CS 4650/7650, Lecture 20
Anaphora and coreference resolution

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1 Coreference terminology

Apple Inc Chief Executive Tim Cook has jetted into China for talks with government officials as he seeks to clear up a pile of problems in the firm's biggest growth market.

- **Referring expressions**: *he*, *Tim Cook*, *the firm*, *the firm's biggest growth market*, ...
- **Referents** are (often) entities, like Tim-Cook, Apple, China
- **Coreference** is when referring expressions have the same referent. *Tim Cook* and *he* are coreferent.
- *Tim Cook* **evokes** the referent, *he* **accesses** it.

Which other expressions are coreferent in this example?

There are many possibilities for describing a referent.

- Indefinite NPs: *a visit*, *two stores*
- Definite NPs: *the capital*, *his first trip*
- Pronouns: *he, it*
- Demonstratives: *this chainsaw*, *that abandoned mall*
- Names: *Tim Cook*, *China*

How do you know which type of referring expression to use?

- **Language generation** requires getting this right!
  You can't say: *Rob Ford apologized for "a lot of stupid things" but Rob Ford only acknowledged a video showing Rob Ford smoking what appears to be crack cocaine to demand police release it.*
- **Language understanding** requires figuring out which referent is intended by ambiguous referring expressions.
  - Anaphora resolution is primarily concerned with pronouns like *it, this, her*
  - Coreference resolution adds two additional phenomena
    * **Names**: *Barack Obama*, *Obama*, *President Obama*, *Barry O*, *Nobama*
    * **Nominals**: *the 44th president*, *the former senator from Illinois*, *our first African-American president*

  What factors determine the choice of referring expression?
  - The **type** of referring expression (pronoun, name, etc) is largely determined by discourse
  - The **specific** referring expression within a type is determined by syntax and semantic constraints

2 About pronouns and reference

Are all referents entities? Nope.

- *They told me that I was too ugly, but I didn't believe* ***it****.*
- *Alice saw Bob get angry, and I saw* ***it*** *too.*
- *They told me that I was too ugly, but* ***that*** *was a lie.*
- *Jess said she had been to prison.*
  I suppose ***that****'s one way to put it.*

Are all pronouns referential? Also no.

Cataphora are references to entities which are evoked *after* the reference.

When she learned what had happened, Alice took the first bus out of town.

Some pronouns have **generic** referents:

- *A good father takes care of **his** kids.*
- *I want to buy a Porsche, **they** are so fast.*
- *On the moon, **you** have to carry **your** own oxygen.*

Some pronouns don't refer to anything at all:

- Pleonastic: ***It**'s raining. **It**'s crazy out there.*
- Cleft: ***It**'s money that she's really after.*
- Extraposition: ***It** sucks that we have to work so hard.*
- Other languages:
  - *S'**il** vous plaît* (literally: *if it pleases you*)
  - *Wie geht es Ihnen*

How to distinguish these from referential pronouns? Bergsma, Lin, and Goebel (2008) propose a substitutability text.

- *You can make it in advance* → *You can make **them** in advance*
- *You can make it in Hollywood* → *You can make **them** in Hollywood*

Specifically, consider 5-gram context patterns.

*... said here Thursdasy that **it** is unnecessary to continue*

said	here	Thursday	that	*				
	here	Thursday	that	*	is			
		Thursday	that	*	is	unnecessary		
			that	*	is	unnecessary	to	
				*	is	unnecessary	to	continue

For each pattern, compute the corpus counts of five **pattern fillers**:

1. *it/its*
2. *they/them/their*
3. other pronouns *she/her/...*
4. rare words (almost always nouns)
5. all other tokens (usually nouns)

These 25 counts are converted into a feature vector, and you can train a supervised classifier.

3 Discourse factors in selecting referring expressions

3.1 Givenness hierarchy

- The choice of referring expression depends the **status** of the referent, with respect to both the discourse and the hearer.
- The "givenness hierarchy" is one way of characterizing referent status.
  - **type identifiable** (you know what dogs are): indefinite
    I couldn't sleep, ***a dog*** *kept me awake.*
  - **referential** (some particular dog): indefinite *this*
    I couldn't sleep, ***this dog*** *kept me awake.*
  - **uniquely identifiable**: definite
    I couldn't sleep, ***the neighbor's dog*** *kept me awake.*
  - **familiar**: distal demonstrative
    That dog *next door kept me awake all night.*
  - **activated**: demonstrative
    My neighbor bought a new dog, and ***that dog*** *kept me awake last night.*
  - **in focus**: pronoun
    Her dog barks constantly. ***It*** *kept me awake all night.*

(this is really difficult for L2 speakers)

The location of an entity in the givenness hierarchy depends (in part) on the discourse:

- *You look tired, did a dog keep you awake?*
- *We bought a dog. It keeps me up all night.*
- Referents which were recently accessed acquire *salience*, and are more likely to be near the top of the givenness hierarchy.

However, background knowledge also plays an important role.

- If a pair of speakers lives with a (single) dog, it is always at least uniquely identifiable.
- Entities may be **inferrable** from the discourse:
  She just bought a new bike.
  The wheels *are made of bamboo fiber.*

3.2 Centering theory

The givenness hierarchy relates the status of the referent in the discourse to the type of referring expression. Centering theory goes further, explaining the syntactic position in the sentence (Grosz et al., 2005).

At each utterance U_n, we have:

- A backward-looking center $C_b(U_n)$:
  the entity currently **in focus** after U_n.
- A forward-looking center $C_f(U_n)$:
  an ordered list of candidates for $C_b(U_{n+1})$.
- The top choice in $C_f(U_n)$ is $C_p(U_{n+1})$

How do we order the candidates from $C_b(U_{n+1})$ to the forward-looking center? By syntax:

1. Subject
   Abigail *saw an elephant.*
2. Existential predicate nominal
   There is ***an elephant*** *in the room.*
3. Direct object
   Abigail gave ***a snack*** *to the elephant.*
4. Indirect object or oblique
   Abigail gave a snack to ***the elephant****.*
5. demarcated adverbial prepositional phrase
   Inside ***the zoo****, the elephant is king.*

Rule: If any element of $C_f(U_n)$ is realized by a pronoun in U_{n+1}, then $C_b(U_{n+1})$ must also be realized as a pronoun.

- Generate possible C_b and C_f for each set of reference assignments
- Filter by constraints: syntax, semantics, and centering rules
- Rank by transition orderings: continue, retain, smooth-shift, rough-shift

	$C_b(U_{n+1}) = C_b(U_n)$ or $C_b(U_n) = \varnothing$	$C_b(U_{n+1}) \neq C_b(U_n)$
$C_b(U_{n+1}) = C_p(U_{n+1})$	Continue	Smooth-shift
$C_b(U_{n+1}) \neq C_p(U_{n+1})$	Retain	Rough-shift

In a coherent discourse, we select transitions according to the following preferences: continue, retain, smooth-shift, rough-shift

Here's an example of how to use centering to resolve pronouns.

U_n	$C_f(U_n)$	$C_p(U_n)$	$C_b(U_n)$	transition
John saw a beautiful Masi at the bike shop	John, Ford, bike shop	John	$\varnothing$	
He showed it to Bob	John, Masi, Bob	John	John	Continue
He showed it to Bob	John, bike shop, Bob	John	John	Continue
He bought it	John, Masi or bike shop	John	John	Continue
He bought it	Bob, Masi or bike shop	Bob	Bob	Smooth-shift

- Centering theory tells us that we prefer *John* over *Bob* as the referent for *he* in U_3, because this would be a continue transition rather than a smooth-shift.
- Centering doesn't really give us a rule for choosing *Masi* over *bike shop* in U_2, because neither is $C_b(U_2)$. We might apply the grammatical role hierarchy since there is no other basis for this decision.

4 Resolving ambiguous pronouns

Apple Inc Chief Executive Tim Cook has jetted into China for talks with government officials as **he** seeks to clear up a pile of problems in the firm's biggest growth market, from **its** contested iPad trademark to treatment of local labor. Cook is on **his** first trip to the country...

- *he* $\stackrel{?}{=}$ *Apple Inc*, *Tim Cook*, *China*, *talks*, *government officials*, *government*, ...
- *its* $\stackrel{?}{=}$ *the firm's biggest growth market*, *the firm*, *problems*, *a pile of problems*, ...
- *his* $\stackrel{?}{=}$ *Cook*, *local labor*, *its contested iPad trademark*, *iPad*, ...

How can we resolve these pronouns?

4.1 Semantic constraints

- **Number**
  - *Tim Cook has jetted in for talks with officials as **he** seeks to clear up a pile of problems...*
    - Number(*he*) = singular
    - Number(*officials*) = plural
    - Number(*Tim Cook*) = singular
  - Mass noun are tricky: *New York has won the superbowl. They are the world champions.*
- **Person**: *We$_1$ *told* them$_1$ *not to go.*
- **Gender and animacy**
  - *Sally met my brother. He charmed her.*
  - *Sally met my brother. She charmed him.*
  - *Putin brought a bottle of vodka. It was from Russia.*

4.2 Syntactic constraints

There are general constraints on reference within sentences, which seem to generalize well across languages.

- x **c-commands** y iff the first branching node above x also dominates y.
- x **binds** y iff x and y are co-indexed and x c-commands y
- if y is not bound, it is **free**

```
\Tree [.S [.NP \example{Mary} ] [.VP \example{cooks} [.PP \example{for} \example{he
```

- *Mary* c-commands *her*/*herself*.
- *her*/*herself* does not c-command *Mary*.
- *her* **cannot** refer to *Mary*, because pronouns cannot refer to antecedents that c-command them.
- *herself* **must** refer to *Mary*.

```
\Tree [.S [.NP \example{Mary's} \example{mom} ] [.VP \example{cooks} [.PP \example{
```

- *Mary* does **not** c-commands *her*
- *Mary's mom* c-commands *her*
- *her* **can** refer to *Mary* (and we cannot use reflexive *herself* in this context, unless we are talking about Mary's mom)
- But it doesn't have to, because pronouns can be free.

```
\Tree [.S [.NP \example{Abigail} ] [.VP [.V \example{says} ] [.S [.NP \example{she}
```

Constraints have a limited domain.

- *she* can refer to *Abigail*
- *her* can also refer to *Abigail*
- But *she* and *her* cannot be coreferent.

Besides these rules, syntax also exercises preferences. See slides.

4.3 Combining the evidence

Three **types** of evidence:

- Semantic constraints
- Syntactic constraints
- Discourse/salience preferences

How do we combine them?

- **Hobbs**: Tree search + constraints

  Walk back through the tree in a deterministic order, select the first referent that satisfies the constraints.

- **Centering**: ordered preferences + constraints

  Apply centering theory to recover the references that give the most preferred transition sequence, subject to semantic constraints.

- **Lappin and Lease**: numerical preferences + constraints

  Basically a hand-tuned linear classifier.

  - -100 for each intervening sentence
  - +80 for subject position
  - +70 for existential emphasis, e.g. *there was a woman who...*
  - +50 for accusative emphasis
  - ...
- Ge, Hale, and Charniak (1999): statistical combination of four probabilities
  - probability of the "Hobbs distance" between pronoun and antecedent
  - probability of the pronoun given the antecedent
    (this considers gender and animacy)
  - how well the proposed antecedent fills the pronoun's slot in the sentence
  - frequency of the proposed referent

5 Coreference resolution

This is a generalization of the anaphora resolution task to cover proper nouns and nominals.

- See the slides for an example.
- The coreference task comes from the information extraction community.
- Candidate spans of text for coreference are called **markables**
- In the harder versions of the coreference task, you have to identify the markables as well as their reference chains.

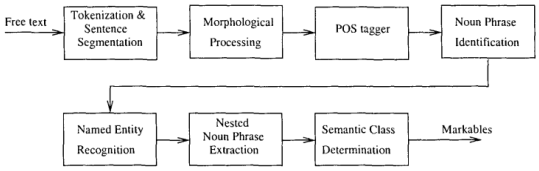
Coreference combines many phenomena: all the ones in anaphora resolution, plus string similarity and knowledge to get nominals.

- *unencrypted Wi-Fi networks* and *networks* have the same head word
- *Dr. King* and *Martin Luther King* can all co-refer
- *Martin Luther King* and *Coretta Scott King* cannot
- **World knowledge**: e.g., *Google* is a *company*,
  companies possess *cars* but *Tuesday* doesn't.

5.1 The mention-pair model

One of the earliest end-to-end machine learning systems for coreference is from Soon, Ng, and Lim (2001).

- Identify markables and their features with an NLP pipeline.



- Train a classifier to predict which pairs of markables corefer. This is the **mention-pair** model.
  - For each markable, go backwards until the classifier selects an antecedent or you reach the beginning of the document.
  - No structured prediction here; each classification decision is made independently.

Learning is performed on mention pairs.

- Given the labeled chain A1-A2-A3-A4, the adjacent pairs A1-A2, A2-A3, A3-A4 are treated as positive examples.
- Negative examples are generated from NPs that occur between the adjacent pairs.
  - Suppose markables A,B,B1 appear between A1 and A2.
  - Then the negative examples are: A-A2, B-A2, B1-A2.

There are fundamental problems with mention-pair approaches.

- They fail to aggregate information across the chain.
- Must reason about transitivity to avoid incoherent chains.
- *Michelle Obama* ← *Obama* ← *Mr. Obama*

5.2 Entity-based coreference

Alternatively, we can try to learn at the entity level, using features of the entities themselves

- Number of entities detected so far
- Mention to entity ratio
- Entity to word ratio
- Number of intervening mentions between mention and linked entity
- ...

Can incorporate these by scoring entire clusterings, $\boldsymbol{w}^\top \boldsymbol{f}(\boldsymbol{x}, \boldsymbol{y})$.
But how to train such a model?

One approach is an incremental perceptron. This is like a structured perceptron, but you incrementally build the structure, and you update as soon as you make a mistake. The Bell Tree can represent the coreference structure.