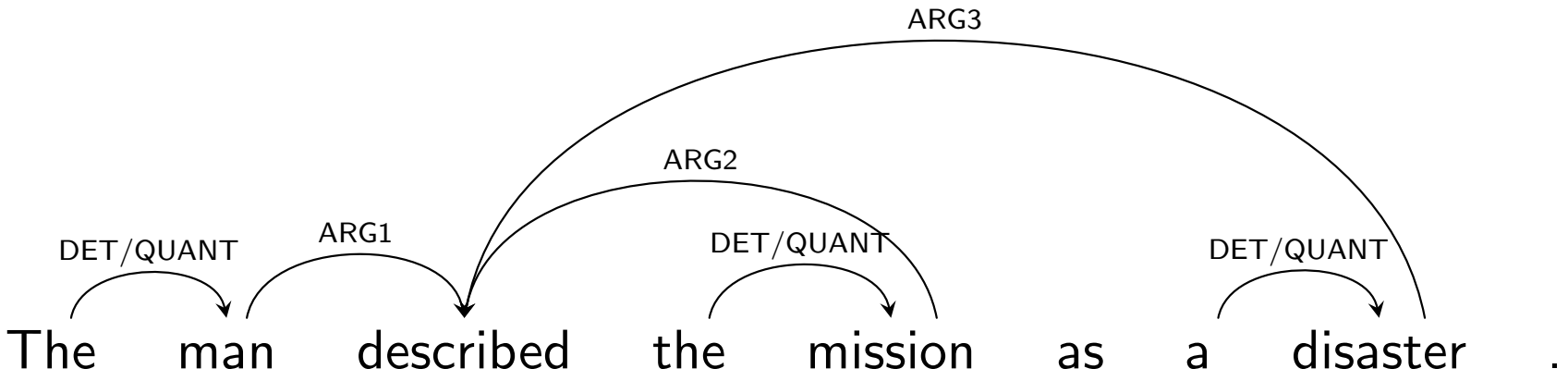
## Principles

**Expressive Adequacy** Linguistic meanings can be expressed correctly

**Grammatical Compatibility** Meanings must be linked to other grammatical information (e.g. Syntax)

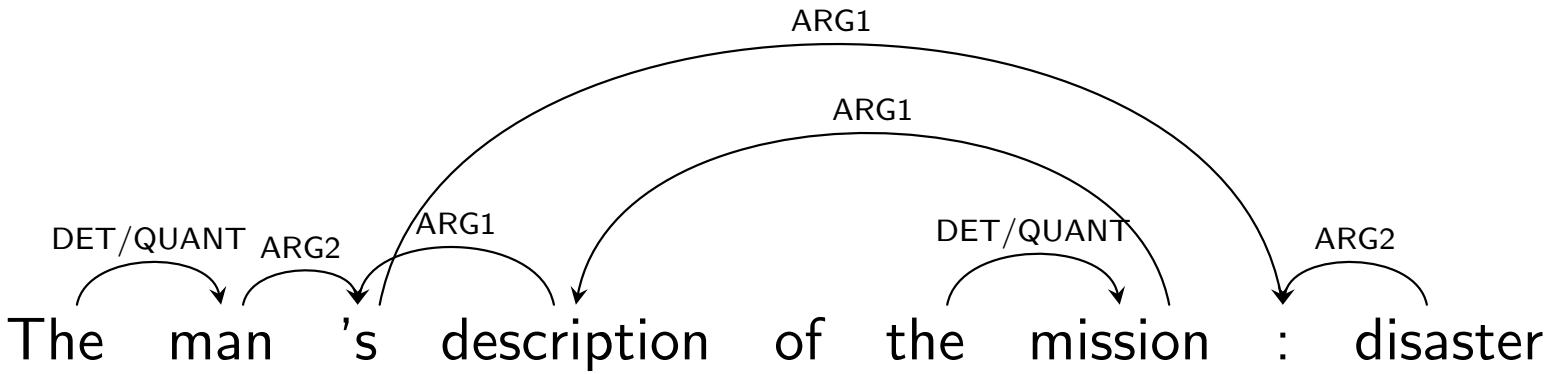
**Computational Tractability** Meanings can be processed and checked for semantic equivalence efficiently

**Underspecifiability** Underspecification should be allowed (leaving semantic distinctions unresolved).




Predicate view

```
 _1:  the_q[x6]
x6:  man_n_1[]
describe_v_as[ARG1 x6, ARG2 x9, ARG3, x10]
_2:  the_q[x9]
x9:mission_n_1[]
_3:  a_q[x10]
x10:disaster_n_1[]
```




Predicate view

```
 _1:_the_q[x6]
x6:_man_n_1[]
_2:def_explicit_q[x11]
e14:poss[ARG1 x11, ARG2 x6]
x11:_description_n_of[ARG1 x15]
_3:_the_q[x15]
x15:_mission_n_1[]
e3:_colon_v_id[ARG1 x11, ARG2 x20]
_4:udef_q[x20]
x20:_disaster_n_1[]
```

# WordNet

## Main Ideas

- Documenting lexical semantics (i.e. words' meanings)
- Traditional method: collections of word-meaning pairs that are ordered by lexicographical order (i.e. dictionaries)
- WordNet: meanings are documented as synonym sets (synsets - collections of near synonyms) with relations among them

# WordNet

## Synsets for *pen*

- Synonym sets

  01698271-v : to produce a literary work
  03906997-n : a writing implement with a point from which ink flows

- Word forms

  01698271-v → write, compose, pen, indite
  03906997-n → pen

# WordNet

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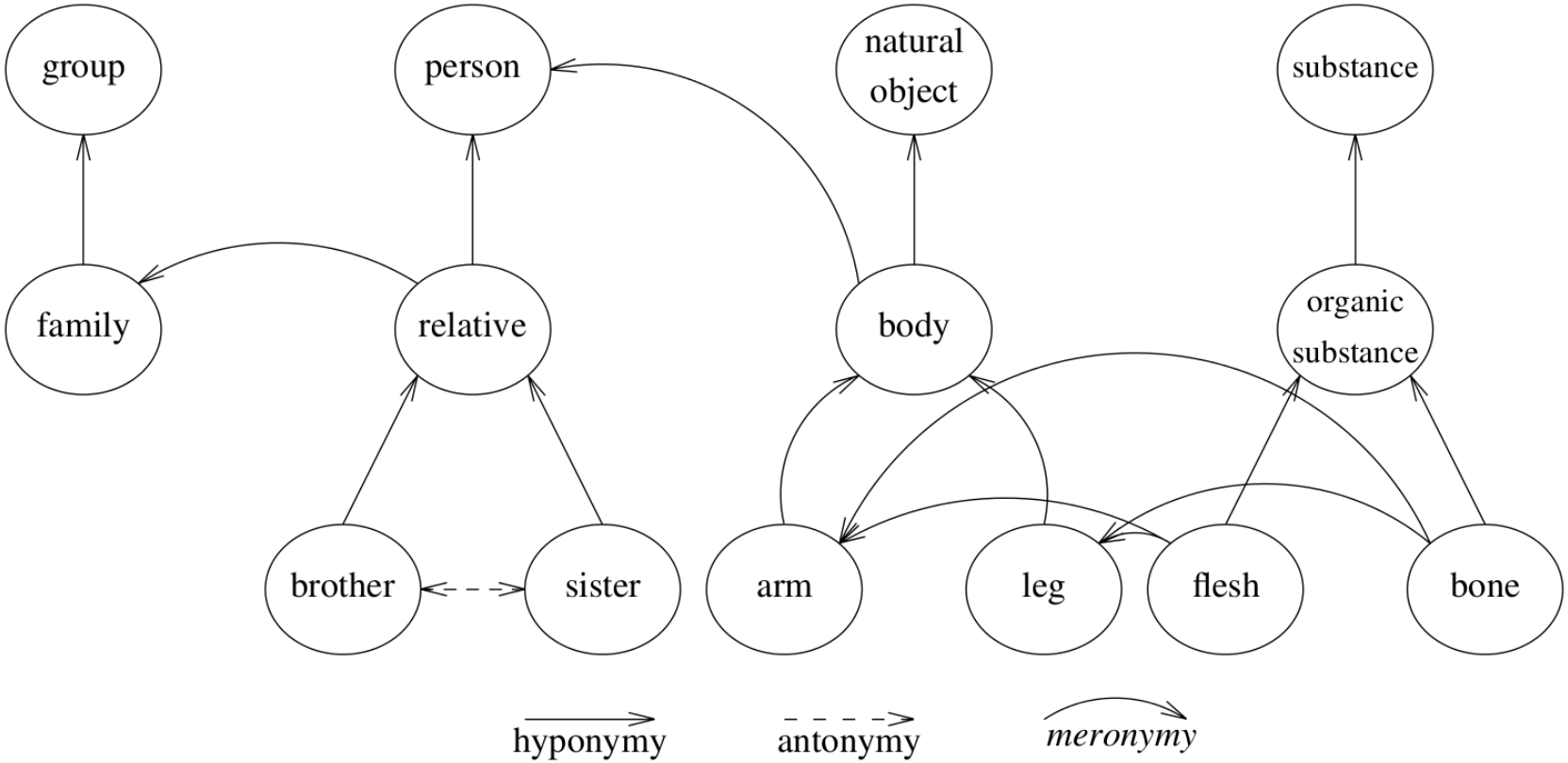
## Main relations

Synonymy/Antonymy Contrastive relations

Hyponymy/Hypenymy Hierarchical relations

Meronymy/Holonymy Part-whole relations

# Synset Relations Example



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# Pipeline Architecture

## Main Ideas

Pipeline architecture is the trending method. I will discuss its basic design and propose my alternative one in the next section.

## Raw sentence

*I saw a girl with a telescope.*

# Pipeline Architecture

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## Raw sentence

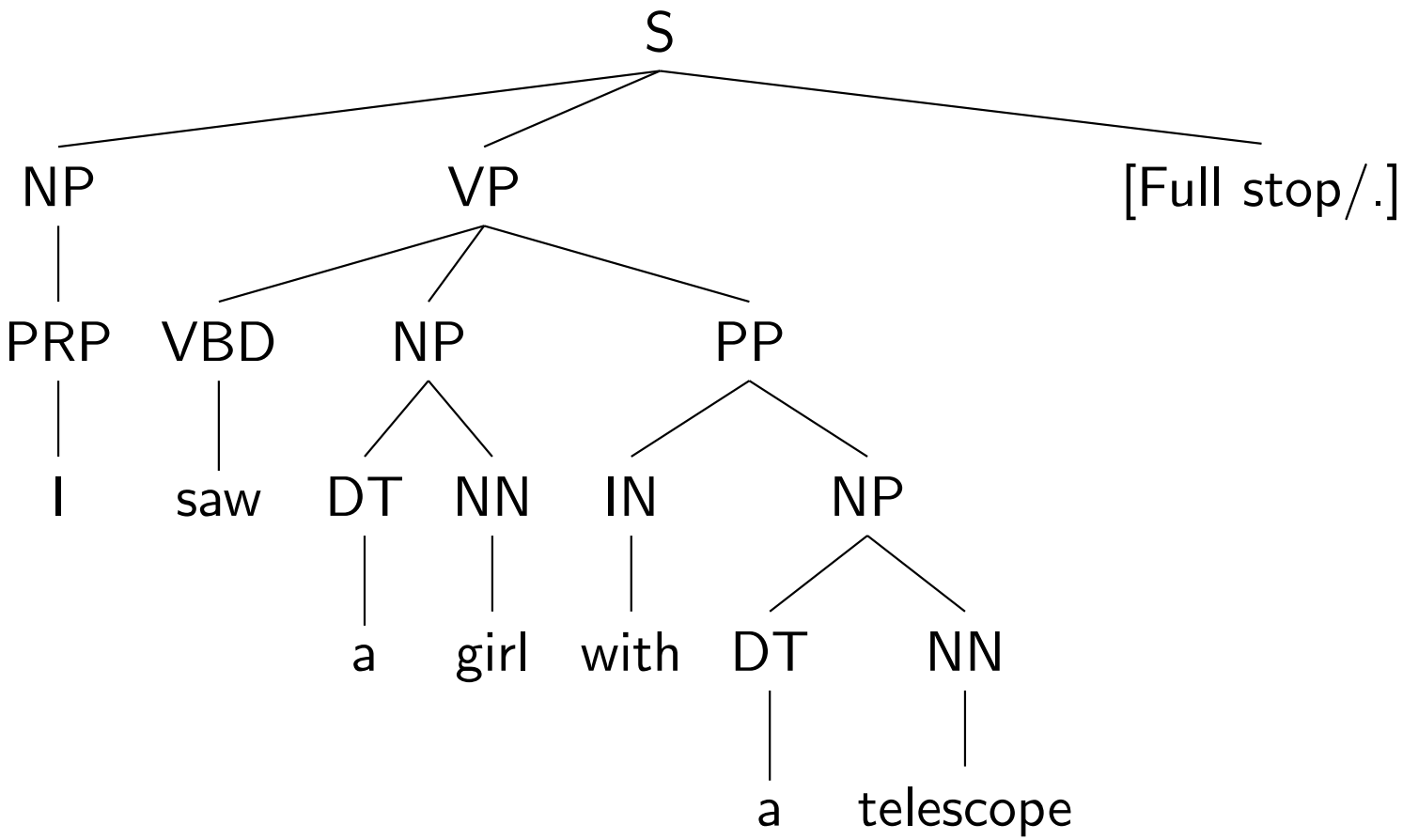
*I saw a girl with a telescope.*

## Tokenization

| *I* | *saw* | *a* | *girl* | *with* | *a* | *telescope* | *.* |
|---|---|---|---|---|---|---|---|
| PRP | VBD | DT | NN | IN | DT | NN | . |

# Pipeline Architecture (Cont.)

## Syntactic Tree



# Pipeline Architecture (Cont.)

## Semantic Role Labelling

| Relation | Word |
|---|---|
| See-er | "I" |
| See-ee | "girl" |
| Instrument | "telescope" |

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| Relation | Word |
|---|---|
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## Word-Sense Disambiguation

| Relation | Word | Sense |
|---|---|---|
| See-er | "I" | |
| See-ee | "girl" | girl_n_1 |
| Instrument | "telescope" | telescope_n_1 |

| Sense | Synset ID | Meaning |
|---|---|---|
| girl_n_1 | 10084295-n | a youthful female person |
| telescope_n_1 | 04403638-n | a magnifier of images of distant objects |

# Problems

- Error accumulation
  - Tokenization's errors
  - Part-of-speech tagger's errors
  - Tree parser's errors
  - Semantic parser's errors
- Lack of underspecification

# Integrated Semantic Framework

## Main Ideas

- No pipeline!
- Use a single integrated semantic representation to represent structural and lexical semantics: *paraphrases have similar semantics*.
- Underspecify information when it's not possible to resolve ambiguities in current context (not completed sentence, lack of references, etc.) as the discourse is carried further.

## Powered by

| | |
|---|---|
| Theory | Sign-Based Construction Grammar |
| Grammar | (enhanced) English Resource Grammar |
| Knowledge base | (enhanced) WordNet |
| Representation | **Integrated Semantic Representation** |

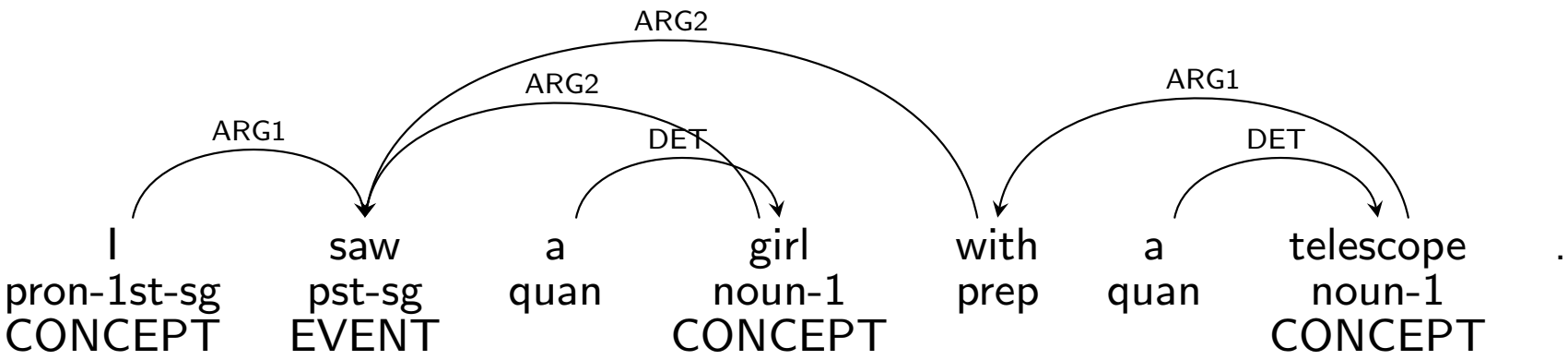
# Example (SBCG)

Word Construction

$$\begin{bmatrix} \text{see-1-le} & \\ \text{ORTH} & \begin{bmatrix} \text{Orthography} & \text{see} \\ \text{Form} & \text{saw} \end{bmatrix} \\ \text{SYN} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{ARG} & \begin{bmatrix} \text{PER} & \text{1st} \\ \text{NUM} & \text{sg} \\ \text{TENSE} & \text{pst} \end{bmatrix} \end{bmatrix} \end{bmatrix} \\ \text{SEM} & \begin{bmatrix} \ldots \end{bmatrix} \\ \ldots & \end{bmatrix}$$

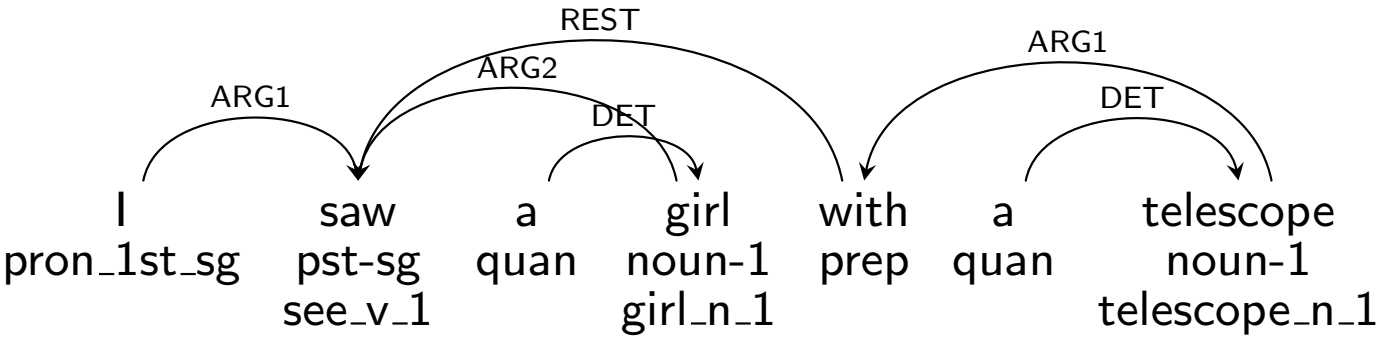
# Example (SBCG+ERG)

Structures with slots for sense information



# Example (SBCG+ERG+WordNet)

With sense information




| Sense | Synset ID | Meaning |
|---|---|---|
| girl_n_1 | 10084295-n | a youthful female person |
| telescope_n_1 | 04403638-n | a magnifier of images of distant objects |

# Discussion

## Main Contributions

- ERG doesn't provide frame semantics for many constructions in English. My final semantic analysis will be much richer than what ERG can give us now. This requires a lot of work.
- WordNet is rich, but it is not perfect. After I chose and studied my reference corpus, based on my analysis for the phenomena that I found, I will propose changes to WordNet.
- Linking the resources is non-trivial, many interesting issues of representation are still unresolved.
- Uniform Semantic Representation

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# Word-Sense Disambiguation

## Main Ideas

LESK is a family of dictionary-based WSD algorithms which determine the correct senses of a word by calculating the score as intersection between its context (e.g. other words in the same sentence) and the gloss information of each sense available for that particular word.

## Simplified LESK

```
for each sense s_i of word w_j:
score_i = overlap(definition of s_i, context of w_j)
if score_i > max_score:
max_score = score_i
best_sense = s_i
```

## Example

```
word      = 'bank'
context = ['I', 'go', 'to', 'the', 'bank', 'to', 'withdraw'
           , 'money']
bank_n_1 = ['a', 'financial', 'institution', 'that', 'accepts',
           'deposits', 'and', 'channels', 'the', 'money',
           'into', 'lending', 'activities']
bank_n_2 = ['sloping', 'land', 'especially', 'the', 'slope',
           'beside', 'a', 'body', 'of', 'water']
score_1 = overlap(bank_n_1, context) # ['money', 'the']
score_2 = overlap(bank_n_2, context) # ['the']
# So the best sense for 'bank' is bank_n_1
```

# Extended Simplified LESK

## Main Ideas

Use hypernyms and hyponyms to extend token list.

```
bank_n_1 = ['a', 'financial', 'institution', 'that', 'accepts',
            'deposits', 'and', 'channels', 'the', 'money',
            'into', 'lending', 'activities']
hype(bank_n_1) = [ financial-institution_n_1 ]
hypo(bank_n_1) = [ agent-bank_n_1, state-bank_n_1 ]
financial-institution_n_1 = ['an', 'institution', 'public', 'or',
    'private', 'that', 'collects', 'funds', 'from', 'the',
    'public', 'or', 'other', 'institutions', 'and', 'invests',
    'them', 'in', 'financial', 'assets']
agent-bank_n_1 = ['a', 'bank', 'that', 'acts', 'as', 'an',
    'agent', 'for', 'a', 'foreign', 'bank']
state-bank_n_1 = ['a', 'bank', 'chartered', 'by', 'a', 'state',
    'rather', 'than', 'by', 'the', 'federal', 'government']
final_tokens = bank_n_1 + hype(bank_n_1) + hypo(bank_n_1)
```

# Le's Lesk

## Main Ideas

Use sense-disambiguated Princeton WordNet Gloss Corpus (PWGC) to extend token list for Extended Simplified LESK.

# PWGC Example

| Word | | Synset ID | Annotated Gloss |
|---|---|---|---|
| a financial institution | → | 08054721-n | an institution (public or private) ... |
| that accepts | → | 02236124-v | receive willingly something ... |
| deposits and channels | → | 01933900-v | direct the flow of |
| the money | → | 13384557-n | the most common medium of exchange ... |
| into lending activities | → | 02324182-v | give temporarily ... |

# Evaluation

## MFS vs Le's Lesk

Most-Frequent Sense (MFS) is the baseline for Word-Sense Disambiguation. Word-senses are provided based on sense-count learnt from an annotated corpus. It's very difficult to beat.

| Information | Instances | | Types | |
|---|---|---|---|---|
| | Le's Lesk | MFS | Le's Lesk | MFS |
| Correct sense ranked the first | 2544 | 2808 | 1143 | 1042 |
| Correct sense ranked the 2nd or 3rd | 1328 | 1203 | 844 | 682 |
| Wrong | 1325 | 1186 | 868 | 756 |
| No Sense | 122 | 122 | 54 | 54 |
| Total Sense | 5319 | 5319 | N/A | |

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# Research Plans

- Study the phenomena in an English text from our corpus and provide linguistic analysis for all sentences
- Design the actual integrated semantic representation and implement the computational model
- Evaluate my analysis against a human annotated gold profile (most likely will be NTU-MC)

# Research Timeline

| Year | Quarter | Tasks |
|---|---|---|
| 2015 | 3 | Study English constructions in NTU-MC |
| | 4 | Provide analysis for documented constructions. Write the chapter on integrated semantic framework. |
| 2016 | 1 | Uniform semantic representation & write the chapter. |
| | 2 & 3 | Fine-tune the system performance |
| | 4 | New way to do WSD (based on constructions, concepts, etc.) |
| 2017 | 1 & 2 | Final design & software. Add more constructions, lexical items and idioms to the knowledge base. Experiment with Machine learning techniques. |
| | 3 & 4 | Complete thesis. (Optional) Experiment with other languages (Japanese, Chinese, Indonesian and Vietnamese). |

# Integrated Semantic Framework

Thank you