Embeddings in Natural Language Processing

Introduction

Eva Maria Vecchi

Computational Linguistics Fall School 2019
IMS, University of Stuttgart

September 9, 2019
Scheduling

- Course: September 9–13, 9:00–12:00, Ground Floor Seminar Room
- Website: www.vecchi.com/eva/teaching/embeddingsNLP.html
- My Contact: evamariavecchi@gmail.com
ECTS Credits

- Select specific topic relevant to Embeddings in NLP
  - *to be pre-approved by me*
  - generally content of 1-2 scientific papers

- Submit the following:
  1. Literature review of scientific literature
  2. Practical implementation on the topic (e.g., re-implementation of system, new data, evaluation using different embeddings, comparison of systems/parameters)
Eva Maria Vecchi

- **2005**: B.A. in Linguistics, with minors in Mathematics and Italian from University of Colorado at Boulder
- **2007**: M.Sc. in Computational Linguistics from Georgetown University
- **2005-2007**: Worked at MITRE and The Federation of American Scientists
- **2008-2010**: Research Fellow at Center for National Research at Pisa, Italy
- **2010-2013**: Ph.D. in Cognitive and Brain Sciences at CIMeC, University of Trento, Italy
- **2014-2017**: Post-doctoral researcher at University of Cambridge: Computer Laboratory
- **2017-2018**: Post-doctoral researcher at University of Stuttgart, IMS
- **2019**: Guest Lecturer at CIS, Ludwig-Maximilians-Universität, Munich
Research Interests

- Distributional/Computational Semantics
- Compositionality & Formal Semantics
- Machine Learning in NLP
- Meaning Representation
- Cognitive Computing
**Embeddings** are used in NLP to model units of meaning.
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Modeling Meaning: *Why?*
Ultimate Goal: “Understand” language like humans

Why can’t you trust atoms?

I dunno… why?

Because they make up everything!

HA
Ultimate Goal: “Understand” language like humans

Why can’t you trust atoms?

I don’t know what you mean

Because they make up everything!

I’m not sure I understand

:-)
Language: one of the most fundamental human abilities

- Language allows us to speak about complex objects that (we think) **exist in the real world**:
  - *Look at that chair with the velvet back, the one with the flowery English pattern.*
  - *Insulin is a peptide hormone produced by beta cells of the pancreatic islets.*
  - *I’m jealous. It’s not that I want that car, but I don’t think he should have it either.*
  - *Bring the curd to a boil, let it boil for exactly three minutes whilst gently stirring.*

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Spot the phenomena: reference to world entity at time $t$, cultural knowledge, vocabulary of speaker, abstract, non-referential concepts, reference to events and processes.

Credit: Herbelot 2018
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- In fact, utterances can be meaningless if meaning is taken to be a relation between words and items in the real world.

(Credit: Herbelot 2018)
A message has to be passed in a way that whatever was in the head of the speaker ends up in the head of the hearer.
Language for conceptualization

- Composition of existing linguistic constituents lead to new concepts.
- Each speaker has their own conceptual space, made of previous experiences and their own (infinite) creativity.

(Credit: Herbelot 2018)
Ultimate Goal: “Understand” language like humans

But how?
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2. Define and understand phenomena involved in human capacity to process meaning in language
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But how?

1. Define *meaning*: What does it mean to understand language?
   What are the components of meaning?

2. Define and understand phenomena involved in human capacity to process meaning in language

3. Determine methods that computationally elaborate components of meaning such that they approximate the phenomena of natural language and remain computationally-friendly and efficient.
Thought exercise: Defining meaning

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3. *Marvelous weather you have here in Ireland.*
   - **INSTANCE$_1$**: Cloudless sunny day
   - **INSTANCE$_2$**: Rain is pouring down outside
   - Contribution of **context** to meaning
Overdoing it...

For instance: “The curtains were blue.”

What your teacher thinks: “The curtains represent his immense depression and his lack of will to carry on.”

What the author meant: “The curtains were *%$!& blue.”
Meaning in a nutshell

- Meaning is **extension**, reference: it ‘points’ at things in the world;
Meaning in a nutshell

- Meaning is **extension** / reference: it ‘points’ at things in the world;

- Meaning is **intension**: intensions are mappings from possible worlds to extensions;
  - e.g. the properties something has to have to count as a member of a category and be identified by a linguistic expression
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- Meaning is **conceptual**: linguistic constituents activate cognitive processes involving extra-linguistic features;

- Meaning is **use**: linguistics constituents have certain patterns of use across a community
Modeling Meaning

Worlds

Words

peptide
rat
zero
jealous
whatever
be

Extension

Intension

Concepts

Language Use

Context "social"

cat
lion
parliament

Context "political"

(Credit: Herbelot 2018)
Integration with the real world

- A system that learns extensions must be able to link language to the world.
- What is a bike, a bus? What do *how*, *many* and *how many* mean?
- Formal meaning of bus: *bus’* (the set of buses in a world)
- *bus’* assumes that the speaker holds entities of *bus* in their head (a model), but how do those relate to the actual world? Via perception.
Introduction

Word Semantics

Constraints: Communication

Words

real, shared

Worlds

Extension

Intension

Concepts

Language Use

shared language use

shared perceptions

(Credit: Herbelot 2018)
Since we share the real world and (roughly) share our perceptions of it, sharing labels (words) for certain categories allows us to successfully refer. Since we see the same world, we are bound to say the same kind of things about it, so we share language use, which is anchored in perception.

(Credit: Herbelot 2018)
Introduction

Word Semantics

Constraints: Individuality

(Credit: Herbelot 2018)
Since we don’t share the same experiences of the world, and since concept composition happens in the mind (separate minds), we are bound to have separate conceptual spaces, separate language use, separate extensions, separate possible worlds, separate intensions.
Larger constituents and compositionality

\[ \text{black cat} = \begin{array}{c}
\text{\textcolor{black}{arsity}} \\
\text{\textcolor{white}{black}}
\end{array} + \begin{array}{c}
\text{\textcolor{white}{cat}} \\
\text{\textcolor{orange}{tabby}}
\end{array} = \begin{array}{c}
\text{\textcolor{black}{black}} \\
\text{\textcolor{black}{cat}}
\end{array} \]
Larger constituents and compositionality

black cat = [image of a black cat] + [image of a ginger cat]

= [image of a black cat] + [image of a witch]
Larger constituents and compositionality

(Credit: Herbelot 2018)
1. Pragmatics

- How does the *broader* context affect meaning? (situation of utterance, community of speaker, etc)
- How does a community contribute to the emergence and spread of meanings? (del Tredici & Fernandez, 2017)
Language in Use

Katherine Johnson, *computer* at NASA, 1966

Much less reliable *computer* at NASA, late 1960s

2. Dynamicity of the lexicon

- The use of *computer* changed meaning over the years.
- Every utterance changes the meaning to its linguistic constituents.
- Members of a community are not necessarily fully in sync.

(Credit: Herbelot 2018)
How hard is it to model meaning, then?

I child-proofed my house but they still get in.

(Example from Teufel 2017)
Semantics

Semantics is the study of meaning communicated through language.

Semantics (and pragmatics) are the glue that connect language to the real world.

Phonology, Morphology, Syntax, etc. are meaningful only once Semantics is taken into account, at some level.

Let’s start at the word-level: Lexical Semantics
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Word Meaning

*I saw my *mother* just now.*
I saw my mother just now.

- We know that the speaker saw a female human, someone who is older than the speaker and is of a specific relation to the speaker
- Lexical relations (e.g. between woman and mother) are central to the way speakers and hearers construct meaning
- Links between linguistic and world knowledge also major factor in determining word meaning
Word Meaning

(Credit: Handke 2012)
**Referential Semantics**: Word meaning described as a relationship between linguistic elements and the non-linguistic world and experiences.

(Credit: Handke 2012)
Lexical Semantics: Word meaning described within a complex relationship between the linguistic elements themselves.
Reference as a Theory of Meaning

- To give the meaning of a word, one shows what it denotes in the real world
- FLY: animate, insect, 2 wings, 6 legs, ...
- COOKING: action

(Credit: Handke 2012)
### Reference as a Theory of Meaning

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But...  

- Real-world referents for words like so, not, very, but, of?  
- In the painting a unicorn is ignoring a maiden.  
- World War III might be about to start.  
- Father Christmas might not visit you this year.  
- I am in love.
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• We can use two expressions without being aware they share the same referent (Frege, 1880)
  3. The morning star is the evening star.
  4. Venus is Venus.
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• Meaning > Reference

• Because we understand the expression President of Egypt, we can use it to refer to a particular individual at any given time
  \rightarrow \textbf{Sense} (aka Intension)
Concepts

- Level needed between words and the world: a *mental representation*
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• Question 1: What form can we assign to concepts?
Introduction

Word Semantics

Concepts

- Level needed between words and the world: a mental representation
- Hypothesize that the sense of words, while mental, is not visual but abstract: a concept
- Question 1: What form can we assign to concepts?
- Question 2: How do children acquire them, along with their linguistic labels?

(Credit: Handke 2012)
Necessary and sufficient conditions

- $x$ is a lion if and only if $L$.
- where $L$ is a list of attributes
  - $x$ is an animal,
  - $x$ has four legs,
  - $x$ is a carnivore,
  - $x$ is a feline,
  - $x$ has a mane, . . .
Class Activity

Say words are labels for concepts, and a concept can be defined by a set of necessary and sufficient conditions (attributes). For each word, establish sets of attributes that would distinguish it from its companions in the group:

1. cake  biscuit/cookie  bread  roll  cracker
2. boil  fry  bake  simmer  grill  roast
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  - $x$ has a mane, ...
Prototype Theory

Prototype Theory (Eleanor Rosch, 1970’s): Theory to represent idea of family resemblances (Wittgenstein)

- **Prototype**: an “ideal” or “typical” example of a category
- A test case is compared with prototype, and if similar, will be considered a member of the category, otherwise it will not.
- Notion of **fuzzy boundaries**: some members are “better” members than others.
- Other approaches to typicality include Frames (Fillmore, 1982) and Idealized Cognitive Models (Lakoff, 1987).
Conceptual Theories

- word-fields
- componential analysis
- semantic networks: computational approach
- prototype theory: cognitive approach
- meaning postulates: logic-based
Approach 1: Decompositional Semantics
Approach 1: Decompositional Semantics

- boy
  - + human
  - — female
  - — adult

- girl
  - + human
  - + female
  - — adult

- man
  - + human
  - — female
  - + adult

- woman
  - + human
  - + female
  - + adult
Introduction

Word Semantics

Word Meaning?

He scored with his left foot\(^1\).

They made camp at the foot\(^2\) of the mountain.

I ate a foot\(^3\)-long hot dog.
Lexical Relations and Meaning

Lexical relations are central to the way speakers and hearers construct meaning
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Lexical relations are central to the way speakers and hearers construct meaning.

1 a. My bank manager has just been murdered.
   b. My bank manager is dead
   c. My bank will be getting a new manager

2 a. This bicycle belongs to Sinead.
   b. Sinead owns this bicycle.
   c. Sinead rides a bicycle.

3 a. Rob has failed his statistics exam.
   b. Rob hasn’t passed his statistics exam.
   c. Rob can’t bank on a glittering career as a statistician.
Lexical Semantics

1. Represent the meaning of each word in the language; and
2. Show to the meanings of words in a language are interrelated
What can we do with Lexical Semantics?

- Recognize word senses in text (manually and automatically)
- Define similarities between words
- Determine how strongly a verb “goes with” its subject (selectional preferences)
- Recognize and interpret figurative uses of words
- Describe relations between words (or better, between word senses)
Lexical Relations

1. **Synonymy**: Different phonological words with the same or similar meanings.
   - couch/sofa  boy/lad  lawyer/attorney  large/big
Lexical Relations

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   - couch/sofa  boy/lad  lawyer/attorney  large/big

2. **Antonymy**: Words which are opposite in meaning
   - dead/alive  pass/fail  hit/miss (complementary)
   - hot (warm tepid cool)  cold (gradable)
   - (go) up/down  (turn) right/left (reverses)
   - own/belong to  employer/employee (converses)
Lexical Relations

3. **Hyponymy**: Relation of (taxonomic) inclusion, aka subset
   - *dog* and *cat* are hyponyms of *animal*
   - *sister* and *mother* are hyponyms of *woman*
Lexical Relations

3. **Hyponymy**: Relation of (taxonomic) inclusion, aka subset
   - *dog* and *cat* are hyponyms of *animal*
   - *sister* and *mother* are hyponyms of *woman*

4. **Hypernymy**: Superset relation between lexical items
   - *human* is a hypernym of *woman* and *man*
   - *saw* is a hypernym of *hacksaw* and *jigsaw*
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5. **Meronymy**: *Part-whole* relationship between lexical items
   - *cover* and *page* are meronyms of *book*
   - *engine* and *door* are meronyms of *car*
6. **Homonymy**: Unrelated senses of the same phonological word
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   - lap/lap  ring/wring  bear/bear  not/knot

7. **Polysemy**: Like homonymy, but senses are judged to be related
   - **hook** (n): 1. a piece of curved material. 2. a trap or snare.
     3. short for fish-hook. 4. something that attracts. . .
Problem with pinning down word meaning

1. Collocations: e.g. *strong* vs. *powerful*
   - *strong argument* and *powerful argument*
   - *strong tea* vs. *powerful tea*
   - *strong car* vs. *powerful car*
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   - spick and span  kith and kin
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3. Creativity and semantic shift: pull word meanings in other directions due to contextual effects
   - I go for a run every morning.
   - He hit a home run.
   - There’s been a run on the dollar.
   - The bears are here for the salmon run.
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1. Collocations: e.g. strong vs. powerful
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   - strong tea vs. powerful tea
   - strong car vs. powerful car

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4. Ambiguity and vagueness: Do the uses of run above have different senses (ambiguous), or share the same sense (vague)?
Class activity: Word senses of “SHOWER”

- Handout: corpora (BNC) examples of uses of shower
- https://www.vecchi.com/eva/teaching/embeddingsNLP/shower_example.pdf
- How many senses does shower have?
- Note: disregard shower if it occurs in a compound noun (e.g. shower curtain)

(Credit: Teufel 2017 T673 Lexical Semantics)
Introduction

Word Semantics

Noun

- **S:** (n) shower#1 (a plumbing fixture that sprays water over you) "they installed a shower in the bathroom"
- **S:** (n) shower#2, shower bath#2 (washing yourself by standing upright under water sprayed from a nozzle) "he took a shower after the game"
- **S:** (n) shower#3, rain shower#1 (a brief period of precipitation) "the game was interrupted by a brief shower"
- **S:** (n) shower#4, cascade#3 (a sudden downpour (as of tears or sparks etc) likened to a rain shower) "a little shower of rose petals"; "a sudden cascade of sparks"
- **S:** (n) exhibitor#1, exhibitioner#1, shower#5 (someone who organizes an exhibit for others to see)
- **S:** (n) shower#6 (a party of friends assembled to present gifts (usually of a specified kind) to a person) "her friends organized a baby shower for her when she was expecting"

Verb

- **S:** (v) lavish#1, shower#1 (expend profusely; also used with abstract nouns) "He was showered with praise"
- **S:** (v) shower#2 (spray or sprinkle with) "The guests showered rice on the couple"
- **S:** (v) shower#3 (take a shower; wash one's body in the shower) "You should shower after vigorous exercise"
- **S:** (v) shower#4, shower down#1 (rain abundantly) "Meteors showered down over half of Australia"
- **S:** (v) shower#5 (provide abundantly with) "He showered her with presents"
Approach 2: Semantic Ontologies and WordNet

- WordNet is a lexical resource that organizes words according to their semantic relations
- Words have different senses
- Each sense is associated with a synset (set of words that are roughly synonymous for a particular sense)
- These synsets are associated with one another using semantic relations (note synonymy is treated differently)
**Word meaning in WordNet**

**fish**#1 (any of various mostly cold-blooded aquatic vertebrates usually having scales and breathing through gills)

- aquatic vertebrate (animal living wholly or chiefly in or on water)
- vertebrate, craniate (animals having a bony or cartilaginous skeleton with a segmented spinal column and a large brain enclosed in a skull or cranium)
- chordate (any animal of the phylum Chordata having a notochord or spinal column)
- animal, animate being, beast, brute, creature, fauna (a living organism characterized by voluntary movement)
- organism, being (a living thing that has (or can develop) the ability to act or function independently)
- living thing, animate thing (a living (or once living) entity)
- whole, unit (an assemblage of parts that is regarded as a single entity)
- ...
Limitations of WordNet and Semantic Ontologies

- WordNet is a glorified thesaurus
- Requires many years and depends on skilled lexicographers, inconsistencies throughout the resource
- Ontology is only as good as ontologist(s) - it is not only data
Approach 3: Distributional semantics
Landauer and Dumais 1997, Turney and Pantel 2010, …
Approach 3: Distributional semantics
Landauer and Dumais 1997, Turney and Pantel 2010, ...

he curtains open and the moon shining in on the barely
ars and the cold, close moon". And neither of the w
rough the night with the moon shining so brightly, it
made in the light of the moon. It all boils down, wr
surely under a crescent moon, thrilled by ice-white
sun, the seasons of the sun and the temple of the moon has risen full and cold
m is dazzling snow, the moon, driving out of the hug
in the dark and now the moon rises, full and amber a
bird on the shape of the moon over the trees in front

But I could n't see the moon or the stars, only the
orning, with a sliver of moon hanging among the stars
they love the sun, the moon and the stars. None of
the light of an enormous moon. The plash of flowing w
man’s first step on the moon; various exhibits, aer
the inevitable piece of moon rock. Housing The Airsh
oud obscured part of the moon. The Allied guns behind
Thanks, see you tomorrow!

https://www.vecchi.com/eva/teaching/embeddingsNLP.html