Natural Language Processing
CS 6320
Lecture 11
Semantic Role Labeling

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What is Semantic Role Labeling?

Semantic Role Labeling, also called Thematic Role Labeling, or Case Role Assignment or Shallow Semantic Parsing is the task of automatically finding the thematic roles for each predicate in a sentence.
What is Automatic Semantic Role Labeling?

Given a sentence:

Abby bought a car from Robin for $5,000.

a) Identify predicates:

Abby bought a car from Robin for $5,000.

b) Identify and assign thematic roles for each predicate:

Abby bought a car from Robin for $5,000.

BUYER

GOODS

SELLER

MONEY
Why Study Semantic Role Labeling?

- **Who did What to Whom, When, Where, Why, How, etc.**

- Proved to be useful in:
  - **Question Answering (QA)**
    [Narayanan and Harabagiu, COLING’02]
  - **Information Extraction (IE)**
    [Surdeanu et al., ACL’03]
Using Semantic Role Labeling in QA

- Parsing Questions

  **Q:** What kind of materials were stolen from the Russian navy?

    $FS(Q):$ What [GOODS: kind of nuclear materials] were [Target-Predicate:stolen] [VICTIM: from the Russian Navy]?

- Parsing Answers

  $A(Q):$ Russia’s Pacific Fleet has also fallen prey to nuclear theft; in 1/96, approximately 7 kg of HEU was reportedly stolen from a naval base in Sovetskaya Gavan.

    $FS(A(Q)): [VICTIM(P1): Russia’s Pacific Fleet] has also fallen prey to [Goods(P1): nuclear] [Target-Predicate(P1): theft]; in 1/96, [GOODS(P2): approximately 7 kg of HEU] was reportedly [Target-Predicate(P2): stolen] [VICTIM(P2): from a naval base] [SOURCE(P2): in Sovetskaya Gavan]

- Result: exact answer= “approximately 7 kg of HEU’
## Thematic Roles

<table>
<thead>
<tr>
<th>Thematic Role</th>
<th>Definition/Example</th>
</tr>
</thead>
</table>
| AGENT         | The volitional causer of an event.  
*The waiter spilled the soup.* |
| EXPERIENCER   | The experiencer of an event.  
*John has a headache.* |
| FORCE         | The non-volitional causer of the event.  
*The wind blows debris from the mall into our yards.* |
| THEME         | The participant most directly affected by an event.  
*Only after Benjamin Franklin broke the ice ...* |
| RESULT        | The end product of an event.  
*The French government has built a regulation-size baseball diamond ...* |
| CONTENT       | The proposition or content of a propositional event.  
*Mona asked "You met Marry Ann at a supermarket"?* |
| INSTRUMENT    | An instrument used in an event.  
*He turned to poaching catfish, stunning them with a shocking device ...* |
| BENEFICIARY   | The beneficiary of an event.  
*Whenever Ann Callahan makes hotel reservation for her boss ....* |
| SOURCE        | The origin of the object of a transfer event.  
*I flew in from Boston.* |
| GOAL          | The destination of an object of a transfer event.  
*I drove to Portland.* |
### Common Realizations for Major Thematic Roles

<table>
<thead>
<tr>
<th>Thematic Role</th>
<th>Realization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AGENT</strong></td>
<td>as subject in active sentences</td>
</tr>
<tr>
<td><strong>EXPERIENCER</strong></td>
<td>as animate subject in active sentences with no agent</td>
</tr>
<tr>
<td><strong>THEME</strong></td>
<td>as object of transitive verbs</td>
</tr>
<tr>
<td><strong>INSTRUMENT</strong></td>
<td>as subject in active sentences with no agent</td>
</tr>
<tr>
<td><strong>BENEFICIARY</strong></td>
<td>as indirect object with transitive verbs</td>
</tr>
</tbody>
</table>
FrameNet

- The FrameNet Project [Baker et al., 1998], developed at ICSI Berkeley, proposes roles that are neither as general as the ten abstract thematic roles, nor as specific as the thousands of potential verb specific roles.

- FrameNet encodes a set of frames (semantic representation of situations)

- Frames are characterized by:
  - target words or lexical predicates whose meaning includes aspects of the frame;
  - frame elements (FEs) which represent the semantic roles of the frame;
  - examples of annotations performed on the British National Corpus for instances of each target word.
Sample Domains and Frames from FrameNet

12 domains in the preliminary version of FrameNet Project:
1. Body
2. Cognition
3. Communication
4. Emotion
5. General
6. Health
7. Motion
8. Perception
9. Society
10. Space
11. Time
12. Transaction

Domain: Communication
- Frame: Conversation
  - Frame Elements: Protagonist-1, Protagonist-2, Protagonists, Topic, Medium
- Frame: Questioning
  - Frame Elements: Speaker, Addressee, Message, Topic, Medium
- Frame: Statement
  - Frame Elements: Speaker, Addressee, Message, Topic, Medium

Target words that evoke Conversation and Judgment frames:
- argue-v
- banter-v
- tiff-n
- converse-v
- dispute-n
- discussion-n
- gossip-v
- blame-v
- admire-v
- blame-n
- appreciate-v
- fault-n
- admire-v
- consider-v
- disapprove-v

Domain: Cognition
The project methodology was done on a **frame-by-frame basis**:

1) choose a semantic frame (e.g. *Commerce_buy*)
2) define the frame and its frame elements (e.g. *BUYER, GOODS, SELLER, MONEY*)
3) list the various lexical predicates (verbs, nouns and adjectives) that evoke the frame (*buy.v, purchase.v, purchase.n*)
4) extract sentences for each predicate from British National Corpus
**Definition:** These are words describing a basic commercial transaction involving a buyer and a seller exchanging money and goods, taking the perspective of the buyer. The words vary individually in the patterns of frame element realization they allow. For example, the typical pattern for the verb BUY: **BUYER buys GOODS from SELLER for MONEY.**

<table>
<thead>
<tr>
<th>Frame Element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Buyer</strong></td>
<td>The Buyer wants the Goods and offers Money to a Seller in exchange for them. <strong>Lee BOUGHT a textbook from Abby.</strong></td>
</tr>
<tr>
<td><strong>Goods</strong></td>
<td>The FE Goods is anything (including labor or time, for example) which is exchanged for Money in a transaction. <em>(Only one winner PURCHASED the paintings)</em></td>
</tr>
<tr>
<td><strong>Money</strong></td>
<td>Money is the thing given in exchange for Goods in a transaction. <strong>Sam BOUGHT the car for $12,000.</strong></td>
</tr>
<tr>
<td><strong>Seller</strong></td>
<td>The Seller has possession of the Goods and exchanges them for Money from a Buyer. <strong>Most of my audio equipment, I PURCHASED from a department store near my apartment</strong></td>
</tr>
<tr>
<td><strong>Place</strong></td>
<td>Where the event takes place.</td>
</tr>
</tbody>
</table>
Frame-to-Frame Relations

Frame Relation – a directed relation between two frames, where one frame is called **Super_Frame** (less dependent, more abstract) and the other frame is called **Sub_Frame** (the more dependent, less abstract)

<table>
<thead>
<tr>
<th>Relation</th>
<th>Sub</th>
<th>Super</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inheritance</td>
<td>Child</td>
<td>Parent</td>
</tr>
<tr>
<td>Perspective_on</td>
<td>Perspectivized</td>
<td>Neutral</td>
</tr>
<tr>
<td>Subframe</td>
<td>Component</td>
<td>Complex</td>
</tr>
<tr>
<td>Precedes</td>
<td>Later</td>
<td>Earlier</td>
</tr>
<tr>
<td>Inchoative_of</td>
<td>Inchoative</td>
<td>State</td>
</tr>
<tr>
<td>Causative_of</td>
<td>Causative</td>
<td>Inchoative/State</td>
</tr>
<tr>
<td>Using</td>
<td>Child</td>
<td>Parent</td>
</tr>
<tr>
<td>See Also</td>
<td>Referring Entry</td>
<td>Main Entry</td>
</tr>
</tbody>
</table>
Frame Relations for Commercial transaction

Commercial_transaction frame specifies a complex schema involving an exchange of multiple themes (Money and Goods) between the Buyer and Seller, including also two sub-frames: Commerce_goods_transfer and Commerce_money_transfer.
Proposition Bank (PropBank)

- A one million word corpus annotated with predicate argument structures
- Developed at University of Pennsylvania
- Annotation is performed on the Penn TreeBank
- Predicates are lexicalized only by verbs
- Arguments numbered from 0..5
- Adjunctive arguments: Locative, Temporal, Manner, Cause, etc.

The futures halt was assailed by Big Board floor traders

ARG1 = entity assailed
PRED
ARG0 = agent
[A₀ He ] [AM-MOD would ] [AM-NEG n't ] [V accept ] [A₁ anything of value ] from [A₂ those he was writing about ] .

Here, the roles for the predicate accept (that is, the roleset of the predicate) are defined in the PropBank Frames scheme as:

V: verb
A₀: acceptor
A₁: thing accepted
A₂: accepted-from
A₃: attribute
AM-MOD: modal
AM-NEG: negation
Using Semantic Role Labeling in QA

• Parsing Questions

**Q**: What kind of materials were stolen from the Russian navy?

PAS(Q): What [%ARG1: kind of nuclear materials] were [%Predicate:stolen] [%ARG2: from the Russian Navy]?  

• Parsing Answers

**A(Q)**: Russia’s Pacific Fleet has also fallen prey to nuclear theft; in 1/96, approximately 7 kg of HEU was reportedly stolen from a naval base in Sovetskaya Gavan.


• Result: exact answer= “approximately 7 kg of HEU”
Common Realizations in Argument Numbers

• Arg0 = agent
• Arg1 = direct object / theme / patient
• Arg2 = indirect object / benefactive / instrument / attribute / end state
• Arg3 = start point / benefactive / instrument / attribute
• Arg4 = end point

Recall that FrameNet employs a large number of frame-specific frame elements as roles, while PropBank makes use of a smaller number of generic argument labels.
Adjuncts in PropBank

<table>
<thead>
<tr>
<th>ArgM-DIR</th>
<th>directionals</th>
<th>walk along the road</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArgM-LOC</td>
<td>locatives</td>
<td>walk around the countryside</td>
</tr>
<tr>
<td>ArgM-MNR</td>
<td>manner</td>
<td>works well with others</td>
</tr>
<tr>
<td>ArgM-TMP</td>
<td>temporal</td>
<td>in 1987</td>
</tr>
<tr>
<td>ArgM-EXT</td>
<td>extent</td>
<td>raised prices by 15%</td>
</tr>
<tr>
<td>ArgM-REC</td>
<td>reciprocals</td>
<td>John and Mary killed each other</td>
</tr>
<tr>
<td>ArgM-PRD</td>
<td>predication</td>
<td>Mary called John an idiot</td>
</tr>
<tr>
<td>ArgM-PRP</td>
<td>purpose</td>
<td>I live to eat</td>
</tr>
<tr>
<td>ArgM-DIS</td>
<td>discourse</td>
<td>also, however</td>
</tr>
<tr>
<td>ArgM-ADV</td>
<td>other adverbial</td>
<td>generally?</td>
</tr>
<tr>
<td>ArgM-MOD</td>
<td>modal</td>
<td>possibly</td>
</tr>
<tr>
<td>ArgM-NEG</td>
<td>negative</td>
<td>did not</td>
</tr>
<tr>
<td>ArgM</td>
<td>bare ArgM</td>
<td>adjuncts not related to verb, e.g. extraposed modifier</td>
</tr>
</tbody>
</table>
**PropBank Example**

*The company bought a wheel-loader from Dresser.*

| Arg0: | The company |
| rel:  | bought      |
| Arg1: | a wheel-loader |
| Arg2-from: | Dresser |

*TV stations bought “Cosby” reruns for record prices.*

| Arg0: | TV stations |
| rel:  | bought      |
| Arg1: | “Cosby” reruns |
| Arg3-for: | record prices |

**BUY**

| Arg0: | buyer |
| Arg1: | commodity |
| Arg2: | seller |
| Arg3: | price |
| Arg4: | beneficiary |

**SELL**

| Arg0: | seller |
| Arg1: | commodity |
| Arg2: | buyer |
| Arg3: | price |
| Arg4: | beneficiary |

**PAY**

| Arg0: | buyer |
| Arg1: | price paid |
| Arg2: | seller |
| Arg3: | commodity |
| Arg4: | beneficiary |

Same roleset; different order
PropBank/FrameNet Role Mappings

BUY
Arg0: buyer
Arg1: commodity
Arg2: seller
Arg3: price
Arg4: beneficiary

SELL
Arg0: seller
Arg1: commodity
Arg2: buyer
Arg3: price
Arg4: beneficiary

Trade, Exchange
Arg0: one party
Arg1: commodity
Arg2: other party
Arg3: price
Arg4: beneficiary
NomBank

- Provides argument structures for instances of about 5000 common nouns in the Penn Treebank II
- Developed at New York University
- Annotation is performed on the Penn TreeBank
- Predicates are lexicalized only by nouns
- Arguments numbered from 0..4
- Adjunctive arguments: Locative, Temporal, Manner, Cause, etc.
- SUPPORT items

```
S
  VP
    NP
      VBD
          The FCC
          ARG0
      CD
      JJ
          specific
          ARGM-MNR
      NNS
          Support
          PRED
      VBG
          ARG1
      NNP
          regarding
          AT&T
```
They gave the chefs a standing ovation

**PropBank**

REL: gave  
Arg0: they  
Arg1: a standing ovation  
Arg2: the chefs

**NomBank**

REL: ovation  
Arg0: they  
Arg1: the chefs  
Support: gave
Automatic Labeling of Semantic Roles

- Given a sentence:

  **Abby bought a car from Robin for $5,000.**

  a) Identify predicates:

  **Abby bought a car from Robin for $5,000.**

  b) Identify and assign thematic roles for each predicate:

  
  \[
  \begin{array}{c}
  \text{[Buyer Abby] bought [Goods a car] [Seller from Robin]} \\
  \text{[Money for $5,000].}
  \end{array}
  \]
A Semantic Role Labeling Algorithm

function SEMANTICROLELABEL(words) returns labeled tree

parse ← PARSE(words)
for each predicate in parse do
    for each node in parse do
        featurevector ← EXTRACTFEATURES(node, predicate, parse)
        CLASSIFYNODE(node, featurevector, parse)
Instead of training a single stage classifier, some role labeling algorithms do classification in multiple stages for efficiency:

- **Pruning**: to speed the execution, some constituents are eliminated from consideration as possible roles, based on simple rules;
- **Identification**: a binary classification of each node as an ARG (positive example) to be labeled or NONE (negative example);
- **Classification**: a one-of-N classification of all the constituents that were labeled as ARG by the previous stage.
Example

[ARG0 The San Francisco Examiner] issued [ARG1 a special edition] [ARGM-TMP around noun yesterday].
Example: Pruning

Also, all the leafs of the parse trees can be ignored.
Example: Argument Identification

The San Francisco Examiner issued a special edition around noun yesterday.

Binary Classifier

The San Francisco Examiner issued a special edition around noun yesterday.
Example: Argument Classification

Multi Class Classifier
Extracting Features

The syntactic parse tree is traversed for each predicate;

In traversing the tree for a predicate each constituent is analyzed in order to determine whether it plays any role with respect to that predicate

The judgment is made by first characterizing the constituent as a set of features with respect to the predicate

A classifier trained on an appropriate training set is then passed this feature set and makes the appropriate assignment.
In our example, the verb **issued**

For PropBank the predicates are always verbs; FrameNet also has noun and adjective predicates.

The predicate is a crucial feature since both PropBank and FrameNet labels are defined only with respect to a particular predicate.

Derived feature: **predicate lemma**
In our example, the phrase type of the constituent is **NP (or NP-SBJ)**

It is the name of the parse node which dominates this constituent in the parse tree.

Different roles tend to be realized by different syntactic categories. Some semantic roles tend to appear as NPs, others as S or PP, etc.
Features: Head Word

- In our example, the head word of the constituent is *Examiner*.
- Each head word if a constituent can be computed using standard head rules.
- Certain head words (e.g. pronouns) place strong constraints on the possible semantic roles they are likely to fill.
Features: Head Word Part of Speech

- In our example, **NNP**
Features: Parse Tree Path

- Is the path in the parse tree from constituent to the predicate
- It describes the syntactic relation between the constituent in the question and the target
- In our example, it is marked by the red dotted line
- Simple linear representation: NP↑S↓VP ↓VBD where ↑ and ↓ represent upward and downward movement in the tree respectively
## Most Frequent Values of the Parse Tree Path Feature

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Path</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.2%</td>
<td>VB↑VP↓PP</td>
<td>PP argument/adjunct</td>
</tr>
<tr>
<td>11.8</td>
<td>VB↑VP↑S↓NP</td>
<td>subject</td>
</tr>
<tr>
<td>10.1</td>
<td>VB↑VP↓NP</td>
<td>object</td>
</tr>
<tr>
<td>7.9</td>
<td>VB↑VP↑VP↑S↓NP</td>
<td>subject (embedded VP)</td>
</tr>
<tr>
<td>4.1</td>
<td>VB↑VP↓ADVP</td>
<td>adverbial adjunct</td>
</tr>
<tr>
<td>3.0</td>
<td>NN↑NP↑NP↓PP</td>
<td>prepositional complement of noun</td>
</tr>
<tr>
<td>1.7</td>
<td>VB↑VP↓PRT</td>
<td>adverbial particle</td>
</tr>
<tr>
<td>1.6</td>
<td>VB↑VP↑VP↑VP↑S↓NP</td>
<td>subject (embedded VP)</td>
</tr>
<tr>
<td>14.2</td>
<td>VB↑VP↑VP↑VP↑VP↑S↓NP</td>
<td>no matching parse constituent</td>
</tr>
<tr>
<td>31.4</td>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>
Features: Position

- Binary linear position of the constituent with respect to the predicate
- In our case, the value is **before**
Features: Voice

- Binary feature indicating whether the voice of the clause in which the constituent appears is active or passive.
- In our case, the value is active.
- Direct objects of active verbs often correspond in semantic role to subjects of passive verbs.
The set of expected arguments that appear in the verb phrase
In our case, the value is $\text{VP} \rightarrow \text{NP PP}$
Can be extracted by using the phrase structure rule that expands the immediate parent of the predicate
Extended Feature Set

- **CONTENT WORD (cw)**: lexicalized feature that selects an informative word from the constituent, other than the head.
- **PART OF SPEECH OF CONTENT WORD (cPos)**: part of speech tag of the content word.
- **PART OF SPEECH OF HEAD WORD (hPos)**: part of speech tag of the head word.
- **NAMED ENTITY CLASS OF CONTENT WORD (cNE)**: the class of the named entity that includes the content word.
- **BOOLEAN NAMED ENTITY FLAGS**: set of features that indicate if a named entity is included at any position in the phrase:
  - **neOrganization**: set to true if an organization name is recognized in the phrase.
  - **neLocation**: set to true if a location name is recognized in the phrase.
  - **nePerson**: set to true if a person name is recognized in the phrase.
  - **neMoney**: set to true if a currency expression is recognized in the phrase.
  - **nePercent**: set to true if a percentage expression is recognized in the phrase.
  - **neTime**: set to true if a time of day expression is recognized in the phrase.
  - **neDate**: set to true if a date temporal expression is recognized in the phrase.
Extended Feature Set

- **PARSE TREE PATH WITH UNIQUE DELIMITER**: remove the direction in the PATH
- **PARTIAL PATH**: uses only the path from the constituent to the lowest common ancestor of the predicate and the constituent
- **FIRST WORD**: first word covered by constituent
- **FIRST POS**: POS of first word covered by constituent
- **LAST WORD**: last word covered by constituent
- **LAST POS**: POS of last word covered by constituent
- **LEFT CONSTITUENT**: left sibling constituent label
- **LEFT HEAD**: left sibling head
- **LEFT POS HEAD**: left sibling POS of head word
- **RIGHT CONSTITUENT**: right sibling constituent label
- **RIGHT HEAD**: right sibling head
- **RIGHT POS HEAD**: right sibling POS of head word
- **PP PREP**: if constituent is labeled PP get first word in PP
- **DISTANCE**: distance in the parse tree from constituent to the target word
Semantic Role Labeling Methods

- Various Stochastic Models
- Supervised Machine Learning
  - Training set:
    - FrameNet
    - PropBank
    - NomBank
  - Algorithms: SVM, HMM, CRF, MaxEnt, etc.
- State of the art:
  - F-Score of about 85% in discovering and classifying semantic roles.
Resources

- **FrameNet**
  - [http://framenet.icsi.berkeley.edu/](http://framenet.icsi.berkeley.edu/)

- **PropBank**
  - [http://www.cs.rochester.edu/~gildea/PropBank/Sort/](http://www.cs.rochester.edu/~gildea/PropBank/Sort/)
  - [http://verbs.colorado.edu/framesets/](http://verbs.colorado.edu/framesets/)

- **NomBank**