CS 6840: Natural Language Processing

Introduction

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What is Natural Language Processing?

- **Natural Language Processing (NLP)** = developing computer systems that can *process*, *understand*, or *communicate* in natural language (*text* or *speech*):
  - **Natural Languages**: English, Turkish, Japanese, Latin, Hawaiian Creole, Esperanto, American Sign Language, …
    - Music?
  - **Formal Languages**: C++, Java, Python, XML, OWL, Predicate Calculus, Lambda Calculus, …
  - **Natural Languages are significantly more difficult to process than Artificial Languages!**

- What about **Computational Linguistics (CL)**?
  - Computational Linguistics is focused on the *study of language*, using computational tools.
  - NLP is focused on solving language tasks such as *machine translation*, *information extraction*, *question answering*, *taking instructions*, *holding conversations*, …

NLP Application: Question Answering

What is the meaning of life?

- Input:
  - A question:
    - *What is the meaning of life?*
  - A large collection of text documents:
    - *all books from OU Library.*

- Output:
  - An answer, or list of answers.
    - Found by '*mining*' the documents in the collection.

Tomorrow, and tomorrow, and tomorrow,
Creeps in this petty pace from day to day,
To the last syllable of recorded time;
And all our yesterdays have lighted fools
The way to dusty death. Out, out, brief candle!
Life's but a walking shadow, a poor player
That struts and frets his hour upon the stage
And then is heard no more. It is a tale
Told by an idiot, full of sound and fury
Signifying nothing.

Skakespeare's Macbeth (Act 5, Scene 5, lines 17-28)

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NLP Application: Question Answering

What is the meaning of life?

- Input:
  - A question:

  Try simple pattern matching:
  "the meaning of life is <?>"

  ts:
  - *all books from OU Library.*

- Output:
  - An answer, or list of answers.
    - Found by '*mining*' the documents in the collection.

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NLP Application: Question Answering

What is the **meaning** of life?

- Input:
  - A question:
    - *What is the meaning of life?*

  <div>

  Word Sense Disambiguation:
  meaning ≃ signifying

  </div>

- Output:
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NLP Application: Question Answering

What is the **meaning** of **life**?

- Input:
  - A question:
    - *What is the meaning of life?*

  > Coreference Resolution:
  > {*Life*, *it*, *tale*} are coreferent.

- Output:
  - An answer, or list of answers.
    - Found by '*mining*' the documents in the collection.

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NLP Application: Question Answering

Input:
- A question:
  - *What is the meaning of life?*

> Syntactic Analysis:
> - *tale* is Subject of *signifying*.
> - *nothing* is Object of *signifying*.

Output:
- An answer, or list of answers.
  - Found by '*mining*' the documents in the collection.

What is the **meaning** of **life**?

Tomorrow, and tomorrow, and tomorrow,
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Fundamental NLP tasks:

- **Tokenization**.
- **Syntactic Analysis**:
  - Part of Speech Tagging.
  - **Dependency Parsing**.
- **Word Sense Disambiguation**.
- **Coreference Resolution**.
- Semantic Role Labeling.
- Semantic Parsing.

What is the **meaning** of **life**?

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Fundamental NLP Tasks in Text Analysis

- Tokenization

- Morphological Analysis

- Part of Speech Tagging

- Syntactic Parsing

- Word Sense Disambiguation

- Semantic Role Labeling

- Semantic Parsing

- Anaphora/Coreference Resolution

Tokenization

- **Tokenization** = segmenting text into words and sentences.
  - A crucial first step in most text processing applications.

- Whitespace indicative of word boundaries?
  - Yes: English, French, Spanish, …
  - No: Chinese, Japanese, Thai, …

- Whitespace is not enough:
  - 'What're you? Crazy?' said Sadowsky. 'I can't afford to do that.'
  - $\Rightarrow$ *'what're you? crazy? Sadowsky. 'I can't that.*

Word Segmentation

- In English, characters other than whitespace can be used to separate words:
    - **, ; . - : ( ) "**

- But punctuation often occurs inside words:
    - m.p.h., Ph.D., AT&T, 01/02/06, google.com, 62.5

- Expansion of clitic constructions:
    - he's happy $\Rightarrow$ he is happy
    - Need ambiguity resolution between clitic construction, possessive markers, quotative markers:
        - he's happy vs. the book's cover vs. 'what are you? crazy?'

Sentence Segmentation

- Generally based on punctuation marks: **? ! .**
  - Periods are ambiguous, as sentence boundary markers and abbreviation/acronym markers:
    - *Mr., Inc., m.p.h.*
  - Sometimes they mark both:
    - SAN FRANCISCO (MarketWatch) – Technology stocks were mostly in positive territory on Monday, powered by gains in shares of Microsoft Corp. and **IBM Corp.**

- Tokenization approaches:
  - Regular Expressions.
  - Machine Learning (state of the art).

Morphological Analysis

- **Morphology** = the field of linguistics that studies the internal structure of words.
  - **Morpheme** is the smallest linguistic unit that has semantic meaning:
    - **stems**: "carry", "depend", "Google", "lock"
    - **affixes**: "pre", "ed", "ly", "s"

- **Morphological analysis** = segmenting words into morphemes:
  - carried $\Rightarrow$ carry + ed (past tense)

  - independently $\Rightarrow$ in + (depend + ent) + ly

  - Googlers $\Rightarrow$ (Google + er) + s (plural)

  - unlockable $\Rightarrow$ un + (lock + able) ?   (un + lock) + able ?

Morphological Analysis: Stemming

- In **IR** applications such as **Web search**, only need to know if two words have the same *stem*:
  - Boolean Query: "marsupial OR kangaroo OR koala".
  - Document contains: "marsupials"
  ⇒ **stemming**, i.e. given a word, extract the stem:
    - marsupials => marsupial
    - played, playing, player, plays => play

- **Porter stemmer** – a series of simple cascaded rewrite rules:
  - ATIONAL => ATE (e.g. relational => relate)
  - ING => ε (e.g. motoring => motor)
  - SSES => SS (e.g. grasses => grass)

Part of Speech (POS) Tagging

- Annotate each word in a sentence with its POS:
  - nouns, verbs, adjectives, adverbs, pronouns, prepositions, …

  PRP VBD TO VB   TO DT NN IN NN   VBD   VBG

  They used to object to the use   of object oriented programming
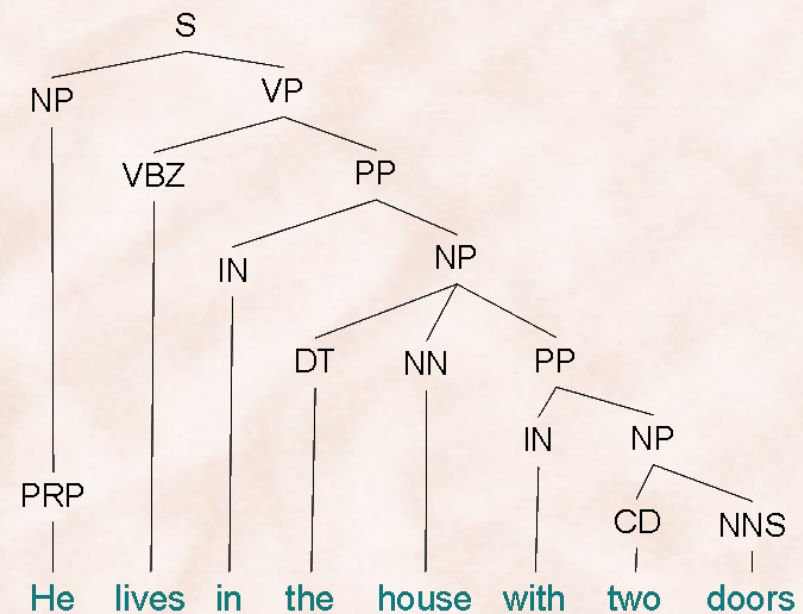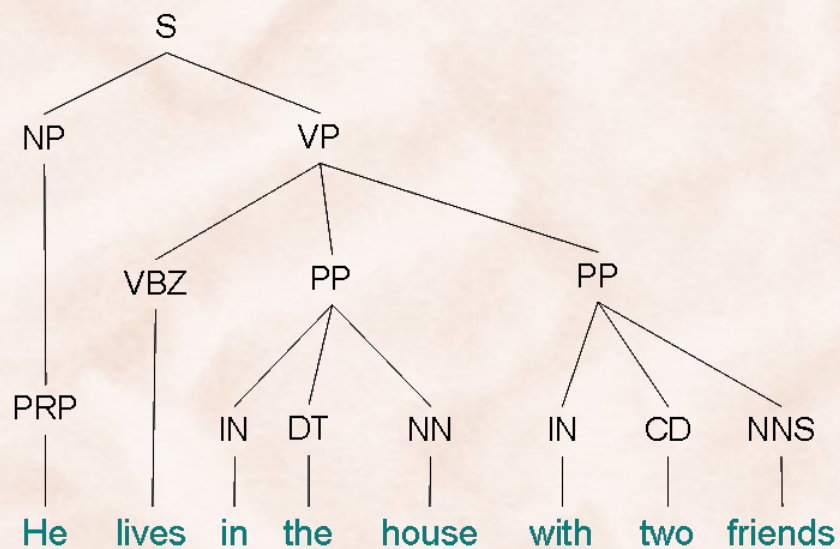
  obJECT   OBject

- Useful for many NLP tasks downstream:
  - speech recognition and synthesis, syntactic parsing, word sense disambiguation, information retrieval, …

- Nowadays superseded in many tasks by (contextualized) *word embeddings*.

Syntactic Analysis

- Compute the *phrase structure* of a sentence:

- Corresponding *dependency structure*:

Word Sense Disambiguation

- Words in natural language may have multiple meanings:
  - he cashed a check at the bank
  - he sat on the bank of the river and watched the currents
  - they built a large plant to manufacture automobiles
  - chlorophyll is generally present in plant leaves

- Use lexical resources such as WordNet that map words to their meanings.

- Identifying the meaning of a word is useful for:
  - machine translation, information retrieval, question answering, text classification, …

- Nowadays superseded in many tasks by (contextualized) *word embeddings*.

Semantic Role Labeling

- For each clause, determine the semantic role played by each noun phrase that is an argument to the verb:

   agent   patient   source   destination   instrument

   – John drove Mary from Athens to Columbus in his Toyota Prius.
   – The hammer broke the window.

- Also referred to a "case role analysis," "thematic analysis," and "shallow semantic parsing".

Semantic Parsing

- Map natural language sentences to a formal semantic representation (*logic form*).

- In GeoQuery, map sentences to Prolog queries:
  - *How many states does the Mississippi run through?*
  - answer(A, count(B, (state(B), const(C, riverid(mississippi)),
    traverse(C, B)), A))

- In RoboCup, map coaching advice to Clang:
  - *If the ball is in our penalty area, all our players except player 4 should stay in our half.*
  - ((bpos (penalty-area our)) (do (player-except our {4})
    (pos (half our))))

Coreference Resolution

- Determine which noun phrases refer to the same discourse entity.

Originally from Hawaii, Obama is a graduate of Columbia University and Harvard Law School, where he was the president of the Harvard Law Review. He was a community organizer in Chicago before earning his law degree.

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Coreference in Mathematical Statements

- **Theorem**: $\sqrt{2}$ is an irrational number.

- **Proof**: Suppose that $\sqrt{2}$ were a rational number, so by definition $\sqrt{2}$ = a / b where a and b are non-zero integers with no common factor. Thus, $b\sqrt{2}$ = a. Squaring both sides yields $2b^2 = a^2$. Since 2 divides the left hand side, 2 must also divide the right hand side (as they are equal and both integers). So a^2 is even, which implies that a must also be even. So we can write a = 2c, where c is also an integer. Substitution into the original equation yields $2b^2 = (2c)^2 = 4c^2$. Dividing both sides by 2 yields $b^2 = 2c^2$. But then, by the same argument as before, 2 divides b^2, so b must be even. However, if a and b are both even, they share a factor, namely 2. This contradicts our assumption, so we are forced to conclude that $\sqrt{2}$ is an irrational number.

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The Curse of Ambiguity

- Computational Linguists are obsessed by ambiguity in NL:
  - unlike compiler writers.

- Ambiguity happens at all basic levels of natural language processing.

- Find at least 5 meanings of the following sentence:
  - I made her duck.

Ambiguity: "I made her duck"

1) I cooked waterfowl for her benefit (to eat).

2) I cooked waterfowl belonging to her.

3) I created the (plaster?) duck she owns.

4) I caused her to quickly lower her head or body.

5) I waved my magic wand and turned her into undifferentiated waterfowl.

Ambiguity: "I made her duck"

- **POS tagging**: "duck" can be a N or V:
  - V: I caused her to quickly lower her head or body
  - N: I cooked waterfowl for her benefit (to eat).

- **POS tagging:** "her" can be a *possessive* ("of her") or *dative* ("for her") or *accusative* pronoun:
  - Possessive: I cooked waterfowl belonging to her.
  - Dative: I cooked waterfowl for her benefit (to eat).
  - Accusative: I waved my magic wand and turned her into waterfowl.

- **WSD:** "make" can mean "create" or "cook":
  - Create: I made the (plaster) duck statue she owns
  - Cook: I cooked waterfowl belonging to her.

Ambiguity: "I made her duck"

- **Syntactic Parsing**:
  - **Make can be Transitive (verb has a noun direct object):**
    - I cooked [waterfowl belonging to her]
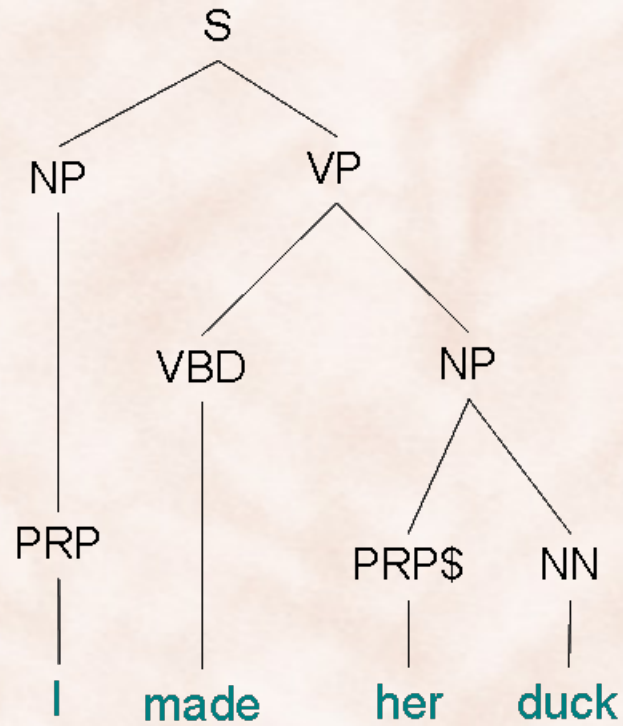
Ambiguity: "I made her duck"

- **Syntactic Parsing**:
  - **Make can be Ditransitive (verb has 2 noun objects):**
    - I made [her] (into) [undifferentiated waterfowl]
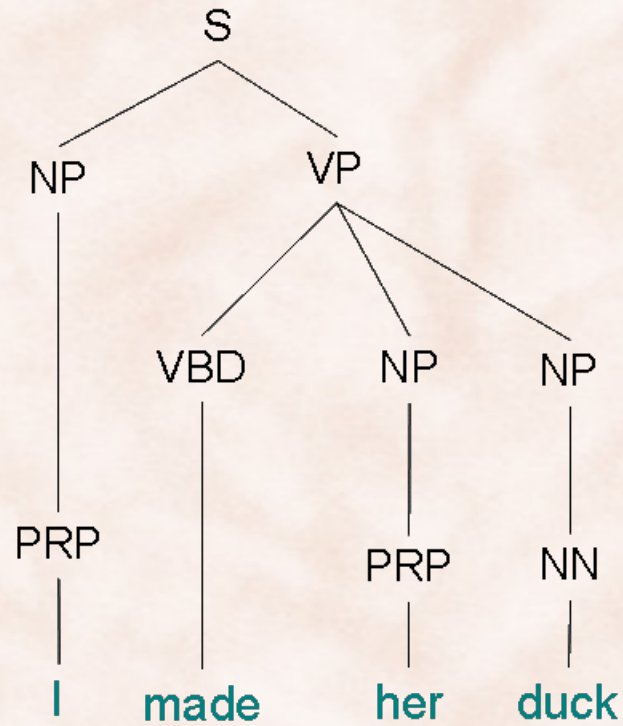
Ambiguity: "I made her duck"

- **Syntactic Parsing**:
  - **Make can be Action-transitive:**
    - I caused [her] [to move her body]
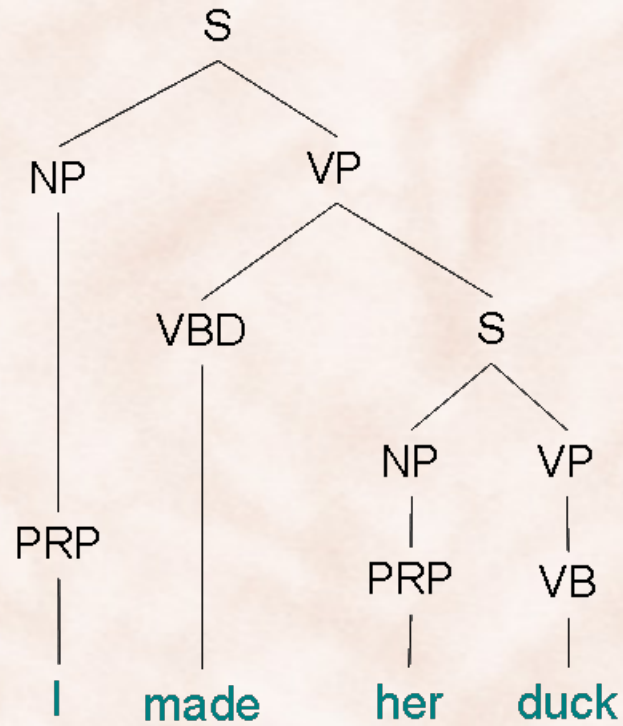
Ambiguity: "I made her duck"

- **Speech Recognition**:
  - I mate or duck
  - I'm eight or duck
  - Eye maid; her duck
  - Aye mate, her duck
  - I maid her duck
  - I'm aid her duck
  - I mate her duck
  - I'm ate her duck
  - I'm ate or duck

Ambiguity and Machine Translation

- English $\Rightarrow$ Italian:
    - Mary **plays** the piano $\Rightarrow$ Maria **suona** il pianoforte.
    - Mary **plays** with her cat $\Rightarrow$ Maria **gioca** con il suo gatto.

- "Lost in translation" jokes from supposedly early MT system output (English $\Rightarrow$ Russian $\Rightarrow$ English):
    - "The spirit is willing, but the flesh is weak".
        - $\Rightarrow$ The vodka is good, but the meat is spoiled.
    - "Out of sight, out of mind".
        - $\Rightarrow$ Invisible idiot.

Ambiguity and Discourse: Coreference Resolution

- Winograd schemas:
    1. The **dog** chased the **cat**, which ran up a **tree**. **It** waited at the [top / bottom].
    2. The city **councilmen** refused the **demonstrators** a permit because **they** [feared / advocated] violence.
    3. The **trophy** doesn't fit into the brown **suitcase** because **it**'s too [small / large].
    4. **Paul** tried to call **George** on the phone, but **he** wasn't [successful / available].
    5. The **man** couldn't lift his **son** because **he** was so [weak / heavy].
    6. **Ann** asked **Mary** what time the library closes, [but / because] **she** had forgotten.

    https://www.cs.nyu.edu/davise/papers/WS.html

Modality and Ambiguity: What does Nancy want?

- **"Nancy wants to mary an analytic philosopher"** [Eco, "Kant and the Platypus", 2000]

- Semantic interpretations:
  - [*de re*]: Nancy wants to marry a determined individual X, who is an analytic philosopher.
  $$\exists x \square A x$$

  - [*de dicto*]: Nancy wants to marry anybody, as long as he is an analytic philosopher.
  $$\square \exists x A x$$

- Pragmatic Interpretations (speaker's intentions):
  - Nancy wants to marry a determined individual, an analytic philosopher: she knows who he is, but the speaker doesn't, because she hasn't told him the name.
  - Nancy wants to marry a determined individual X, an analytic philosopher: she has also given the speaker the name and introduced them to each other, but out of discretion the speaker has thought it more fitting to avoid going into details.
  - …

Ambiguity is Pervasive in Natural Language

- CL and NLP are obsessed with ambiguity:
  - unlike compiler writers.

- Ambiguity happens at all basic levels of language processing.

- [Pros] Allows for significant compression of utterances:
  - people use context and knowledge about the world to disambiguate.

- [Cons] Very challenging for NLP!

Knowledge Involved in Resolving Ambiguity

- Syntax:
  - An agent is typically the subject of the verb (SRL).

- Semantics:
  - John and Mary are names of people.
  - Columbus and Athens are city names.

- Pragmatics:
  - If she is hungry and she is not vegetarian, it is likely she will enjoy cooked duck.

- Word knowledge:
  - Houses have a (variable number of) doors.
  - An individual may live with other people (friends) in the same house.

Two Major Approaches to NLP

1. **NLP Pipelines**:
   - Transforming text into a stack of general-purpose linguistic structures:
     - from subword units called *morphemes*, to word-level *parts-of-speech*, to *tree-structured representations* of grammar, and beyond, to *logic-based representations* of meaning.
   - These general-purpose structures should then be able to support any desired application
   - Should generalize better across applications, scenarios, and languages:
     - linguistic structure seems to be particularly important when training data is limited.

2. **End-to-End** (*learning from scratch*):
   - Started by [Collobert et al., 2011], transform raw text into any desired output structure:
     - a summary, a database, a translation, …
   - buoyed by results in computer vision and speech recognition.

NLP Pipeline Example

Semantic Role Labeling

Syntactic Parsing

POS Tagging

Tokenization

NLP Pipeline Example

Semantic Parsing

Syntactic Parsing

POS Tagging

Tokenization
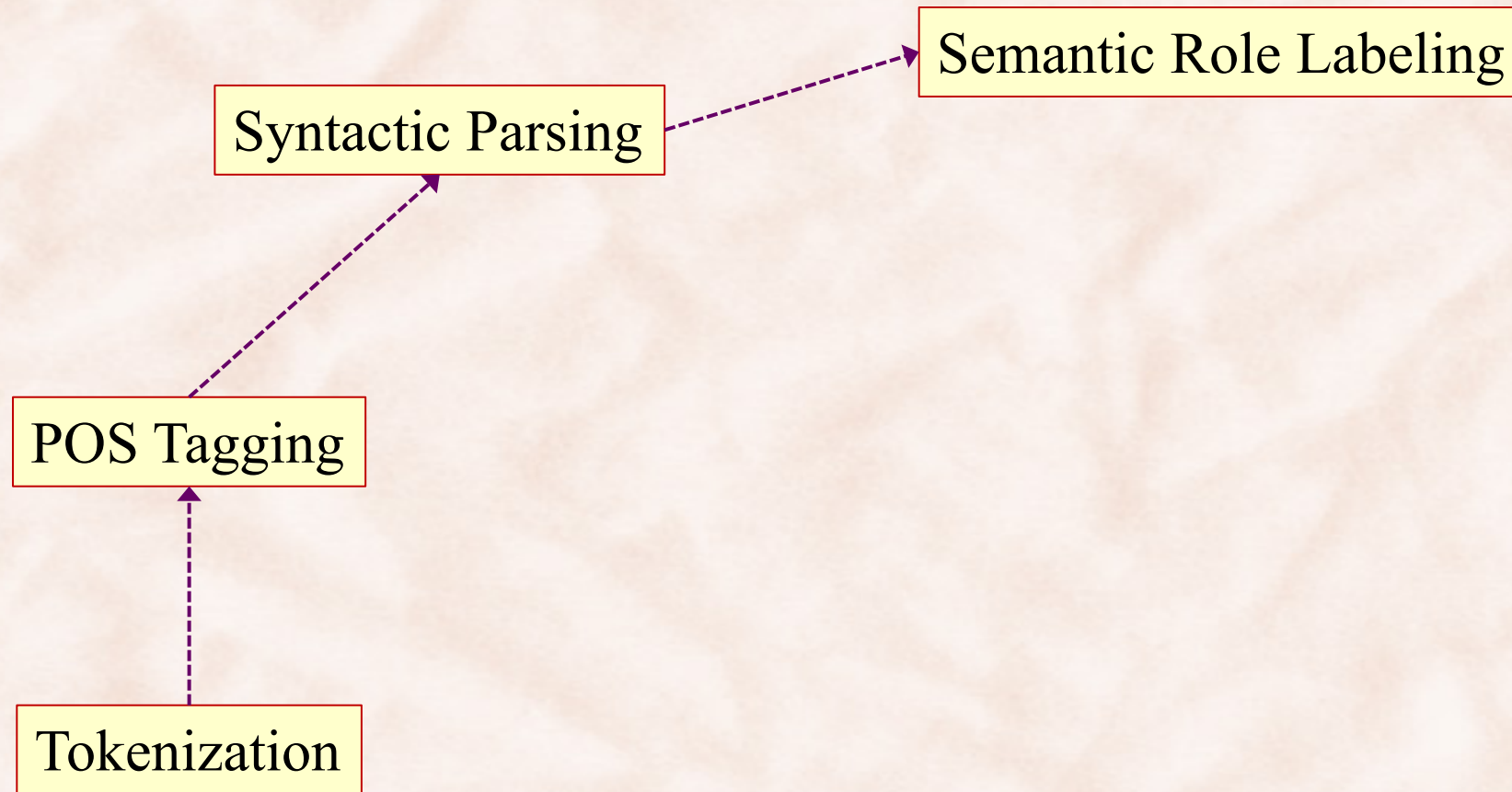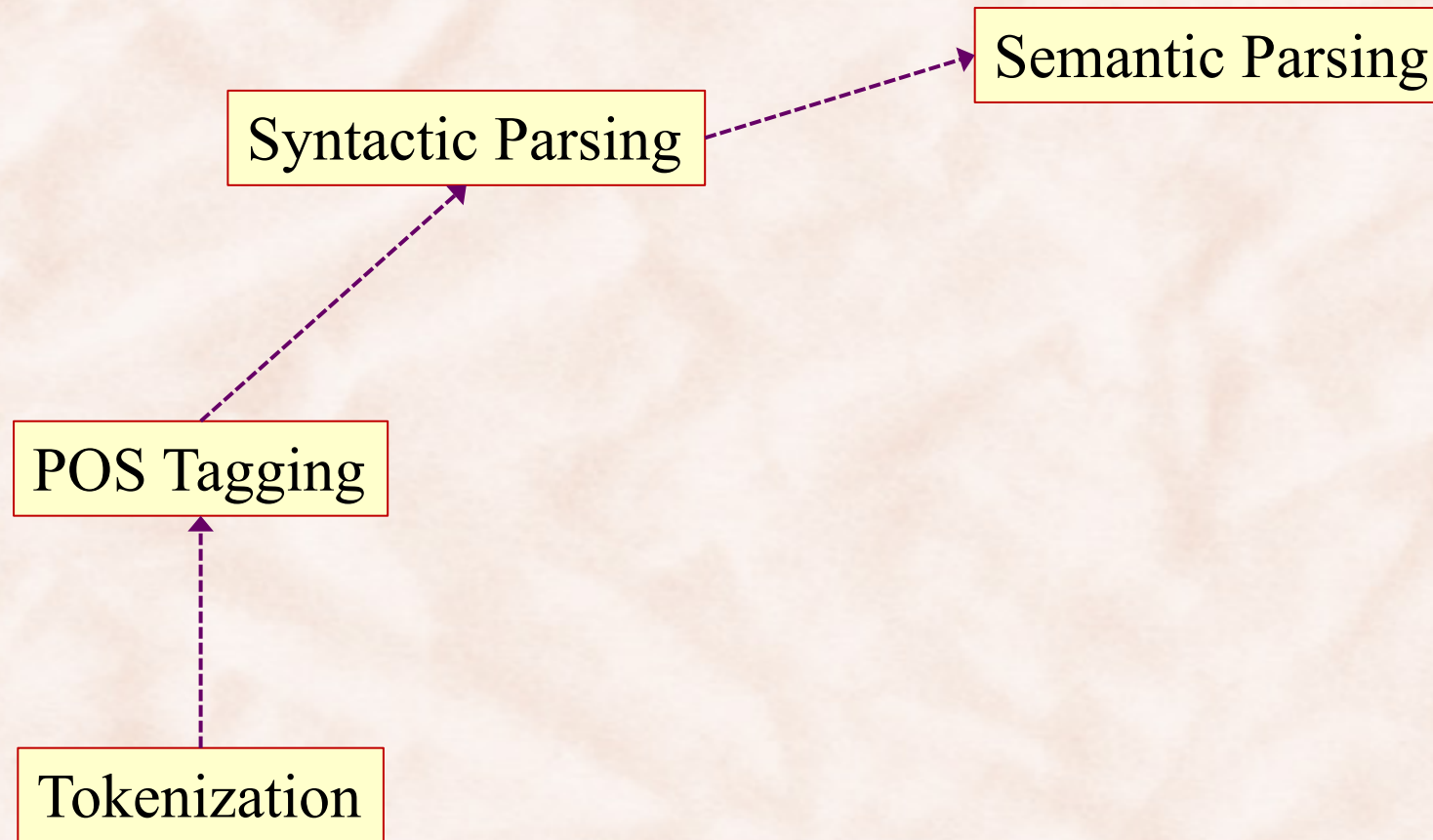
NLP Pipeline Example
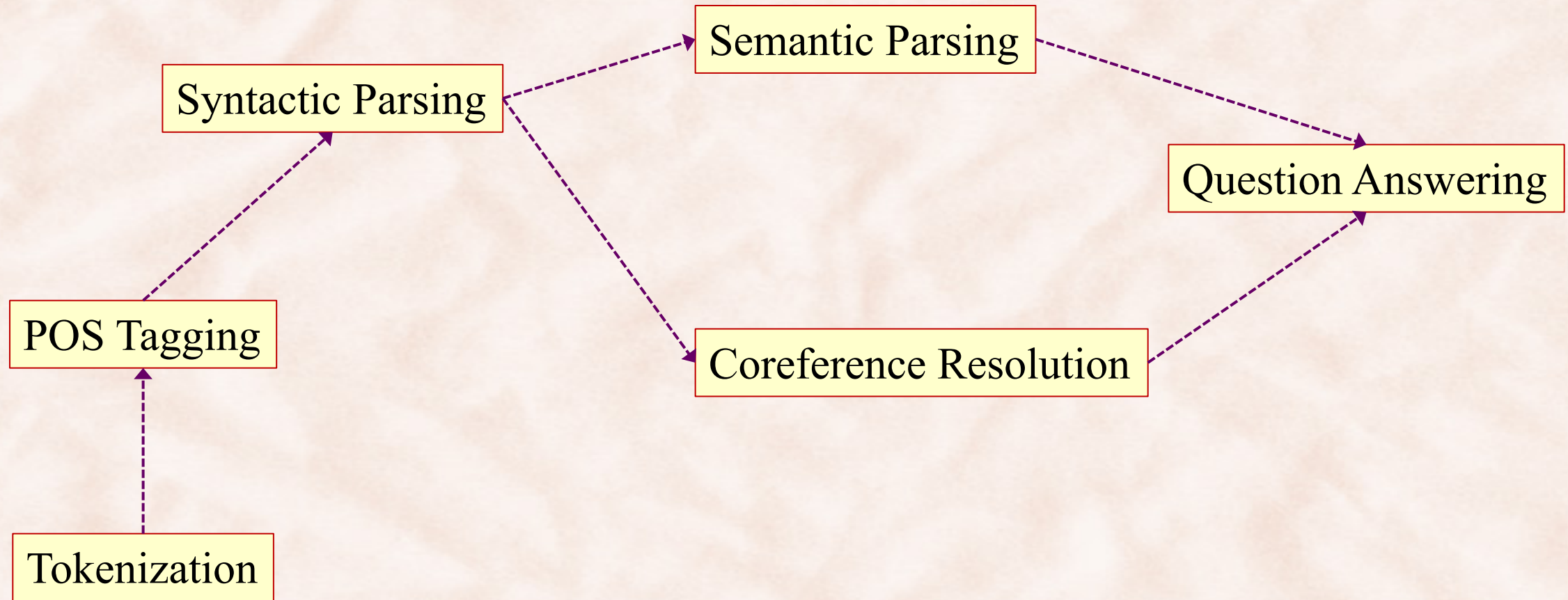
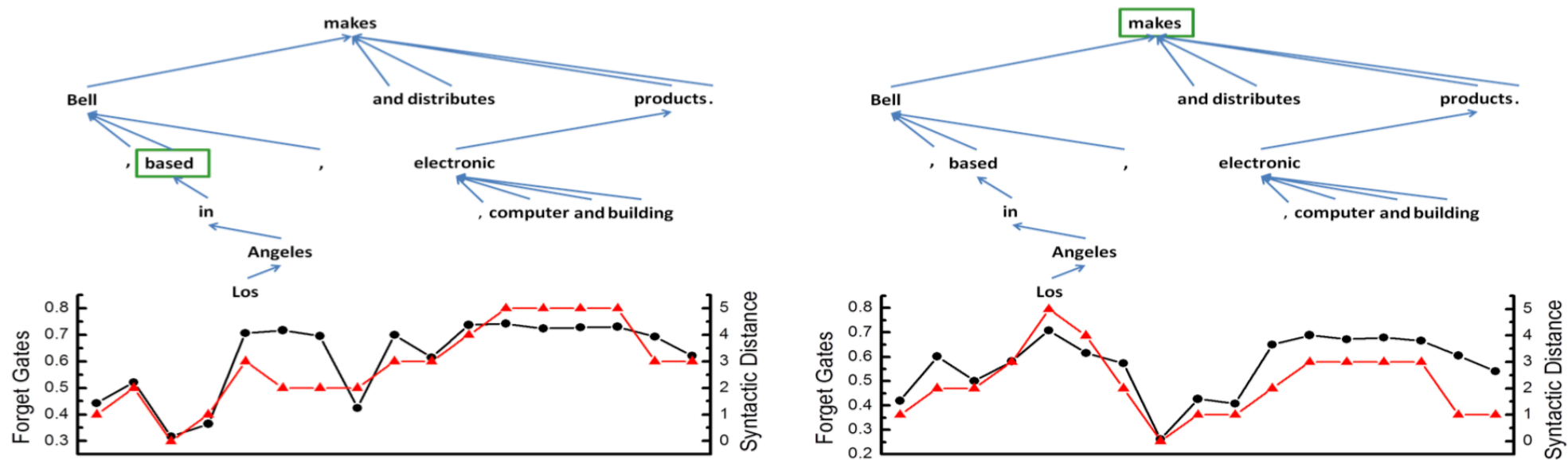"*End-to-end Learning of Semantic Roles using RNNs* [Zhou & Xu, ACL 2015]

Figure 6: Forget gates value $vs.$ Syntactic distance on four example sentences. Top: dependency parsing tree from gold tag. Green square word: predicate word. Bottom black solid lines: forget gates value at each time step. Bottom red empty square lines: gold syntactic distance between the current argument and predicate.
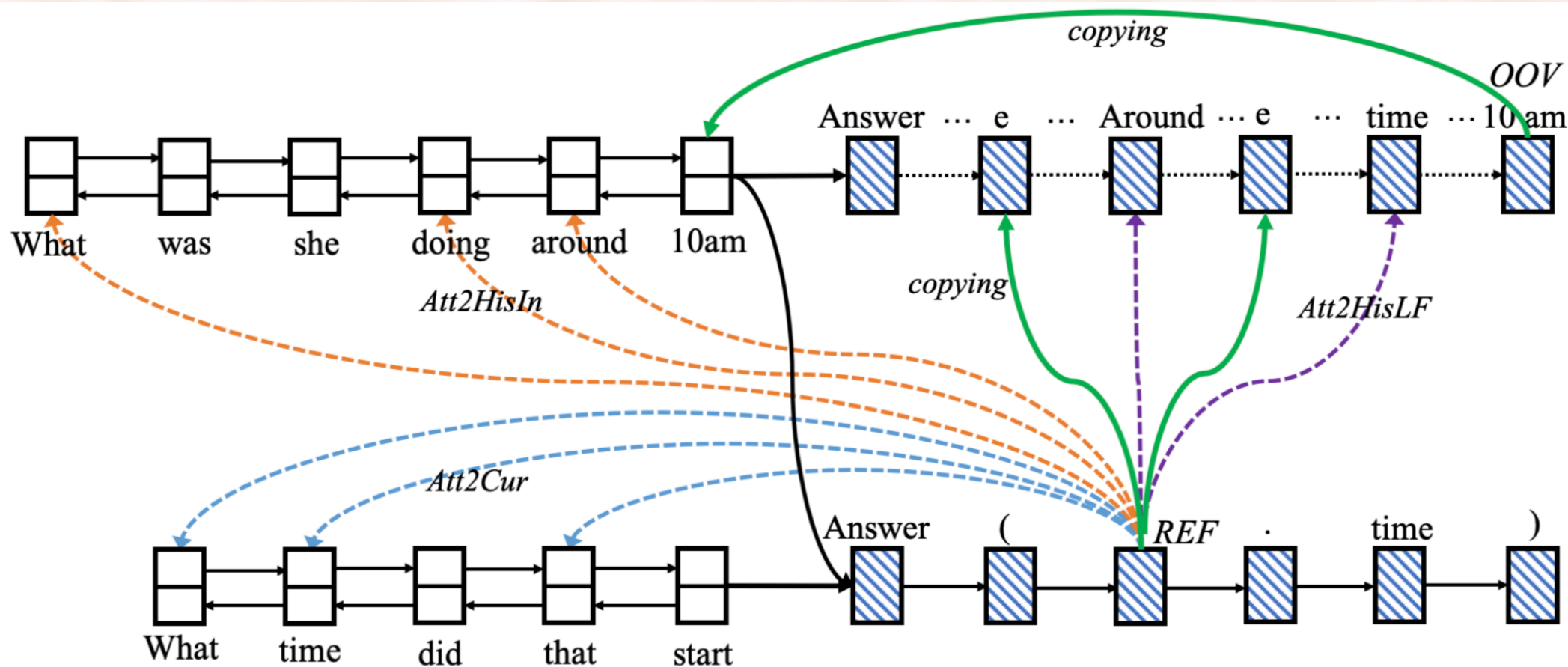
Figure 4: Context-dependent semantic parsing architecture. We use a Bi-LSTM (left) to encode the input and a LSTM (right) as the decoder. We show only parts of the LF to save space. The complete generated LF at time T-1 is Y^{-1} = [*Answer, (, e,),* $\wedge$, *Around, (, e, ., time, OOV,),* $\wedge$, *e, ., type, ==, DiscreteType*]. The token *10am* is copied
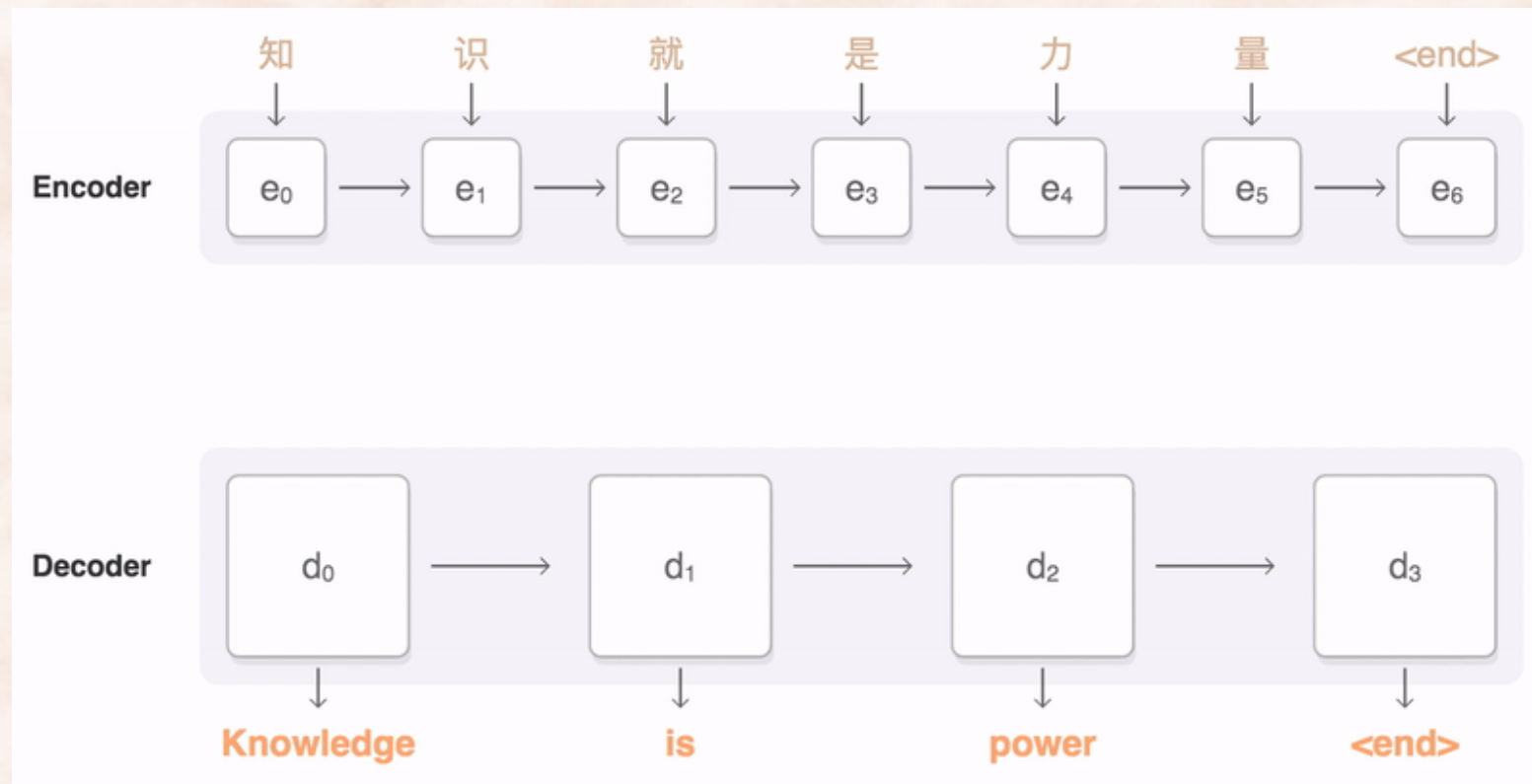
End-to-End: Question Answering

"*End-to-End Open-Domain Question Answering with BERTserini* [Yang et al., NAACL Demo 2019]
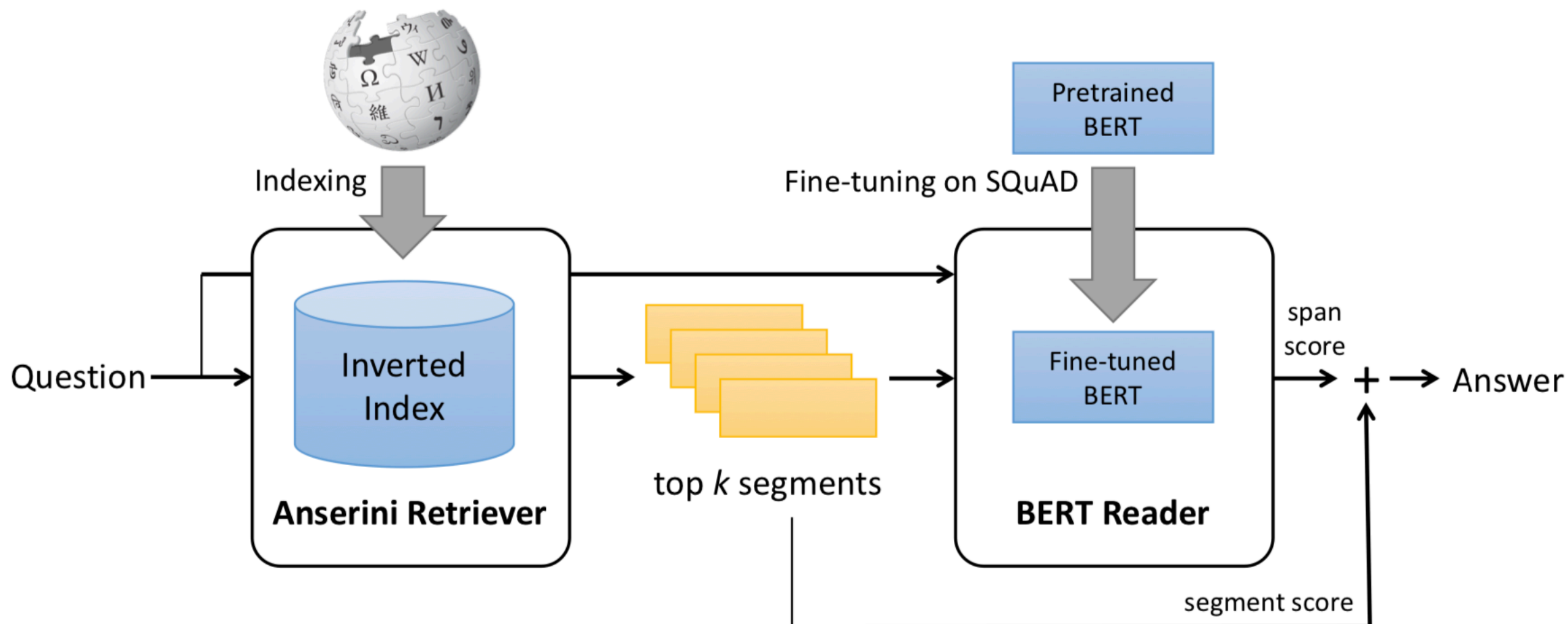
End-to-End: Machine Translation

- From Phrase-Based Machine Translation to Neural Machine Translation:

https://research.googleblog.com/2016/09/a-neural-network-for-machine.html

End-to-End: Machine Translation

- Before November 2016:
  - Kilimanjaro is 19,710 feet of the mountain covered with snow, and it is said that the highest mountain in Africa. Top of the west, "Ngaje Ngai" in the Maasai language, has been referred to as the house of God. The top close to the west, there is a dry, frozen carcass of a leopard. Whether the leopard had what the demand at that altitude, there is no that nobody explained.

- After November 2016:
  - Kilimanjaro is a mountain of 19,710 feet covered with snow and is said to be the highest mountain in Africa. The summit of the west is called "Ngaje Ngai" in Masai, the house of God. Near the top of the west there is a dry and frozen dead body of leopard. No one has ever explained what leopard wanted at that altitude.

    http://www.nytimes.com/2016/12/14/magazine/the-great-ai-awakening.html

End-to-End: Conditional Text Generation

- System prompt (human written):

  – *In a shocking finding, scientist discovered a herd of unicorns living in a remote, previously unexplored valley, in the Andes Mountains. Even more surprising to the researchers was the fact that the unicorns spoke perfect English.*

- Model completion (machine written):

  – The scientist named the population, after their distinctive horn, Ovid's Unicorn. These four-horned, silver-white unicorns were previously unknown to science. Now, after almost two centuries, the mystery of what sparked this odd phenomenon is finally solved. Dr. Jorge Pérez, an evolutionary biologist from the University of La Paz, and several companions, were exploring the Andes Mountains when they found a small valley, with no other animals or humans. Pérez noticed that the valley had what appeared to be a natural fountain, surrounded by two peaks of rock and silver snow. Pérez and the others then ventured further into the valley. "By the time we reached the top of one peak, the water looked blue, with some crystals on top," said Pérez …

What is Natural Language Processing?

- **Natural Language Processing (NLP)** = developing computer systems that can *process*, *understand*, or *communicate* in natural language (*text* or *speech*):
  - **Natural Languages**: English, Turkish, Japanese, Latin, Hawaiian Creole, Esperanto, American Sign Language, …
    - Music?
  - **Formal Languages**: C++, Java, Python, XML, OWL, Predicate Calculus, Lambda Calculus, …
  - **Natural Languages are significantly more difficult to process than Artificial Languages!**

- What about **Computational Linguistics (CL)** ?
  - Computational Linguistics is focused on the *study of language*, using computational tools.
  - NLP is focused on solving language tasks such as *machine translation*, *information extraction*, *question answering*, *taking instructions*, *holding conversations*, …

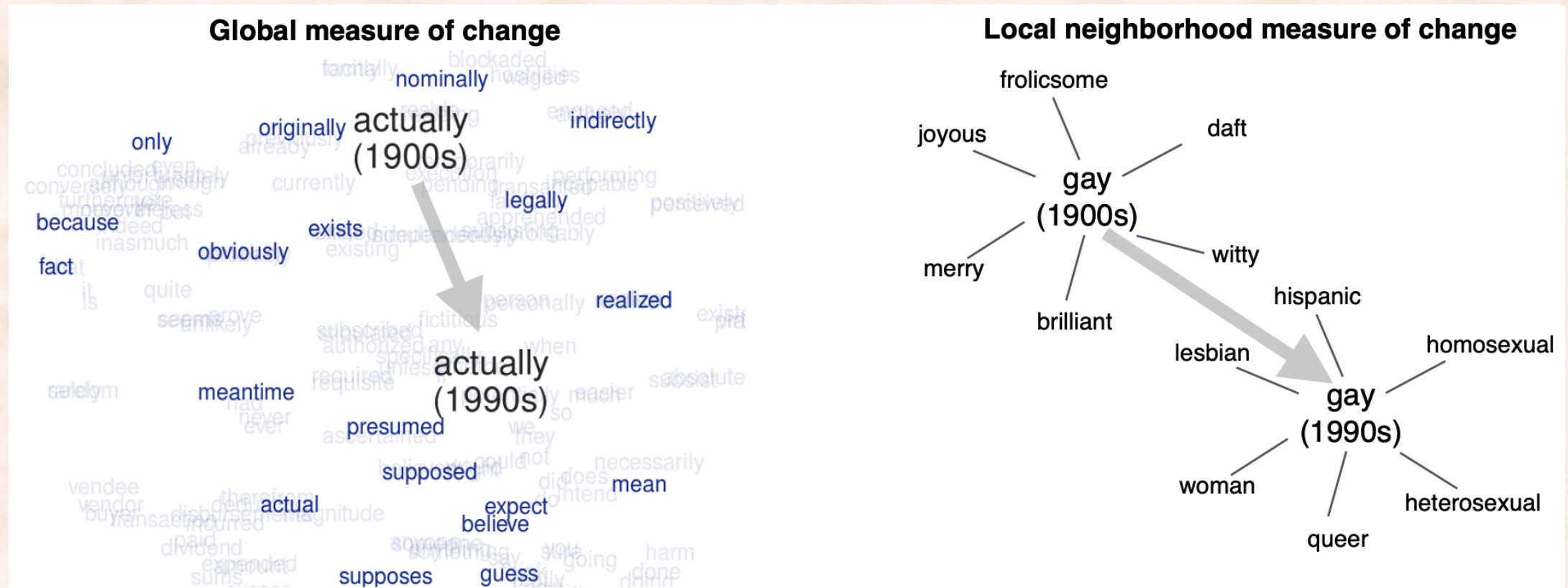# CL studies language using NLP/computational tools

Figure 1: Two different measures of semantic change. With the global measure of change, we measure how far a word has moved in semantic space between two time-periods. This measure is sensitive to subtle shifts in usage and also global effects due to the entire semantic space shifting. For example, this captures how *actually* underwent subjectification during the 20th century, shifting from uses in objective statements about the world ("actually did try") to subjective statements of attitude ("I actually agree"; see Traugott and Dasher, 2001 for details). In contrast, with the local neighborhood measure of change, we measure changes in a word's nearest neighbors, which captures drastic shifts in core meaning, such as *gay*'s shift in meaning over the 20th century.

Supplementary Readings

- Chapter 1 (Introduction) in [Eisenstein]

    and/or

- Chapter 1 (Introduction) in [Jurafsky & Martin]