Semantic Analysis

Ling571
Deep Processing Techniques for NLP
February 14, 2011

Updating Attachments

- Noun -> restaurant $\{\lambda x.Restaurant(x)\}$
- Nom-> Noun { Noun.sem }
- Det -> Every $\{ \lambda P.\lambda Q.\forall x P(x) \Rightarrow Q(x) \}$
- NP -> Det Nom { Det.sem(Nom.sem) }

$$\lambda P.\lambda Q.\forall x P(x) \Rightarrow Q(x)(\lambda x.\mathrm{Re}\,staurant(x))$$

$$\lambda P.\lambda Q.\forall x P(x) \Rightarrow Q(x)(\lambda y.\mathrm{Re}\,staurant(y))$$

$$\lambda Q.\forall x \lambda y.\mathrm{Re}\,staurant(y)(x) \Rightarrow Q(x)$$

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- New style: λx.x(Maharani)

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$$\lambda w.\lambda z.w(\lambda x.\exists e Opened(e) \wedge Opener(e,z) \wedge OpenedThing(e,x))$$

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  - Introduce special predicate *eq*
- Use transitive verb structure with new predicate
  - eq(y,x)

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Strategy for Semantic Attachments

- General approach:
  - Create complex, lambda expressions with lexical items
    - Introduce quantifiers, predicates, terms
  - Percolate up semantics from child if non-branching
  - Apply semantics of one child to other through lambda
    - Combine elements, but don't introduce new

Sample Attachments

Grammar Rule	Semantic Attachment
$S \rightarrow NP\ VP$	$\{NP.sem(VP.sem)\}$
$NP \rightarrow Det\ Nominal$	$\{Det.sem(Nominal.sem)\}$
$NP \rightarrow ProperNoun$	$\{ProperNoun.sem\}$
$Nominal \rightarrow Noun$	$\{Noun.sem\}$
$VP \rightarrow Verb$	$\{Verb.sem\}$
$VP \rightarrow Verb\ NP$	$\{Verb.sem(NP.sem)\}$
$Det \rightarrow every$	$\{\lambda P.\lambda Q.\forall x P(x) \Rightarrow Q(x)\}$
$Det \rightarrow a$	$\{\lambda P.\lambda Q.\exists x P(x) \wedge Q(x)\}$
$Noun \rightarrow restaurant$	$\{\lambda r.Restaurant(r)\}$
$ProperNoun \rightarrow Matthew$	$\{\lambda m.m(Matthew)\}$
$ProperNoun \rightarrow Franco$	$\{\lambda f.f(Franco)\}$
$ProperNoun \rightarrow Frasca$	$\{\lambda f.f(Frasca)\}$
$Verb \rightarrow closed$	$\{\lambda x.\exists e Closed(e) \wedge ClosedThing(e,x)\}$
$Verb \rightarrow opened$	$\{\lambda w.\lambda z.w(\lambda x.\exists e Opened(e) \wedge Opener(e,z) \wedge Opened(e,x))\}$

Quantifier Scope

- Ambiguity:
  - *Every restaurant has a menu*

$$\forall x\, Restaurant(x) \Rightarrow \exists y(Menu(y) \wedge (\exists e Having(e) \wedge Haver(e,x) \wedge Had(e,y)))$$

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    - all have a menu;
    - all have same menu
  - Only derived one

$$\exists y Menu(y) \wedge \forall x(Restaurant(x) \Rightarrow \exists e Having(e) \wedge Haver(e,x) \wedge Had(e,y)))$$

  - Potentially O(n!) scopings (n=# quantifiers)

- There are approaches to describe ambiguity efficiently and recover all alternatives.

Earley Parsing with Semantics

- Implement semantic analysis
  - In parallel with syntactic parsing
    - Enabled by compositional approach
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  - Augment grammar rules with semantic field
  - Augment chart states with meaning expression
  - Completer computes semantics – e.g. unifies
    - Can also fail to unify
      - Blocks semantically invalid parses
    - Can impose extra work

Sidelight: Idioms

- Not purely compositional
  - E.g. kick the bucket = die
  - tip of the iceberg = beginning
- Handling:
  - Mix lexical items with constituents (word nps)
  - Create idiom-specific const. for productivity
  - Allow non-compositional semantic attachments
- Extremely complex: e.g. metaphor

Semantic Analysis

- Applies principle of compositionality
  - Rule-to-rule hypothesis
  - Links semantic attachments to syntactic rules
    - Incrementally ties semantics to parse processing
    - Lambda calculus meaning representations
    - Most complexity pushed into lexical items
    - Non-terminal rules largely lambda applications

Semantics Learning

- Zettlemoyer & Collins, 2005, 2007, etc; Mooney 2007

- Given semantic representation and corpus of parsed sentences
  - Learn mapping from sentences to logical form
    - Structured perceptron
    - Applied to ATIS corpus sentences

Lexical Semantics

- Motivation: Word sense disambiguation
- Meaning at the word level
  - Issues
    - Ambiguity
    - Meaning
    - Meaning structure
      - Relations to other words
      - Subword meaning composition
  - WordNet: Lexical ontology

What is a plant?

There are more kinds of plants and animals in the rainforests than anywhere else on Earth. Over half of the millions of known species of plants and animals live in the rainforest. Many are found nowhere else. There are even plants and animals in the rainforest that we have not yet discovered.

The Paulus company was founded in 1938. Since those days the product range has been the subject of constant expansions and is brought up continuously to correspond with the state of the art. We're engineering, manufacturing, and commissioning world-wide ready-to-run plants packed with our comprehensive know-how.

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  - Internal meaning structure of words
    - Basic internal units combine for meaning

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      - Sing: sing, sings, sang, sung,…
- **Lexicon**: finite list of lexemes

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  - Problem for applications: TTS, ASR transcription, IR

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- Polysemy
  - Multiple RELATED senses
    - E.g. bank: money, organ, blood,...
  - Big issue in lexicography
    - # of senses, relations among senses, differentiation
    - E.g. serve breakfast, serve Philadelphia, serve time

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    - Register:
      - social factors: e.g. politeness, formality

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  - Organize as ontology/taxonomy

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- Relations between entries:
  - Synonymy: in synset
  - Hypo(per)nym: Isa tree

WordNet

The noun "bass" has 8 senses in WordNet.

1. bass^1 - (the lowest part of the musical range)
2. bass^2, bass part^1 - (the lowest part in polyphonic music)
3. bass^3, basso^1 - (an adult male singer with the lowest voice)
4. sea bass^1, bass^4 - (the lean flesh of a saltwater fish of the family Serranidae)
5. freshwater bass^1, bass^5 - (any of various North American freshwater fish with lean flesh (especially of the genus Micropterus))
6. bass^6, bass voice^1, basso^2 - (the lowest adult male singing voice)
7. bass^7 - (the member with the lowest range of a family of musical instruments)
8. bass^8 - (nontechnical name for any of numerous edible marine and freshwater spiny-finned fishes)

The adjective "bass" has 1 sense in WordNet.

1. bass^1, deep^6 - (having or denoting a low vocal or instrumental range)
   "a deep voice"; "a bass voice is lower than a baritone voice"; "a bass clarinet"

Noun WordNet Relations

Relation	Also Called	Definition	Example
Hypernym	Superordinate	From concepts to superordinates	$breakfast^1 \rightarrow meal^1$
Hyponym	Subordinate	From concepts to subtypes	$meal^1 \rightarrow lunch^1$
Instance Hypernym	Instance	From instances to their concepts	$Austen^1 \rightarrow author^1$
Instance Hyponym	Has-Instance	From concepts to concept instances	$composer^1 \rightarrow Bach^1$
Member Meronym	Has-Member	From groups to their members	$faculty^2 \rightarrow professor^1$
Member Holonym	Member-Of	From members to their groups	$copilot^1 \rightarrow crew^1$
Part Meronym	Has-Part	From wholes to parts	$table^2 \rightarrow leg^3$
Part Holonym	Part-Of	From parts to wholes	$course^7 \rightarrow meal^1$
Substance Meronym		From substances to their subparts	$water^1 \rightarrow oxygen^1$
Substance Holonym		From parts of substances to wholes	$gin^1 \rightarrow martini^1$
Antonym		Semantic opposition between lemmas	$leader^1 \Longleftrightarrow follower^1$
Derivationally Related Form		Lemmas w/same morphological root	$destruction^1 \Longleftrightarrow destroy^1$

WordNet Taxonomy

```
Sense 3
bass, basso --
(an adult male singer with the lowest voice)
=> singer, vocalist, vocalizer, vocaliser
   => musician, instrumentalist, player
      => performer, performing artist
         => entertainer
            => person, individual, someone...
               => organism, being
                  => living thing, animate thing,
                     => whole, unit
                        => object, physical object
                           => physical entity
                              => entity
               => causal agent, cause, causal agency
                  => physical entity
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    - The $\text{window}_{\text{THEME}}$ was broken by $\text{John}_{\text{AGENT}}$

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  - Verbs allow different surface realizations of roles
    - Doris$_{AGENT}$ gave the book$_{THEME}$ to Cary$_{GOAL}$
    - Doris$_{AGENT}$ gave Cary$_{GOAL}$ the book$_{THEME}$
  - Group verbs into classes based on shared patterns

Canonical Roles

Thematic Role	**Example**
AGENT	*The waiter* spilled the soup.
EXPERIENCER	*John* has a headache.
FORCE	*The wind* blows debris from the mall into our yards.
THEME	Only after Benjamin Franklin broke *the ice*...
RESULT	The French government has built a *regulation-size baseball diamond*...
CONTENT	Mona asked *"You met Mary Ann at a supermarket?"*
INSTRUMENT	He turned to poaching catfish, stunning them *with a shocking device*...
BENEFICIARY	Whenever Ann Callahan makes hotel reservations *for her boss*...
SOURCE	I flew in *from Boston*.
GOAL	I drove *to Portland*.

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  - Standard definition of roles
    - Most AGENTs: animate, volitional, sentient, causal
    - But not all....
- Strategies:
  - Generalized semantic roles: PROTO-AGENT/PROTO-PATIENT
    - Defined heuristically: PropBank
  - Define roles specific to verbs/nouns: FrameNet

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- Strategies:
  - Generalized semantic roles: PROTO-AGENT/PROTO-PATIENT
    - Defined heuristically: PropBank
  - Define roles specific to verbs/nouns: FrameNet

PropBank

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    - Ex1: [$_{Arg0}$The group] agreed [$_{Arg1}$it wouldn't make an offer]

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  - Core, non-core roles
  - Relationships b/t frames, frame elements
    - Add causative: cause_change_position_on_scale

Core Roles	
ATTRIBUTE	The ATTRIBUTE is a scalar property that the ITEM possesses.
DIFFERENCE	The distance by which an ITEM changes its position on the scale.
FINAL_STATE	A description that presents the ITEM's state after the change in the ATTRIBUTE's value as an independent predication.
FINAL_VALUE	The position on the scale where the ITEM ends up.
INITIAL_STATE	A description that presents the ITEM's state before the change in the ATTRIBUTE's value as an independent predication.
INITIAL_VALUE	The initial position on the scale from which the ITEM moves away.
ITEM	The entity that has a position on the scale.
VALUE_RANGE	A portion of the scale, typically identified by its end points, along which the values of the ATTRIBUTE fluctuate.
Some Non-Core Roles	
DURATION	The length of time over which the change takes place.
SPEED	The rate of change of the VALUE.
GROUP	The GROUP in which an ITEM changes the value of an ATTRIBUTE in a specified way.

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  - Associate with WordNet synset (and hyponyms)

Primitive Decompositions

- Jackendoff(1990), Dorr(1999), McCawley (1968)

- Word meaning constructed from primitives
  - Fixed small set of basic primitives
    - E.g. cause, go, become,
    - kill=cause X to become Y
  - Augment with open-ended "manner"
    - Y = not alive
    - E.g. walk vs run
- Fixed primitives/Infinite descriptors

Word Sense Disambiguation

- Selectional Restriction-based approaches
  - Limitations
- Robust Approaches
  - Supervised Learning Approaches
    - Naïve Bayes
  - Bootstrapping Approaches
    - One sense per discourse/collocation
  - Unsupervised Approaches
    - Schutze's word space
  - Resource-based Approaches
    - Dictionary parsing, WordNet Distance
  - Why they work
  - Why they don't

Word Sense Disambiguation

- Application of lexical semantics
- Goal: Given a word *in context,* identify the appropriate sense
  - E.g. plants and animals in the rainforest
- Crucial for real syntactic & semantic analysis
  - Correct sense can determine
    - Available syntactic structure
    - Available thematic roles, correct meaning,..

Selectional Restriction Approaches

- Integrate sense selection in parsing and semantic analysis – e.g. with Montague
- Concept: Predicate selects sense
  - Washing dishes vs stir-frying dishes
    - Stir-fry: patient: food => dish~food
  - Serve Denver vs serve breakfast
    - Serve vegetarian dishes
      - Serve1: patient: loc; serve1: patient: food
      - => dishes~food: only valid variant
- Integrate in rule-to-rule: test e.g. in WN

Selectional Restrictions: Limitations

- Problem 1: Predicates too general
  - Recommend, like, hit....
- Problem 2: Language too flexible
  - “The circus performer ate fire and swallowed swords”
    - Unlikely but doable
  - Also metaphor
- Strong restrictions would block all analysis
  - Some approaches generalize up hierarchy
    - Can over-accept truly weird things

Robust Disambiguation

- More to semantics than P-A structure
  - Select sense where predicates underconstrain
- Learning approaches
  - Supervised, Bootstrapped, Unsupervised
- Knowledge-based approaches
  - Dictionaries, Taxonomies
- Widen notion of context for sense selection
  - Words within window (2,50,discourse)
  - Narrow cooccurrence - collocations

Disambiguation Features

- Key: What are the features?
  - Part of speech
    - Of word and neighbors
  - Morphologically simplified form
  - Words in neighborhood
    - Question: How big a neighborhood?
      - Is there a single optimal size? Why?
  - (Possibly shallow) Syntactic analysis
    - E.g. predicate-argument relations, modification, phrases
  - Collocation vs co-occurrence features
    - Collocation: words in specific relation: p-a, 1 word +/-
    - Co-occurrence: bag of words..

Naïve Bayes' Approach

- Supervised learning approach
  - Input: feature vector X label
- Best sense = most probable sense given V

$$\hat{s} = \arg\max_{s \in S} P(s \mid V)$$

$$\hat{s} = \arg\max_{s \in S} \frac{P(V \mid s) P(s)}{P(V)}$$

$$P(V \mid s) = \prod_{j=1}^{n} P(v_j \mid s)$$

- "Naïve" assumption: features independent

$$\hat{s} = \arg\max_{s \in S} P(s) \prod_{j=1}^{n} P(v_j \mid s)$$

Example: “Plant” Disambiguation

There are more kinds of plants and animals in the rainforests than anywhere else on Earth. Over half of the millions of known species of plants and animals live in the rainforest. Many are found nowhere else. There are even plants and animals in the rainforest that we have not yet discovered.

Biological Example

The Paulus company was founded in 1938. Since those days the product range has been the subject of constant expansions and is brought up continuously to correspond with the state of the art. We’ re engineering, manufacturing and commissioning world-wide ready-to-run plants packed with our comprehensive know-how. Our Product Range includes pneumatic conveying systems for carbon, carbide, sand, lime and many others. We use reagent injection in molten metal for the…

Industrial Example

Label the First Use of “Plant”

Yarowsky's Decision Lists: Detail

- One Sense Per Discourse - Majority
- One Sense Per Collocation
  - Near Same Words

→ Same Sense

Yarowsky's Decision Lists: Detail

- Training Decision Lists
  - 1. Pick Seed Instances & Tag
  - 2. Find Collocations: Word Left, Word Right, Word ±K
    - (A) Calculate Informativeness on Tagged Set,
      - Order:
    - (B) Tag New Instances with Rules
    - (C)* Apply 1 Se

$$abs(\log \frac{Pr(sense_1|Collocation)}{Pr(sense_2|Collocation)})$$

    - (D) If Still Unlabeled, Go To 2
  - 3. Apply 1 Sense/Discouse
- Disambiguation: First Rule Matched

Sense Choice With Collocational Decision Lists

- Use Initial Decision List
  - Rules Ordered by $abs(\log \frac{Pr(sense_1|Collocation)}{Pr(sense_2|Collocation)})$
- Check nearby Word Groups (Collocations)
  - Biology: “Animal” in ± 2-10 words
  - Industry: “Manufacturing” in ± 2-10 words
- Result: Correct Selection
  - 95% on Pair-wise tasks

Semantic Ambiguity

- "Plant" ambiguity
  - Botanical vs Manufacturing senses
- Two types of context
  - Local: 1-2 words away
  - Global: several sentence window
- Two observations (Yarowsky 1995)
  - One sense per collocation (local)
  - One sense per discourse (global)

Schutze' s Vector Space: Detail

- Build a co-occurrence matrix
  - Restrict Vocabulary to 4 letter sequences
  - Exclude Very Frequent - Articles, Affixes
  - Entries in 5000-5000 Matrix

→ 97 Real Values

- Word Context
  - 4grams within 1001 Characters
  - Sum & Normalize Vectors for each 4gram
  - Distances between Vectors by dot product

Schutze's Vector Space: continued

- Word Sense Disambiguation
  - Context Vectors of All Instances of Word
  - Automatically Cluster Context Vectors
  - Hand-label Clusters with Sense Tag
  - Tag New Instance with Nearest Cluster

Sense Selection in “Word Space”

- Build a Context Vector
  - 1,001 character window - Whole Article
- Compare Vector Distances to Sense Clusters
  - Only 3 Content Words in Common
  - Distant Context Vectors
  - Clusters - Build Automatically, Label Manually
- Result: 2 Different, Correct Senses
  - 92% on Pair-wise tasks

Resnik's WordNet Labeling: Detail

- Assume Source of Clusters
- Assume KB: Word Senses in WordNet IS-A hierarchy
- Assume a Text Corpus
- Calculate Informativeness
  - For Each KB Node:
    - Sum occurrences of it and all children
    - Informativeness

$$(\mathrm{I}) = -\log\left(\frac{\sum_{w \in C} Count(w)}{N}\right)$$

- Disambiguate wrt Cluster & WordNet
  - Find MIS for each pair, I
  - For each subsumed sense, Vote += I
  - Select Sense with Highest Vote

Sense Labeling Under WordNet

- Use Local Content Words as Clusters
  - Biology: Plants, Animals, Rainforests, species…
  - Industry: Company, Products, Range, Systems…
- Find Common Ancestors in WordNet
  - Biology: Plants & Animals isa Living Thing
  - Industry: Product & Plant isa Artifact isa Entity
  - Use Most Informative
- Result: Correct Selection

$$(I) = -\log\left(\frac{\sum_{w \in C} Count(w)}{N}\right)$$

The Question of Context

- Shared Intuition:
  - Context ⟶ Sense
- Area of Disagreement:
  - What is context?
- Wide vs Narrow Window
- Word Co-occurrences

Taxonomy of Contextual Information

- Topical Content
- Word Associations
- Syntactic Constraints
- Selectional Preferences
- World Knowledge & Inference

A Trivial Definition of Context

All Words within X words of Target

- Many words: Schutze - 1000 characters, several sentences
- Unordered "Bag of Words"
- Information Captured: Topic & Word Association
- Limits on Applicability
  - Nouns vs. Verbs & Adjectives
  - Schutze: Nouns - 92%, "Train" -Verb, 69%

Limits of Wide Context

- Comparison of Wide-Context Techniques (LTV '93)
  - Neural Net, Context Vector, Bayesian Classifier, Simulated Annealing
    - Results: 2 Senses - 90+%; 3+ senses ~ 70%
    - People: Sentences ~100%; Bag of Words: ~70%
- Inadequate Context
- Need Narrow Context
  - Local Constraints Override
  - Retain Order, Adjacency

Surface Regularities = Useful Disambiguators

- Not Necessarily!
- "Scratching her nose" vs "Kicking the bucket" (deMarcken 1995)
- Right for the Wrong Reason
  - Burglar Rob… Thieves Stray Crate Chase Lookout
- Learning the Corpus, not the Sense
  - The "Ste." Cluster: Dry Oyster Whisky Hot Float Ice
- Learning Nothing Useful, Wrong Question
  - Keeping: Bring Hoping Wiping Could Should Some Them Rest

Interactions Below the Surface

- Constraints Not All Created Equal
  - “The Astronomer Married the Star”
  - Selectional Restrictions Override Topic
- No Surface Regularities
  - “The emigration/immigration bill guaranteed passports to all Soviet citizens
  - No Substitute for Understanding

What is Similar

- **Ad-hoc Definitions of Sense**
  - Cluster in "word space", WordNet Sense, "Seed Sense": Circular
- Schutze: Vector Distance in Word Space
- Resnik: Informativeness of WordNet Subsumer + Cluster
  - Relation in Cluster not WordNet is-a hierarchy
- Yarowsky: No Similarity, Only Difference
  - Decision Lists - 1/Pair
  - Find Discriminants