Referring Expressions

Cognitive Status and Givenness Hierarchy
Syntactic Constraints
Salience

Pronoun resolution algorithms
Hobbs
Lappin and Leass
Ge et al.

Centering (Grosz et al. 1995)

Reading:
Jurafsky and Martin, chapter 21.3-21.6

From The Adventures of Tom Sawyer by Mark Twain

The old lady pulled her spectacles down and looked over them about the room; then she put them up and looked out under them. She seldom or never looked THROUGH them for so small a thing as a boy; they were her state pair, the pride of her heart, and were built for "style," not service—she could have seen through a pair of stove-lids just as well.

Aunt Polly pulled Aunt Polly’s spectacles down and looked over Aunt Polly’s spectacles about the room; then Aunt Polly put Aunt Polly’s spectacles up and looked out under Aunt Polly’s spectacles. Aunt Polly seldom or never looked THROUGH Aunt Polly’s spectacles for so small a thing as a boy…

This one neither (all pronominalised)…

She pulled them down and looked over them about it; then she put them up and looked out under them. She seldom or never looked THROUGH them for so small a thing as that; they were her state pair, the pride of it, and were built for “style,” not service—She could have seen through them just as well.

Appropriate use of referring expressions reduces communication effort for both listener and speaker.
Anaphora resolution vs. coreference resolution

Anaphora resolution
Task of finding an antecedent for each anaphor (typically, pronoun).

Coreference resolution
Task of partitioning the set of all referring expressions into equivalence classes (chains) that refer to one referent.

Terminology

- **anaphora**: the phenomenon of referring to an antecedent (metonymically also refers to the referring expression). Subtypes are pronouns and definite NPs.
- **referent**: a real world entity that some piece of text (or speech) refers to.
- **referring expressions**: bits of language used to perform reference by a speaker.
- **coreference**: two references to the same referent
- **antecedent**: the text evoking a referent.
- **cataphora**: the phenomenon where the referring expression precedes the antecedent (metonymically also refers to the referring expression)
  - After his class, John will play football.

Types of referring expressions

- **Indefinite Noun Phrase**: introduce new entities into the discourse; e.g., a pair of stove-lids
- **Proper Noun**: evoke uniquely identifiable known entity.
- **Definite and Demonstrative Noun Phrase**: refer to entities that are uniquely identifiable by the listener; e.g., the room. (Not all definite NPs are referring, e.g. the fact that the earth is round; the US president)
- **Personal Pronoun**: refers to entities that have high level of activation in the listener’s attentional state; e.g., her, them.
- **Demonstrative Pronoun**: can refer to entities and to events (e.g., I had not expected that).
- **One-Anaphora**: select one from a set of entities. It can introduce a new entity into the discourse, but this is dependent on an existing representation for the larger set; e.g., I would like one.
Types of Reference

Coreference
- referring expression refers to an entity that has been explicitly evoked

John owns a car. It is a Ford.

Bridging Reference
- refer to entities that are inferable from previously evoked entities

John’s car is very old. The engine is noisy and a door is dented.

- can involve Synonymy, Hyponymy, Meronymy
- or other form of inference, e.g.,

I bought an iPad today. They are so cool.

Cognitive Status and Givenness Hierarchy

Syntactic Constraints

Salience

Non-referential usage

Cleft

It was Frodo who took the ring.

Pleonastic

It was raining.

Extraposition

It was unnecessary to repeat it.

Cognitive Status

- type identifiable: Listener is able to access a representation of the object type (in 1, knowing what a dog is).
- referential: Listener can either retrieve from memory the specific dog referred to, or construct a new representation for this specific dog.
- uniquely identifiable: Listener can uniquely identify the intended referent on basis of the noun phrase alone.
- familiar: Listener already has an accessible representation in memory. (4 can be used if the listener knows there is a dog next door.)
- activated: Listener has immediate access to the referent, i.e., it is in short-term memory, either through discourse or real world. (5 is acceptable if the listener can hear the dog barking.)
- in focus: The referent is the focus in the discourse, not only in short-term memory (compare to 5).
Givenness Hierarchy

**focus > activated > familiar > unique > referential > type identifiable**

<table>
<thead>
<tr>
<th></th>
<th>Focus</th>
<th>Activated</th>
<th>Familiar</th>
<th>Unique</th>
<th>Referential</th>
<th>Type identifiable</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>I</td>
<td>He, this, that, this N</td>
<td>that N</td>
<td>the N</td>
<td>indef., this N</td>
<td>a N</td>
</tr>
<tr>
<td>Chinese</td>
<td>0, ta (he, she, it)</td>
<td>TA, the, ne, zhe N (this, that N)</td>
<td>net N</td>
<td>v N (a N), if N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japanese</td>
<td>N</td>
<td>sore (he), sore (this), are (that-distal), kono N (this N), sono N (that-medial)</td>
<td>ano N (that-distal N)</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russian</td>
<td>0, on (he)</td>
<td>UN, esta (this), to (that)</td>
<td>inon N (this N), to N (this N)</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spanish</td>
<td>0, el (he)</td>
<td>EL, este (this), este (that-medial), aquel (that-distal), el N (this N)</td>
<td>est N (this N), to N (this N)</td>
<td>N, on N (a N)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Agreement Constraints on Coreference

- **number** = singular, plural
- **person** = first, second, third
- **gender** = masculine, feminine, non-personal
- **case** = nominative, accusative, genitive

<table>
<thead>
<tr>
<th>First Person</th>
<th>Second Person</th>
<th>Third Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singular</td>
<td>Plural</td>
<td>Singular</td>
</tr>
<tr>
<td>l</td>
<td>we</td>
<td>he, she, they</td>
</tr>
<tr>
<td>you</td>
<td>you</td>
<td>him, her, them</td>
</tr>
</tbody>
</table>

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Binding Theory (Chomsky, 1981)

**Principle A:** Reflexives must have local antecedents:
- *John*; washed *himself*;
- *John*; asked Mary to wash *himself*;

**Principle B:** Personal pronouns must not have local antecedents:
- *John*; asked Mary to wash *him*;
- *John*; washed *him*;

**Principle C:** A referring expression cannot have an antecedent that c-commands it:
- *John*; saw *John*;

C-command: the relationships “brother, uncle, great-uncle, great-great-uncle . . .”
In general, any shared knowledge between the speaker and the listener can be used to constrain the choice of referring expression. In particular:

**Selectional Restrictions**
Jerry bought coffee from the store. Henry drank it.

**Verb semantics and “implicit cause”**
John telephoned Bill. He had lost the laptop.
John criticised Bill. He had lost the laptop.

**Discourse Accessibility**
George didn’t buy a Volvo. *It was blue.

**Recency:** Entities introduced in recent utterances are more likely to be referred to by a pronoun than entities introduced in utterances further back.

**Grammatical Role:** Entities introduced in subject position tend to get topicalised, and are more likely to be referred to by a pronoun than entities in object positions.

**Repetition:** Entities that have already been referred to frequently are more likely to be pronominalised than those that have not.
George needed a new car. His previous car got totaled, and he had recently come into some money. Jerry went with him to the car dealers. He bought a Nexus.

**Parallelism:** Pronouns are more likely to refer to those entities that do not violate syntactically parallel constructions.
John took Bill to the zoo; Mary took him to the park.

**Many factors influence pronoun resolution**
Many of these factors might contradict each other for specific examples
No pronoun resolution algorithm successfully accounts for all these factors
Next: three pronoun resolution algorithms
- Purely syntax-based (Hobbs)
- Salience model (Lappin & Leass)
- Supervised ML (Ge et al.)
These give a broad overview of the field
Hobbs’ (1978) Algorithm

- Simple syntax-based algorithm for 3rd person anaphoric pronouns
- Relies on:
  - syntactic parser (with X-Bar output)
  - morphological number and gender checker
- Searches syntactic trees of current and preceding sentences in breadth-first, left-to-right manner. Stops when it finds matching NP.

Hobbs’ Algorithm, continued

5. If N2 is an NP which is not in c-command, propose it as the antecedent.
6. Otherwise, apply steps 2-3 to N2.
7. If no antecedent NP is found, continue to apply steps 4 and 5 and then steps 2-3 to progressively higher NP/S nodes.
8. If no antecedent found at highest S of sentence, find the highest S node of the immediately preceding sentence and apply steps 2-3.
9. If still no antecedent found after n sentences, search for cataphora in current sentence from left-to-right, starting with first NP to the right of pronoun.

Hobbs: An Example

- Start search at NP5 in S2.
- Reject NP4 – c-commands NP5
- Move to S1. NP1 is first NP we encounter, so finish.
- Result: Lyn’s mom
- What would have happened if the subject of S2 was Craige’s mom?
Two different operations are performed:

- Maintaining and updating a discourse model consisting of a set of co-reference classes:
  - Each co-reference class corresponds to one entity that has been evoked in the discourse
  - Each co-reference class has an updated salience value
- Resolving each Pronoun from left to right
  - Collect potential referents from up to 4 sentences back
  - Filter out coreference classes that don’t satisfy agreement/syntax constraints
  - Select remaining co-reference class with the highest salience value; add pronoun to class.

The salience of a referent is calculated on the basis of recency and grammatical function.

<table>
<thead>
<tr>
<th>Salience Factor</th>
<th>Example</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current sentence</td>
<td>John opened the door</td>
<td>100</td>
</tr>
<tr>
<td>Subject emphasis</td>
<td>There was a dog standing outside</td>
<td>80</td>
</tr>
<tr>
<td>Existential emphasis</td>
<td>John liked the dog</td>
<td>70</td>
</tr>
<tr>
<td>Accusative emphasis</td>
<td>John gave a biscuit to the dog</td>
<td>50</td>
</tr>
<tr>
<td>Indirect object</td>
<td>Inside the house, the cat looked on</td>
<td>40</td>
</tr>
<tr>
<td>Non-adverbial emphasis</td>
<td>The cat in the house looked on</td>
<td>50</td>
</tr>
<tr>
<td>Head Noun emphasis</td>
<td></td>
<td>80</td>
</tr>
</tbody>
</table>

Non-adverbial emphasis penalises nouns in adverbial phrases. Head-noun emphasis penalises NPs contained in other NPs.

Lappin and Leass report 86% accuracy for their algorithm on a corpus of Computer manuals.

The Camelot Example

The castle in Camelot remained the residence of the king until 536 when he moved it to London.
A Longer Example

Niall Ferguson is prolific, well-paid and a snappy dresser. Stephen Moss hated him, at least until he spent an hour being charmed in the historian’s Oxford study.

- Discourse Referents:
  - \( N_0 = \{Niall Ferguson\} = 105 \)
  - \( S_0 = \{Stephen Moss\} *does not pass syntax filter* 
- New Discourse referents
  - Add him to \( N_0; N_1 = \{Niall Ferguson, him\} \)

Ge et al.’s Algorithm

- The algorithm by Ge et al. (1998)
  - does not use an explicit model of discourse
  - collapses the distinction between hard constraints and soft preferences
    - Gender information is often noisy (eg: Clinton, Alex etc)
    - Number agreement not an absolute constraint in all cases
- They use a Bayesian Approach that incorporates all factors in a machine learning framework.

Ge et al. Algorithm

- Features are derived from agreement values, grammatical roles, recency and repetition
- Calculate the probability \( p(a|p, f_1...f_n) \) that \( a \) is the antecedent of a pronoun \( p \) given the features \( f_{1-n} \).
- Pronoun is resolved by maximising \( P(a_i|p, f_{1-n}) \) over all potential antecedents \( a_i \).
Bootstrapping Gender Information

Unsupervised approach to learning gender information:

- First run Hobbs’ algorithm on the entire Penn Treebank (WSJ)
- Count number of times a noun was labelled as the antecedent of he/his/him/himself, she/her/herself/hers and it/its/itself
- This allows to compute $p(m|w_i)$, $p(f|w_i)$ and $p(n|w_i)$ for every word $w_i$ in Penn Treebank (the probabilities that a word $w_i$ is male, female or inanimate)
- Now use (preliminary) gender information to improve the pronoun resolution algorithm
- This results in recalculation of revised gender probabilities for all words in the Penn Treebank.

Ge et al. results

- Ge et al. report 82.9% of pronouns resolved correctly by their algorithm.
  - removing the syntax features brings the accuracy down to 43%
  - providing perfect gender information improves the accuracy to 89.3%

Centering Theory (Grosz et al. 1995)

Motivation I: Centering provides a model for judging the coherence aspect of text quality.

**Less Coherent Text**

John went to his favourite music store to buy a piano. It was a store John had frequented for many years. He was excited that he could finally buy a piano. It was closing just as John arrived.

**More Coherent Text**

John went to his favourite music store to buy a piano. He had frequented the store for many years. He was excited that he could finally buy a piano. He arrived just as the store was closing for the day.

Motivation II: It can also be used for pronoun resolution, by predicting which references would be hard to process by a human.

**A bad example**

Tony was furious at being woken up so early. He told Terry; to get lost and hung up. Of course, he; hadn’t intended to upset Tony.

- We want to predict that the use of he is inappropriate for referring to Terry.
Centering Theory

- A model of the local aspects of attentional state
  - tracks changes in local focus
  - does not provide an account of entities that are globally relevant throughout the discourse.
- The term center is used for an entity that links an utterance to other utterances in the same discourse segment
- Hence, the centers introduced by an utterance are also influenced by the surrounding context, not just by the utterance in isolation.

Centering

Every utterance \( U \) in a discourse introduces
- a set of forward-looking centers \( C_f(U) \) (contains all the discourse entities evoked by the utterance \( U \))
  - \( C_f(U) \) is ordered according to the prominence of its member entities in the utterance \( U \).
  - Ordering principle: grammatical function (subjects > objects > everything else).
- exactly one backward-looking center \( C_b(U) \).
  - \( C_b(U_n) \) of an utterance \( U_n \) is defined as the entity with the highest rank in \( C_f(U_{n-1}) \) that is evoked in \( U_n \).
  - The backward-looking center \( C_b(U_n) \) thus serves as a link with the preceding utterance \( U_{n-1} \).

Centering: A model of discourse

- The forward-looking centers \( C_f(U_{n-1}) \) are a rough model of the listener’s attentional state after \( U_{n-1} \)
- They predict what the backward-looking center of the utterance \( U_n \) will be; in particular, \( C_b(U_n) = C_{f,\text{top}}(U_{n-1}) \)
- Need to perform pronoun resolution as you go along, in order to build forward-looking centers (use the same model)
- Abrupt changes in the focus of the discourse are reflected in changes in the backward-looking center.
- Discourse is then modelled by the types of transitions in the backward-looking centers from sentence to sentence.
- A discourse that keeps its center is most coherent, but if changes in topic occur, they should be transitioned smoothly

Four Types of Transitions

Two contributing factors:
- Did \( C_b \) change from \( U_{n-1} \) to \( U_n \)? ([Undefined-to-any-\( C_b \] counts as “no change”)
- Was \( C_{f,\text{top}} \) correctly predicted by \( C_b \)?

<table>
<thead>
<tr>
<th>( C_{f,\text{top}} ) predicted</th>
<th>Same ( C_b )</th>
<th>Change in ( C_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTINUE</td>
<td>SMOOTH</td>
<td></td>
</tr>
<tr>
<td>SHIFT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( C_{f,\text{top}} ) not predicted</th>
<th>RETAIN</th>
<th>ROUGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHIFT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CONTINUE: \(C_b(U_n) = C_b(U_{n-1}) = C_{f,\text{top}}(U_n)\)

**U_1:** John went to his favourite music store to buy a piano.

\[C_b(U_1) = \text{Undefined}; \ C_f(U_1) = \{\text{John, store, piano}\}\]

**U_2:** He had frequented the store for many years.

**CONTINUE:** \(C_b(U_2) = \text{John}; \ C_f(U_2) = \{\text{John, store, years}\}\)

**U_3:** He was excited that he could finally buy a piano.

**CONTINUE:** \(C_b(U_3) = \text{John}; \ C_f(U_3) = \{\text{John, piano}\}\)

In center continuation, the discourse stays focused on the same entity.

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**U_1:** John was excited that he could finally buy a piano.

\[C_b(U_1) = \text{Undefined}; \ C_f(U_1) = \{\text{John, piano}\}\]

**U_2:** He had frequented the store for many years.

**CONTINUE:** \(C_b(U_2) = \text{John}; \ C_f(U_2) = \{\text{John, store, piano}\}\)

**U_3:** It was about to close for the day.

**RETAINT:** \(C_b(U_3) = \text{John}; \ C_f(U_3) = \{\text{store, day}\}\)

**U_4:** It was his favourite shop in the world.

**S-SHIFT:** \(C_b(U_4) = \text{store}; \ C_f(U_4) = \{\text{store, John, world}\}\)

Smooth shifts are predictable changes in focus.

---

**U_1:** John was excited that he could finally buy a piano.

\[C_b(U_1) = C_b(U_{n-1}) = C_{f,\text{top}}(U_n)\]

**U_2:** He had frequented the store for many years.

**CONTINUE:** \(C_b(U_2) = \text{John}; \ C_f(U_2) = \{\text{John, store, years}\}\)

**U_3:** It was closing just as John arrived.

**RETAINT:** \(C_b(U_3) = \text{John}; \ C_f(U_3) = \{\text{store, John}\}\)

In center retaining, a connecting sentence which evokes the next focus of discourse. \(C_b\) is retained from \(U_{n-1}\) to \(U_n\), but it is likely to change in \(U_{n+1}\).

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**U_1:** John had always liked going to this store.

\[C_b(U_1) = \text{Undefined}; \ C_f(U_1) = \{\text{John, store}\}\]

**U_2:** It had a wide selection of musical instruments.

**RETAINT:** \(C_b(U_2) = \text{John}; \ C_f(U_2) = \{\text{store, instruments}\}\)

**U_3:** Mary visited it just as he left.

**R-SHIFT:** \(C_b(U_3) = \text{store}; \ C_f(U_3) = \{\text{Mary, store, John}\}\)

Rough shifts are unpredictable changes in discourse focus.
Referring Expressions
Pronoun resolution algorithms
Centering (Grosz et al. 1995)

Center-Realisation Rules

So far, all pronoun resolution was unambiguous. Now let’s move to non-trivial pronoun resolution with this algorithm. Centering theory postulates two rules that constrain center-realisation:

**Rule 1**
If any element in $C_f(U_{n-1})$ is realised by a pronoun in $U_n$, then the center $C_b(U_n)$ must also be realised by a pronoun.

**Rule 2**
Sequences of center continuation are considered less disruptive than sequences of retaining, which are in turn less disruptive than sequences of shifts (smooth being better than rough).

Centering Algorithm

**Goal**: Find the referent that causes the smoothest $C_b$ transition according to Rule 2, without violating Rule 1 or any agreement or syntactic constraints.

- Move through the discourse window from left to right. At each pronoun:
  - Generate $C_f$ combinations for each possible set of referent assignments; this will create $C_b$s (top-ranked).
  - Filter by agreement and syntactic constraints and Rule 1.
  - Rank remaining referent assignments using Rule 2, i.e., transition orderings.

Pronoun Resolution

**U₁**: Tony was furious at being woken up so early.

$C_b(U₁) = \text{Undefined}; \; C_f(U₁) = \{\text{Tony}\}$

**U₂**: He told Terry to get lost and hung up.

CONTINUE: $C_b(U₂) = \text{Tony}; \; C_f(U₂) = \{\text{Tony, Terry}\}$

**U₃**: *Of course, he hadn’t intended to upset Tony.

$C_b(U₃) = \text{Tony}; \; C_f(U₃) = \{\text{Terry, Tony}\}$

- As Terry is a member of $C_f(U₂)$ that is realised as a pronoun in $U₃$, Rule 1 says that Tony, being $C_b(U₃)$, must also be realised as a pronoun in $U₃$ (but it isn’t).
- Rule 1 filters this interpretation out.

**U₄**: Brennan drives an Alfa Romeo.

$C_b(U₄) = \text{Undefined}; \; C_f(U₄) = \{\text{Brennan, Alfa}\}$

**U₅**: Friedman races her on Sundays.

RETAIN: $C_b(U₅) = \text{Brennan}, \; C_f(U₅) = \{\text{Friedman, Brennan}\}$

**U₆**: She often beats her.

- Case 1: She=Brennan, her=Friedman
  - $C_f(U₆) = \{\text{Brennan, Friedman}\} \rightarrow \text{ROUGH SHIFT}$
- Case 2: She=Friedman, her=Brennan
  - $C_f(U₆) = \{\text{Friedman, Brennan}\} \rightarrow \text{SMOOTH SHIFT}$

Therefore: She=Friedman and her=Brennan
Looking at the coherence examples again

**U₁**: John went to his favourite music store to buy a piano.

*Cb*(U₁) = Undefined; * Cf(U₁) = {John, store, piano}

**U₂**: It was a store John had frequented for many years.

RETAIN: *Cb*(U₂) = John; * Cf(U₂) = {store, John, years}

**U₃**: He was excited that he could finally buy a piano.

CONTINUE: *Cb*(U₃) = John; * Cf(U₃) = {John, piano}

**U₄**: It was closing just as John arrived.

RETAIN: *Cb*(U₄) = John; * Cf(U₄) = {store, John}

**U₅**: It would open again tomorrow.

SMOOTH SHIFT: *Cb*(U₅) = store; * Cf(U₅) = {store}

Looking at the other coherence example

**U₁**: John went to his favourite music store to buy a piano.

*Cb*(U₁) = Undefined; * Cf(U₁) = {John, store, piano}

**U₂**: He had frequented the store for many years.

CONTINUE: *Cb*(U₂) = John; * Cf(U₂) = {John, store, years}

**U₃**: He was excited that he could finally buy a piano.

CONTINUE: *Cb*(U₃) = John; * Cf(U₃) = {John, piano}

**U₄**: He arrived just as the store was closing for the day.

CONTINUE: *Cb*(U₄) = John; * Cf(U₄) = {John, store, day}

**U₅**: It would open again tomorrow.

RETAIN: *Cb*(U₅) = John; * Cf(U₅) = {store}

Commonalities Centering vs. Lappin/Leass

- Both Lappin & Leass and Centering Approach
  - first identifying possible antecedents
  - then applying a set of filters to rule out some of them
  - and finally applying a decision procedure to select one of the remaining candidates
    - Centering uses Rule 2 (Continuation > Retain > Shift)
    - Lappin & Leass uses Salience Value

- Both algorithms
  - maintain a Discourse Model
  - differentiate between constraints (hard) and preferences (soft)

Summary

- Referring expressions and cognitive status
- Salience Factors:
  - Recency
  - Grammatical position
  - Repetition
  - Parallelism
- Knock-out Criteria:
  - Clashes in Gender, Number
  - Binding Theory
- Three algorithms:
  - Hobbs
  - Lappin and Leass
  - Ge et al
  - ... and a Discourse Theory
  - Centering Theory
References

- Jurafsky and Martin, Chapter 21.4