Recall:

- Attention:
  - For each decoder state, compute weighted sum of input states
  - Very helpful for seq2seq models
  - $P(y_i|x, y_1, \ldots, y_{i-1}) = \text{softmax}(W[c_i; \tilde{h}_i])$
  - Weighted sum of input hidden states (vector)
  - $c_i = \sum_j \alpha_{ij} h_j$
  - $\alpha_{ij} = \frac{\exp(e_{ij})}{\sum_j \exp(e_{ij})}$
  - $e_{ij} = f(\tilde{h}_i, h_j)$
  - Unnormalised scalar weight

Recall: Alternatives

- When do we compute attention? Can compute before or after RNN cell
- After RNN cell
- Before RNN cell; this one is a little more convoluted and less standard

This Lecture

- How do we represent information for information extraction?
  - Semantic role labeling / abstract meaning representation
  - Relation extraction
  - Slot filling
  - Open Information Extraction
Representing Information

Semantic Representations

- “World” is a set of entities and predicates
- Statements are logical expressions that evaluate to true or false

Brutus stabs Caesar  \[\text{stab(Brutus, Caesar)} \rightarrow \text{true}\]
Caesar was stabbed  \[\exists x \text{stab}(x, \text{Caesar}) \rightarrow \text{true}\]

Example credit: Asad Sayeed

Neo-Davidsonian Events

Brutus stabbed Caesar with a knife at the theater on the Ides of March

\[\exists e \text{stabs}(e, \text{Brutus, Caesar}) \land \text{with}(e, \text{knife}) \land \text{location}(e, \text{theater}) \land \text{time}(e, \text{Ides of March})\]

- Lets us describe events as having properties
- Unified representation of events and entities:

  * some clever driver in America

\[\exists x \text{driver}(x) \land \text{clever}(x) \land \text{location}(x, \text{America})\]

Example credit: Asad Sayeed

Real Text

Barack Obama signed the Affordable Care act on Tuesday. He gave a speech later that afternoon on how the act would help the American people. Several prominent Republicans were quick to denounce the new law.

\[\exists e \text{sign}(e, \text{Barack Obama}) \land \text{patient}(e, \text{ACA}) \land \text{time}(e, \text{Tuesday})\]

- Need to impute missing information, resolve coreference, etc.
- Still unclear how to represent some things precisely or how that information could be leveraged (several prominent Republicans)
Other Challenges

Bob and Alice were friends until he moved away to attend college

\[ \exists e_1 \exists e_2 \text{ friends}(e_1, \text{Bob}, \text{Alice}) \land \text{moved}(e_2, \text{Bob}) \land \text{end_of}(e_1, e_2) \]

- How to represent temporal information?

Bob and Alice were friends until around the time he moved away to attend college

- Representing truly open-domain information is very complicated! We don’t have a formal representation that can capture everything

(At least) Three Solutions

- Crafted annotations to capture some subset of phenomena: predicate-argument structures (semantic role labeling), time (temporal relations), ...

- Slot filling: specific ontology, populate information in a predefined way

  (Earthquake: magnitude=8.0, epicenter=central Italy, ...)

- Entity-relation-entity triples: focus on entities and their relations (note that prominent events can still be entities)

  (Lady Gaga, singerOf, Bad Romance)

Open IE

- Entity-relation-entity triples aren’t necessarily grounded in an ontology

- Extract strings and let a downstream system figure it out

Barack Obama signed the Affordable Care act on Tuesday. He gave a speech later that afternoon on how the act would help the American people. Several prominent Republicans were quick to denounce the new law.

  (Barack Obama, signed, the Affordable Care act)
  (Several prominent Republicans, denounce, the new law)

IE: The Big Picture

- How do we represent information? What do we extract?

  - Semantic roles
  
  - Abstract meaning representation
  
  - Slot fillers
  
  - Entity-relation-entity triples (fixed ontology or open)
Semantic Role Labeling/Abstract Meaning Representation

- Identify predicate, disambiguate it, identify that predicate's arguments
- Verb roles from Propbank (Palmer et al., 2005)

**Gold**

- **ARG1**
- **V**
- **ARG2**
- **ARG3**

Gold: 

Housing starts are expected to quicken a bit from August’s pace

**quicken:**

- **Arg0-PAG:** cause of speed-up
- **Arg1-PPT:** thing becoming faster (vrole: 45.4-patient)
- **Arg2-EXT:** EXT
- **Arg3-DIR:** old speed
- **Arg4-PRD:** new speed

Figure from He et al. (2017)

Semantic Role Labeling

- Identify predicates (*love*) using a classifier (not shown)
- Identify ARG0, ARG1, etc. as a tagging task with a BiLSTM conditioned on *love*
- Other systems incorporate syntax, joint predicate-argument finding

Figure from He et al. (2017)

**SRL for QA**

- Question and several answer candidates

Q: Who discovered prions?

AC1: In 1997, Stanley B. Prusiner, a scientist in the United States, discovered prions...

AC2: Prions were researched by...

Score by matching expected answer phrase (EAP) against answer candidate (AC)

Shen and Lapata (2007)
Abstract Meaning Representation

- Graph-structured annotation
- Superset of SRL: full sentence analyses, contains coreference and multi-word expressions as well
- F1 scores in the 60s: hard!
- So comprehensive that it’s hard to predict, but still doesn’t handle tense or some other things...

Summarization with AMR

- Merge AMRs across multiple sentences
- Summarization = subgraph extraction
- No real systems actually work this way (more when we talk about summarization)

Slot Filling

- Most conservative, narrow form of IE

Speaker: Alan Clark
"Gender Roles in the Holy Roman Empire"
Allagher Center Main Auditorium
This talk will discuss...

Old work: HMMs, later CRFs trained per role

Freitag and McCallum (2000)
Slot Filling: MUC

**Template**

<table>
<thead>
<tr>
<th>SELLER</th>
<th>BUSINESS</th>
<th>ACQUIRED</th>
<th>PURCHASER</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSR Limited</td>
<td>Oil and Gas</td>
<td>Delhi Fund</td>
<td>Esso Inc.</td>
</tr>
</tbody>
</table>

**Document**

[S CSR] has said that [S it] has sold [S its] [B oil interests] held in [A Delhi Fund]. [P Esso Inc.] did not disclose how much [P they] paid for [A Dehli].

- Key aspect: need to combine information across multiple mentions of an entity using coreference

Haghighi and Klein (2010)

Slot Filling: Forums

- Extract product occurrences in cybercrime forums, but not everything that looks like a product is a product

```
TITLE: [ buy ] Backconnect bot
BODY: Looking for a solid backconnect bot.
      If you know of anyone who codes them please let me know

(a) File 0-initiator4856
```

```
TITLE: Exploit cleaning ?
BODY: Have some Exploits I need fix.

(b) File 0-initiatorI0815
```

Not a product in this context

Portnoff et al. (2017), Durrett et al. (2017)

Relation Extraction

- Extract entity-relation-entity triples from a fixed inventory
  - Located_In
  - Nationality

During the war in Iraq, American journalists were sometimes caught in the line of fire

- Use NER-like system to identify entity spans, classify relations between entity pairs with a classifier
- Systems can be feature-based or neural, look at surface words, syntactic features (dependency paths), semantic roles
- Problem: limited data for scaling to big ontologies

ACE (2003-2005)
### Hearst Patterns

- Syntactic patterns especially for finding hypernym-hyponym pairs ("is a" relations)
  - "Y is a X"  
    - Example: Berlin is a city
  - "X such as [list]"  
    - Example: cities such as Berlin, Paris, and London.
  - "other X including Y"  
    - Example: other cities including Berlin

- Totally unsupervised way of harvesting world knowledge for tasks like parsing and coreference (Bansal and Klein, 2011-2012)

*Hearst (1992)*

### Distant Supervision

- Lots of relations in our knowledge base already (e.g., 23,000 film-director relations); use these to bootstrap more training data
- If two entities in a relation appear in the same sentence, assume the sentence expresses the relation
- Totally unsupervised way of harvesting world knowledge for tasks like parsing and coreference (Bansal and Klein, 2011-2012)

*Open IE*

#### Distant Supervision

- Learn decently accurate classifiers for ~100 Freebase relations
- Could be used to crawl the web and expand our knowledge base

<table>
<thead>
<tr>
<th>Relation name</th>
<th>100 instances</th>
<th>1000 instances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Syn</td>
<td>Lex</td>
</tr>
<tr>
<td>/film/director/film</td>
<td>0.49</td>
<td>0.43</td>
</tr>
<tr>
<td>/film/.writer/film</td>
<td>0.70</td>
<td>0.60</td>
</tr>
<tr>
<td>/geography/tiver/basin.countries</td>
<td>0.65</td>
<td>0.64</td>
</tr>
<tr>
<td>/location/country/administrative.divisions</td>
<td>0.68</td>
<td>0.59</td>
</tr>
<tr>
<td>/location/location/contains</td>
<td>0.81</td>
<td>0.89</td>
</tr>
<tr>
<td>/location/us.country/country.seat</td>
<td>0.51</td>
<td>0.51</td>
</tr>
<tr>
<td>/music/artist/origin</td>
<td>0.64</td>
<td>0.66</td>
</tr>
<tr>
<td>/people/deceased.person/place_of_death</td>
<td>0.80</td>
<td>0.79</td>
</tr>
<tr>
<td>/people/person/nationality</td>
<td>0.61</td>
<td>0.70</td>
</tr>
<tr>
<td>/people/person/place_of_birth</td>
<td>0.78</td>
<td>0.77</td>
</tr>
<tr>
<td>Average</td>
<td>0.67</td>
<td>0.66</td>
</tr>
</tbody>
</table>

*Mintz et al. (2009)*

- [Steven Spielberg]'s film [Saving Private Ryan] is loosely based on the brothers' story
- Allison co-produced the Academy Award-winning [Saving Private Ryan], directed by [Steven Spielberg]
Open Information Extraction

- “Open”ness — want to be able to extract all kinds of information from open-domain text
- Acquire commonsense knowledge just from “reading” about it, but need to process lots of text (“machine reading”)
- Typically no fixed relation inventory

TextRunner

- Extract positive examples of (e, r, e) triples via parsing and heuristics
- Train a Naive Bayes classifier to filter triples from raw text: uses features on POS tags, lexical features, stopwords, etc.
  - Barack Obama, 44th president of the United States, was born on August 4, 1961 in Honolulu
  - Barack Obama, was born in, Honolulu
- 80x faster than running a parser (which was slow in 2007...)
- Use multiple instances of extractions to assign probability to a relation

Exploiting Redundancy

- 9M web pages / 133M sentences
- 2.2 tuples extracted per sentence, filter based on probabilities
- Concrete: definitely true
- Abstract: possibly true but underspecified
- Hard to evaluate: can assess precision of extracted facts, but how do we know recall?

ReVerb

- More constraints: open relations have to begin with verb, end with preposition, be contiguous (e.g., was born on)
- Extract more meaningful relations, particularly with light verbs

Banko et al. (2007)

Fader et al. (2011)
ReVerb

- For each verb, identify the longest sequence of words following the verb that satisfy a POS regex (V .* P) and which satisfy heuristic lexical constraints on specificity
- Find the nearest arguments on either side of the relation
- Annotators labeled relations in 500 documents to assess recall

Fader et al. (2011)

QA from Open IE

(a) CCG parse builds an underspecified semantic representation of the sentence.

<table>
<thead>
<tr>
<th></th>
<th>Former</th>
<th>municipalities</th>
<th>in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandenburg</td>
<td>N</td>
<td>N</td>
<td>NP</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>N(N/NP)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
<td>λx, f(x) ∧ former(x)</td>
<td>λx.municipalities(x)</td>
<td>in(y, x)</td>
</tr>
<tr>
<td></td>
<td>λx, f(x) ∧ in(x, Brandenburg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>λx, f(x) ∧ in(x, Brandenburg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>λx, f(x) ∧ municipalities(x)</td>
<td>in(y, Brandenburg)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>λx, f(x) ∧ in(x, Brandenburg)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Takeaways

- SRL/AMR: handle a bunch of phenomena, but more or less like syntax++ in terms of what they represent
- Relation extraction: can collect data with distant supervision, use this to expand knowledge bases
- Slot filling: tied to a specific ontology, but gives fine-grained information
- Open IE: extracts lots of things, but hard to know how good or useful they are
  - Can combine with standard question answering
  - Add new facts to knowledge bases
- Many, many applications and techniques

Choi et al. (2015)