

Natural Language Processing

Lecture 7

Lexical semantics and Latent Semantic Analysis

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As we have seen (in Lecture 1), according to the *principle of compositionality*,

*The meaning of a complex expression is determined by the meanings of its constituent expressions and the rules used to combine them.*¹

Although the principle is not without its problems,² it suggests that to know the meaning of larger textual units (sentences, paragraphs etc.) it is necessary to know the *meaning of words* they are composed of.

¹Wikipedia: Principle of Compositionality.

²See, e.g., Szabó [2020].

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Intuitively, several words have more than one meanings, e.g. *mouse* has a different meaning in

*A **mouse** ate the cheese.*

and in


*Click on the close button with the **mouse**.*


mouse can mean a *type of small rodent* or an *electronic pointing device*. The identification and characterization of word meanings or **word senses** such as these is the task of **lexical semantics**.


Word senses in dictionaries


One way of characterizing word senses is offered by traditional *dictionaries*. E.g., the online version of the *Oxford Advanced Learner's Dictionary* describes these senses as



mouse *noun*

 A1

 /maʊs/

 /maʊs/

1 ★  A1

(plural **mice**  /maɪs/  /maɪs/)

a small animal that is covered in fur and has a long thin tail. Mice live in fields, in people's houses or where food is stored.

- *a house mouse*
- *The stores were overrun with rats and mice.*
- *She crept upstairs, quiet as a mouse.*
- *(figurative) He was a weak little mouse of a man.*

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Word senses in dictionaries cont.

and

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(plural **mice** or **mouses**)

(*computing*) a small device that is moved by hand across a surface to control the movement of the **cursor** on a computer screen

- *Use the mouse to drag the icon to a new position.*
- *I prefer a wireless mouse.*
- *The keyboard and mouse are wireless devices.*
- *Click the left **mouse button** twice to highlight the program.*
- *With simple **mouse clicks**, the viewer can navigate the room.*

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Notable features of these sense descriptions are that

- word senses have precise identifiers: the surface form *mouse*, the POS-tag *noun* and the sense number together unambiguously identify the senses;
- each sense has a *textual definition* which is not formal, but
 - uses a relatively small definitional vocabulary,
 - follows certain conventions, e.g., starts with a more general word plus characteristic property (*small animal, small device*);
- there are several *example sentences* illustrating typical patterns in which the sense is used.

Lexical relations

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Dictionaries may contain information about *lexical relations* between senses, especially about

- *synonymy*: whether two word senses are (close to) identical;
- *antonimy*: whether two word senses are opposites of each other.

Other important lexical relations include *taxonomical relations*:

- sense s_1 is a *hyponym* of s_2 if it is strictly more specific, e.g. $mouse_1$ is a hyponym of $animal_1$;
- conversely, sense s_1 is a *hypernym* of s_2 if s_2 is more specific than s_1 .

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And, finally, *meronymy*, the *part-whole* relation: e.g., *finger* is a meronym of *hand*.

Collectively, word senses and their lexical relations constitute a *network*, in which

- nodes are sets of synonymous word senses, and
- edges are lexical relations.

Since the hyponymy relation (also called *is_a*) is transitive, it makes sense to have only *direct hyponymy* edges in the network, i.e., there have an $s_1 \xrightarrow{is_a} s_2$ edge only if there is no node s_3 for which $s_1 \xrightarrow{is_a} s_3$ and $s_3 \xrightarrow{is_a} s_2$.

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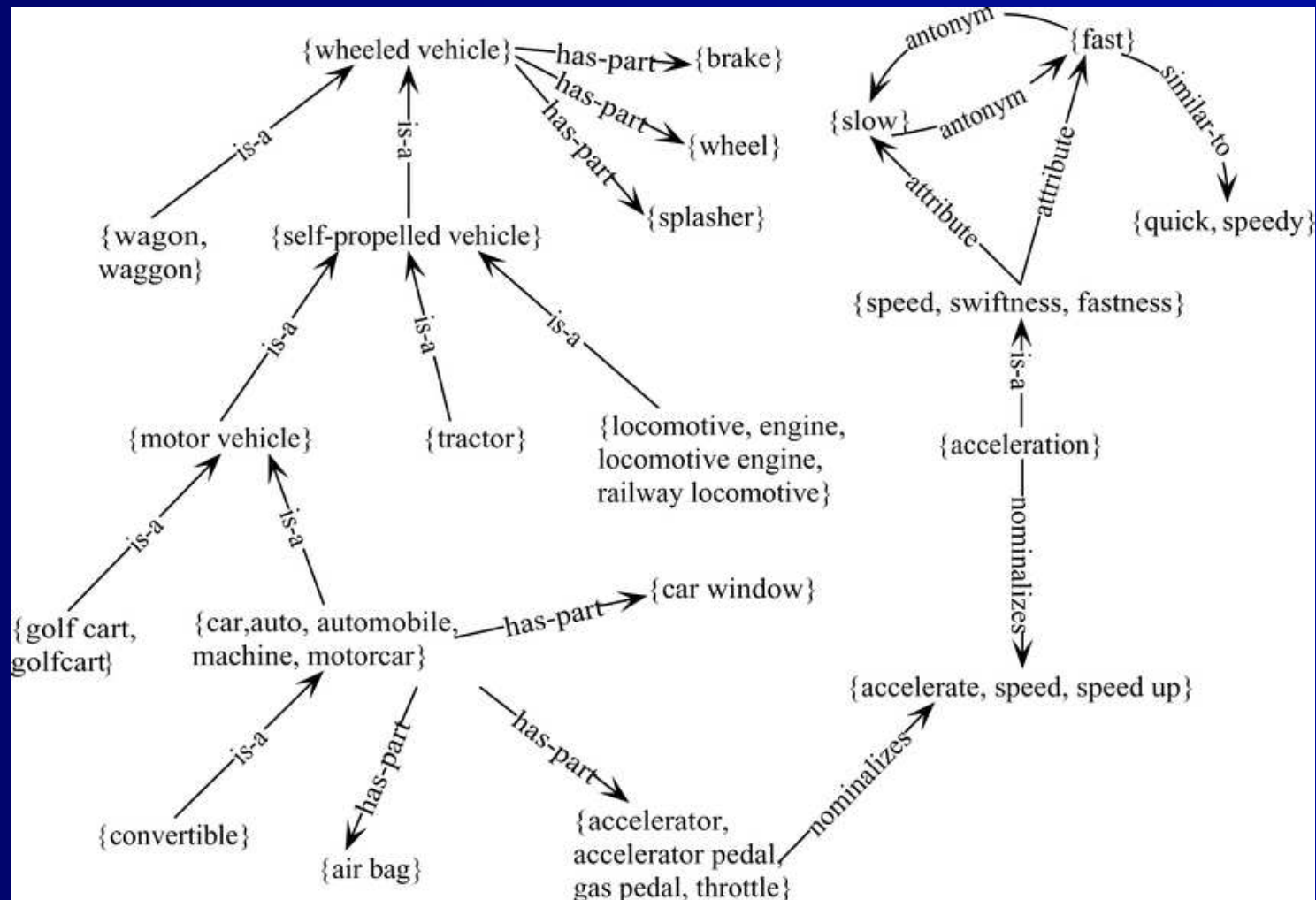
To be usable for NLP purposes, lexical semantic information has to be accessible as a computational resource with a well defined query API, and, starting from the mid. 1980s a number of projects developed such resources.

The most important has been the *WordNet* English lexical database, which contains a large number of synonym sets with definitions, examples and lexical relations. After its success, WordNets were developed for a large number of other languages, now more than 200 WordNets are available.

WordNet cont.

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A part of the English WordNet network:



(Figure from Navigli [2009].)

Knowledge bases as lexical resources

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In addition to dedicated lexical databases, *knowledge bases* can also serve as useful lexical semantic resources, since they contain information about *entities* and *concepts*, which can be linked to words in a vocabulary. Important examples include

- *Wikis*, most importantly the English Wikipedia, here various types of links and references between the entries provide relational information;
- *formal ontologies*: these describe relationships between concepts in a formal logical language.

Word sense disambiguation

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To use the information about word senses provided by these lexical resources, NLP applications must be able to determine in which sense words are used in the input, i.e., perform *word sense disambiguation (WSD)*. The details of the WSD task depend on which lexical resource it is based on and how the resource is used. Given a resource containing word senses,

- *supervised WSD* uses machine learning methods on training data which is annotated with the correct word senses; while
- *knowledge-based WSD* exploits the information in the lexical resource, e.g. the lexical relations and definitions in WordNet.

Vector-based lexical semantics

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The lexical semantic approach we have seen so far has certain features that make it difficult to achieve large coverage and adapt to new languages or domains:

- the lexical databases were manually assembled by highly qualified experts;
- the development of high-performance WSD modules typically requires a large amount of expert-annotated training data.

These problems led to research into alternatives that assign useful word meaning representation in an *unsupervised* fashion, simply learning them from text corpora.

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Although there have been attempts to learn *semantic networks* from text corpora, the first successful unsupervised lexical semantic methods have been learning *word vectors* from text corpora, i.e., embedding functions of the form

$$E : V \rightarrow R^d$$

which assign d -dimensional ($d \in \mathbb{N}$) vectors to each word in the V vocabulary. Of course, not any such function will do: the obvious requirement is that the learned vectors has to convey useful information about the *meaning* of the words they are assigned to.

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One way of ensuring the connection is to utilize the *distributional hypothesis*:

- “You shall know a word by the company it keeps.” ³
- “Linguistic items with similar distributions have similar meanings.” ⁴

This suggests that if the word vectors reflects the *distribution* of the words they are assigned to, then they will also reflect the words’ meanings.

³J.R. Firth, *Papers in Linguistics 1934–1951* (1957).

⁴[Wikipedia: Distributional semantics](#).

Co-occurrence matrices

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The most direct way of getting word vectors that reflect the words' distribution in a corpus is to consider *co-occurrence* matrixes. If there are D documents in the corpus and V is the corpus vocabulary then

- *term-document* matrixes are $|V| \times D$ dimensional matrixes in which each row is a word vector whose i -th element is the occurrence count of the word in the i -th document, while
- *term-term* matrixes are $|V| \times |V|$ dimensional matrixes in which each row is a word vector whose i -th element is the co-occurrence count of the word with the i -th *other word*.

Latent Semantic Analysis

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An important problem of using these vectors directly is their huge dimensionality and sparsity. To solve this problem, *Latent Semantic Analysis* methods apply dimension reducing matrix factorization methods, typically *truncated SVD* to find a *low-rank approximation* of the original C co-occurrence matrix. With SVD the factorization is

$$C = USV^T$$

with U, V orthonormal and S diagonal. In case of truncated SVD, the rows of the U matrix can be used as low-dimensional, approximate representations of the co-occurrence based original word vectors.

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