

# Two levels of lexical ambiguity and a unified categorical approach

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- 1 Introduction
- 2 Types of lexical ambiguity (NLP perspective)
- 3 Levels of lexical ambiguity (Linguistics perspective)
- 4 Lexical ambiguity representation via Category Theory
- 5 Conclusion



*[S]tatistical systems can accomplish natural language processing to a considerable degree, but they cannot achieve natural language understanding, which necessarily involves meaning, something which purely statistical approaches cannot capture. Something more is needed. **To start down the path from NLP to NLU we have to go back to linguistics.***

*(Van Valin, 2016, p. 2)*

So, to the extent that human-analogous NLU is a desirable goal, insights from linguistics are still useful. The question is how to feed research results from linguistics into NLU/NLP, given the increasingly huge gap between the two fields.



I focus on the **formal representation** of language and use **lexical ambiguity** as a case to demonstrate how insights from **theoretical linguistics** can help us achieve more rigorous representation.

The formal tool I adopt is **Category Theory**, which is already in use in NLP research. Category Theory provides a nice bridge between lexical and compositional semantics.

Plan:

- Review the established types of lexical ambiguity in NLP.
- Distinguish two broad levels of lexical ambiguity in Linguistics.
- Formally represent the two levels and aim for a tentative unification.

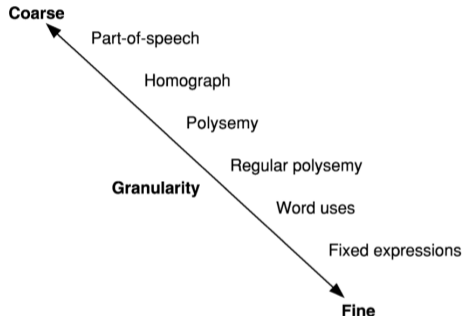


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Edmonds (2006):

- Lexical ambiguity is a fundamental defining characteristic of human language.
- Lexical disambiguation or **word sense disambiguation (WSD)** is one of the oldest problems in NLP.



(Edmonds's spectrum of lexical ambiguity)

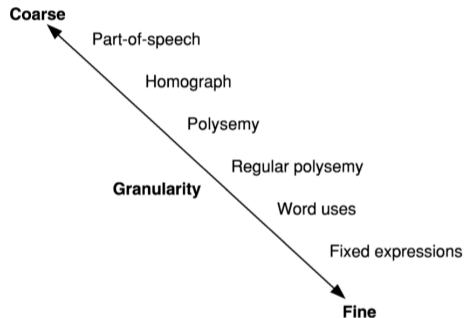
Edmonds's “word uses” and “fixed expressions” are not clearly defined, so I skip them.



Homographic ambiguity: e.g., *bow*

- /bau/ n. the front part of a boat or ship
- /bou/ n. an arrow-shooting weapon

(Same pronunciation  $\Rightarrow$  homonymy; e.g., *bank*)



(Edmonds's spectrum of lexical ambiguity)

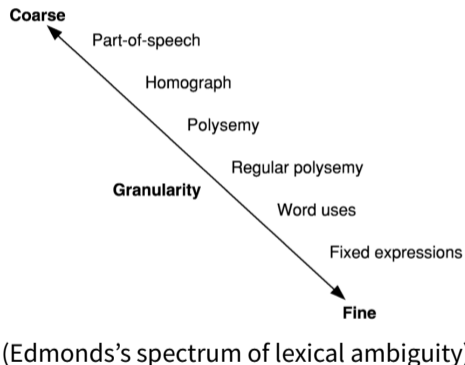


Polysemy: e.g., *bank*

- **n.** the company or institution
- **n.** the building itself
- **n.** a place where a supply of something is held (*blood bank*)
- ...

Regular polysemy: e.g.,

- institution vs. building (*bank*)
- physical object vs. content (*book*)



(Edmonds's spectrum of lexical ambiguity)

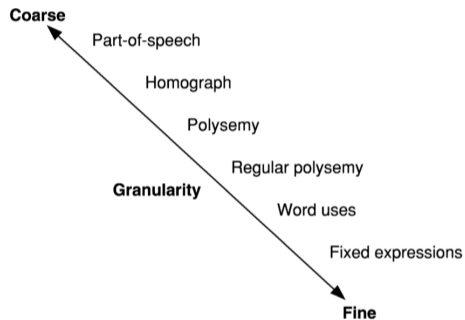




POS and homographic ambiguity are considered **solved problems** in NLP, by

- POS-tagging
- clear contextual clues

The real challenge is **polysemy**.



(Edmonds's spectrum of lexical ambiguity)

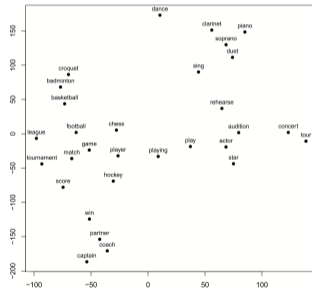
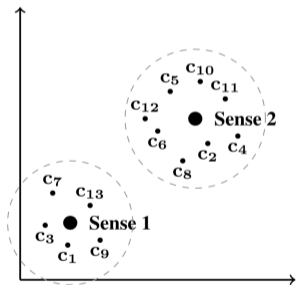
# Lexical ambiguity and disambiguation



Polysemy is also somewhat solved in NLP, by **word sense induction (WSI)** techniques that represent word senses as

- clusters of contexts, or
- clusters of neighbors

*Homograph/homonymy and polysemy are treated alike, while POS is considered a separate task.*



(Lenci & Sahlgren, 2023, pp. 223–227)



The NLP perspective is **task-oriented**:

- POS-tagging task, WSD task (homograph/homonymy, polysemy)

While this gets the job done, it does not align well with human intuition.

- ① Homonymy/polysemy may also involve POS-level ambiguity.
  - Homonymy + POS: *stalk* ‘n. part of a plant / v. follow a person’
  - Polysemy + POS: *ship* ‘n. a large boat / v. send to a customer’
- ② Homograph/homonymy and polysemy do have qualitative differences.
  - Homograph/homonymy usually arises by historical accident.
  - Polysemy usually arises by meaning extension or modification.

Overall, the NLP perspective on lexical ambiguity is **convenient but impressionistic**. It is not quite human-analogous.



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The NLP perspective on lexical ambiguity reflects a **form-over-meaning** mindset. Given a word form like *bank*, how to pin down its meaning?

This mindset is tied to the task of **parsing**. However, from the perspective of linguistics, human language works in more of a **meaning-over-form** fashion.

*[L]anguage ... is fundamentally a system of meaning. Aristotle's classic dictum that language is sound with meaning should be reversed. Language is meaning with sound (or some other externalization, or none).*  
(Berwick & Chomsky, 2016, p. 101)



To reach a more human-analogous treatment of lexical ambiguity:

- 1 We should treat homographic/homonymous words as separate lexical entries.
- 2 We should treat POS ambiguity as an integral part of polysemy.

Example: *bank*

- *bank*<sub>1</sub> n. a mound, pile, or ridge raised above the surrounding level; the rising ground bordering a lake, river, or sea; ...  
vt. to raise a bank about;  
to heap or pile in a bank; ...  
vi. to rise in or form a bank; ...
- *bank*<sub>2</sub> n. an establishment for the custody, loan, exchange, or issue of money; ...  
vt. to deposit or store in a bank; ...  
vi. to manage a bank; ...

This is just the dictionary organization of word senses!



- *bank*<sub>1</sub> n. a mound, pile, or ridge raised above the surrounding level; the rising ground bordering a lake, river, or sea; ...  
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Rationale behind dictionary organization:

- Word entries are built on separate **etymological roots**.
- Word senses sharing the same root are organized into **syntactic categories**.

The relationship between syntactic categories and word senses is mediated by the overarching roots: **root (abstract) + syntactic category (abstract) = word sense (concrete)**



The rationale we have seen is a standard part of current theoretical linguistics. It is a basic idea in the branch of generative syntax known as **root syntax**.

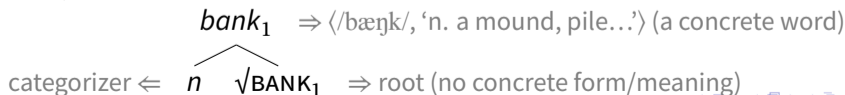
- Halle & Marantz (1993 et seq.): Distributed Morphology (DM)
- Borer (2005, 2013): Exoskeletal Syntax (XS)
- Chomsky (2019):

*If you accept ... the Hagit Borer–Alec Marantz theory of root categorization, which I think is pretty strongly motivated, the roots in the lexicon are independent of category.*

## A theory-neutral definition of “root”

A root is a purely lexical unit in formal representation that is **void of categorial information**. Its syntactic category (and categorized meaning) is represented combinatorially.

Example (in DM style):







The “super-concept” (Fellbaum 2006) status of the root is most evident in Semitic languages.

## Root-and-pattern morphology in Hebrew (Arad, 2005, p. 16)

$\sqrt{\text{š-M-N}}$	‘about some fatty substance’	$\sqrt{\text{x-š-B}}$	‘about some mental activity’
<i>šamen</i>	‘adj. fat’	<i>xašav</i>	‘v. think’
<i>šuman</i>	‘n. fat’	<i>xišev</i>	‘v. calculate’
<i>šaman</i>	‘v. grow fat’	<i>maxšava</i>	‘n. thought’
<i>hišmin</i>	‘v. fatten’	<i>maxšev</i>	‘n. computer’
...		...	

*[I]n an Arabic-English bilingual wordnet, the derivational root and form of each content word should be stored, since this way of semantically linking words is a basic expectation of a literate Arabic speaker.*

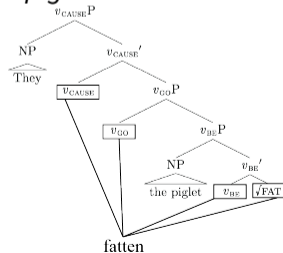
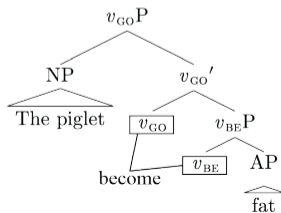
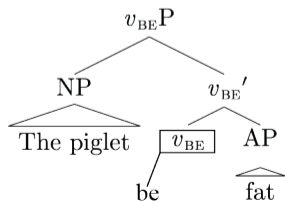
*(Black & ElKateb, 2004, p. 69)*

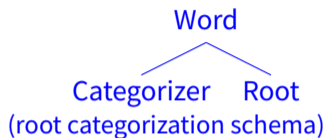


Root syntax is a fruitful research area in current theoretical linguistics. NB it is **not** a mere restatement of POS-tagging, because categorizers are not necessarily run-of-the-mill POS tags.

- 1 The categorizer may encode more subtle, language-specific information.
  - e.g., the “verbalizer” can encode event types, the “nominalizer” can encode genders
- 2 The categorizer may be a complex functional structure.
  - e.g., some verbs have a multi-layer structure

Examples: *The piglet is fat.* / *The piglet became fat.* / *They fattened the piglet.*



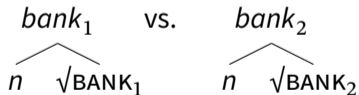


Two types of lexical ambiguity at the root categorization level:

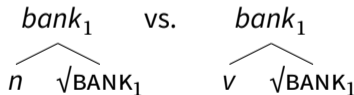
- Homograph/homonymy: different roots
- POS-based polysemy: same root, different categorizers

Examples:

homonymy



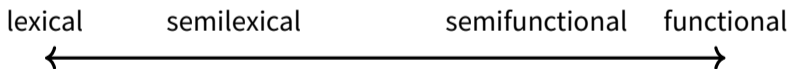
POS-based polysemy





Root syntax is not limited to content words but has been extended to certain function words too—primarily to **semilexical** or **semifunctional** (aka **semigrammatical**) items (Acedo-Matellán & Real-Puigdollers 2019; Song, 2019; Cavirani-Pots, 2020).

Semilexical or semifunctional items are linguistic elements with **both lexical content and grammatical function**. They are at an intermediate stage of grammaticalization.



(Continuum of lexicality in linguistic elements; Song, 2022)

I use “semilexicality” as a cover term for expository convenience.



Semilexicality is prevalent in **analytic** languages.

(1) Classifiers

*yī wèi / míng / gè lǎoshī*  
one CL<sub>respectful</sub> CL<sub>professional</sub> CL<sub>neutral</sub> teacher  
'a teacher'

[Mandarin Chinese]

(2) Conjunctions

a. *hālì bōtè yǔ / ?hé / ?gēn mófǎ shí*  
Harry Potter and<sub>literary</sub> and<sub>neutral</sub> colloquial magic stone  
'*Harry Potter and the Philosopher's Stone*'

[Mandarin Chinese]

b. *xiǎomíng / ?yǔ / hé / gēn xiǎohóng dōu zài shātān-shàng wán*  
Xiaoming and<sub>literary</sub> and<sub>neutral</sub> colloquial Xiaohong both be.in beach-on play  
'Both Xiaoming and Xiaohong are playing on the beach.'



Semilexicality is observed in **synthetic** languages too, though to a lesser extent.

(3) Alternative voice auxiliaries

*La pasta va / viene mangiata subito.* [Italian]  
the pasta PASS<sub>obligatory</sub> PASS<sub>regular</sub> eaten immediately  
'Pasta must be / is eaten immediately.' (Cardinaletti & Giusti, 2001, p. 392)

(4) Alternative aspect auxiliaries

a. *Ik heb de hele dag zitten te lezen.* [Dutch]  
I have the entire day sit<sub>PROG</sub> to read  
'I have been reading the entire day.' (Cavirani-Pots, 2020, p. 1)

b. *Ek het gister baie (ge-)loop (en) praat.* [Afrikaans]  
I have yesterday a.lot walk<sub>PROG</sub> and talk  
'I have been (walking and) talking a lot yesterday.' (ibid., p. 344)



Somewhat surprisingly, semilexicality is also prevalent in **polysynthetic** languages, though in a different guise, as affixes (see Song 2021a for more data).

(5) Classifiers

*tíx<sup>w</sup>-əqən*      *lisék*  
three-CL<sub>container</sub> sack  
'three sacks'

[Halkomelem]

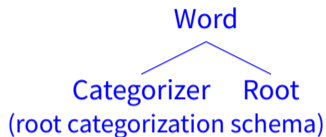
(Gerdtts & Hinkson, 1996, p. 10)

(6) a. *dikwh-okwł*      *bołak*  
three-CL<sub>salmon</sub> salmon  
'three salmon'

[Yurok]

b. *nahks-oh*      *ha'aag*  
three-CL<sub>round</sub> rock  
'three rocks'

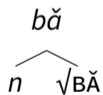
(Conathan, 2004, pp. 26–27)



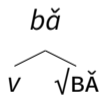
Semilexicality is a special type of POS-based polysemy:

- Categorizer: a functional/grammatical category
- Root: a normal root (chosen for various reasons)

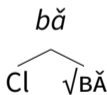
Example: Mandarin Chinese



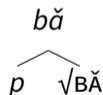
(n. handle)



(v. hold)



(cl. for holdable objects)



(p. for affected direct objects)





In sum, two types of lexical ambiguity may arise at the root categorization level:

- Homograph/homonymy: different roots
- POS-based polysemy: same root, different categorizers
  - Content words (a solved problem in NLP)
  - Semigrammatical words (not yet dealt with in NLP)

Theoretical linguistics provides a way to systematically represent these ambiguity types (via the theory of generalized root syntax).



The only remaining type of lexical ambiguity we have not addressed yet is **word sense polysemy**; e.g., *bank*

- n. the company or institution
- n. the building itself
- n. a place where a supply of something is held (*blood bank*)
- ...

We encounter the limit of root syntax, which is not designed to tackle issues at the post-categorization level. In root syntax, all categorized senses of a word are lumped together in an area in the Lexicon called the **Encyclopedia**, whose internal structure is left unstudied.

The categorical approach I will introduce offers a way to formally represent word sense ambiguity at the post-categorization level.



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Category Theory is a branch of mathematics dedicated to the representation and reasoning of abstract, complex structures.

*Category theory is [...] unmatched in its ability to organize and layer abstractions, to find commonalities between structures of all sorts, and [...] it has also been branching out into science, informatics, and industry.*  
(Fong & Spivak, 2019)

Category Theory has also been applied to the study of natural language, especially to NLP. The most representative application is that of the Lambek-Coecke school (Lambek, 1988; Coecke et al., 2010; et seq.).

Fong & Spivak (2019) is also an accessible modern textbook on the subject.



The focus of this school of categorical linguistics, called “DisCoCat,” is a principled integration of lexical semantics and compositional semantics in NLP. The main idea is to treat semantic interpretation as a **functor** from syntax to semantics (see Coecke et al., 2013 for an overview).

- Syntax: a free category  $\mathcal{C}$  based on Lambek’s (1999) grammatical type system
- Semantics: the category  $\mathcal{F}Vect$  of finite-dimensional vector spaces

$$\mathcal{C} \xrightarrow{I} \mathcal{F}Vect$$

*I* maps grammatical types to vector spaces that represent meanings, but thanks to the shared structure of the two categories, meaning vectors now live in vector spaces of different “types” and can compose according to grammatical relations.



Lexical ambiguity has not received a lot of attention in the DisCoCat framework. The few studies dedicated to it (Piedeleu, 2014; Kartsaklis, 2014; Piedeleu et al., 2015) are all inspired by quantum mechanics:

- ambiguous words  $\Rightarrow$  mixed states
- nonambiguous words  $\Rightarrow$  pure states (represented in a “mixed” way)

Technical details aside, this modeling of lexical ambiguity mainly focuses on **polysemy**, while homonymy is separately treated in a pre-compositional disambiguation step. Two problems:

- The classification of ambiguity types is a coarse one.
  - With just the coarsely defined polysemy and homonymy
- There is no built-in way to disambiguate word senses.
  - The mixed states are weighted summations of pure states  $\sum_i p_i |s_i\rangle\langle s_i|$ .

What this model does is mainly **give ambiguous words a place** in DisCoCat.



DisCoCat is not the only application of Category Theory to linguistics.

- Asudeh & Giorgolo (2020): conventional implicature via monad
  - e.g., the negative speaker attitude in words like *Yank* and *cur*
  - The monad tool keeps “at-issue” and “side-issue” aspects of meaning separate.
- Song (2021b): an extension of the monadic approach to root syntax
  - The arbitrary meaning of words is essentially also a matter of conventionalization.
  - e.g., the meaning of *bank* has a non-arbitrary part (its POS) and an arbitrary part (its root)
  - The POS is an “at-issue” for compositional semantics, while the root content is a “side-issue.”
- Asher (2011), Babonnaud (2019, 2021, 2022): “dot type” polysemy via topos
  - This corresponds to regular polysemy in the WSD task.
  - e.g., *book* has the type  $P \cdot I$ , with a physical and an informational aspect
  - A dot type can be categorically reduced to its individual aspects (i.e., be disambiguated).



DisCoCat is not the only application of Category Theory to linguistics.

- Asudeh & Giorgolo (2020): conventional implicature via monad
- Song (2021b): an extension of the monadic approach to root syntax
- Asher (2011), Babonnaud (2019, 2021, 2022): “dot type” polysemy via topos

The categorical environment in Song (2021b) is a topos too, so these alternative approaches could potentially be combined. Such a unified approach would have two advantages:

- It would preserve the fine-grained classification of lexical ambiguity from the theoretical linguistic perspective.
- It would support meaning composition along the way (though not using distributional semantics, which is still a unique feature of DisCoCat).

Overall, this potential unified approach could provide **a better channel to connect theoretical linguistics and NLU** (e.g., the topos environment naturally supports ontology building).





Monad is a general concept from Category Theory, but the particular type of monad Asudeh & Giorgolo (2020) use to model conventional implicature—the **writer** monad—is borrowed from functional programming (which in turn has a category-theoretic basis).

*[T]he writer monad [is] used for logging or tracing the execution of functions. It's also an example of a more general mechanism for **embedding [side] effects in pure computations**.*

*(Milewski, 2019, p. 49)*

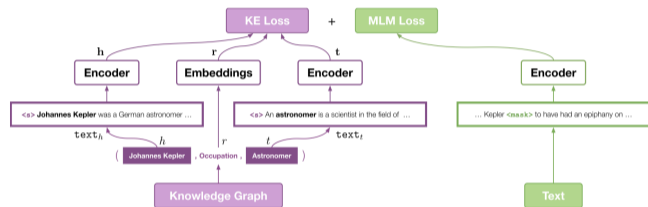
```
type Writer a = (a, String)
```

*(Writer a creates a log area for any type a)*

(7)  $\llbracket \text{Yank} \rrbracket = (\text{American}, \{\text{The speaker has a negative attitude.}\})$



The **two-track representation** in monadic semantics is reminiscent of a common method in **knowledge-enhanced PLMs** (e.g., Zhang et al., 2020; Wang et al., 2021; Sun et al., 2020, 2021).



$$\mathcal{L} = \mathcal{L}_{KE} + \mathcal{L}_{MLM}$$

(Wang et al., 2021)

Figure 2: The KEPLER framework. We encode entity descriptions as entity embeddings and jointly train the knowledge embedding (KE) and masked language modeling (MLM) objectives on the same PLM.

*Jointly optimizing the two objectives can implicitly integrate knowledge from external KGs into the text encoder, while preserving the strong abilities of PLMs for syntactic and semantic understanding.*  
(Wang et al., 2021, p. 179)



A monad is an **endofunctor** with two natural transformations. Abstracting away from technical details, the core idea is to represent meanings with non-pure-function content as a pair

(pure-function meaning, {non-pure-function content})

- (8) a.  $\llbracket [N \ n \ \sqrt{BANK_1}] \rrbracket = (\llbracket n \rrbracket, \{(n, \sqrt{BANK_1})\})$   
(an entity that is idiosyncratically characterized by  $\sqrt{BANK_1}$ )
- b.  $\llbracket [Cl \ Cl \ \sqrt{B\check{A}}] \rrbracket = (\llbracket Cl \rrbracket, \{(Cl, \sqrt{B\check{A}})\})$   
(a classifier that is idiosyncratically characterized by  $\sqrt{B\check{A}}$ )



A topos is a special category that, in addition to the basic categorical setting, has some extra features, including products, “pullbacks,” exponentials, and most importantly a **subject classifier** (usually denoted by  $\Omega$ ).

The above features together make the topos a richly structured, quasi-set-theoretic environment that is **particularly suitable for knowledge and meaning representation**. Specifically, the  $\Omega$  tool can be used to represent **subtypes** and thereby to build **type ontologies**.

In this “pullback” square (which exists for all subtype relations),

$$\begin{array}{ccc} A & \xrightarrow{u} & B \\ \downarrow ! & \lrcorner & \downarrow \chi_A \\ 1 & \xrightarrow{\top} & \Omega \end{array}$$

- $\Omega$  represents the truth-value type,
- $A$  represents any subtype of  $B$ ,
- $\chi_A$  is the characteristic map of  $A$ .



$$\begin{array}{ccc} \text{Bank}_1 & \xrightarrow{u} & E \\ \downarrow ! & \lrcorner & \downarrow \chi_{\text{Bank}_1} \\ 1 & \xrightarrow{\tau} & \Omega \end{array}$$

(content word)

$$\begin{array}{ccc} \text{Conj}_v & \xrightarrow{u} & \text{Conj} \\ \downarrow ! & & \downarrow \chi_{\text{Conj}_v} \\ 1 & \xrightarrow{\tau} & \Omega \end{array}$$

(semigrammatical word)



$$\begin{array}{ccc}
 \text{Bank}_1 & \xrightarrow{u} & E \\
 \downarrow ! & \lrcorner & \downarrow \chi_{\text{Bank}_1} \\
 1 & \xrightarrow{\top} & \Omega
 \end{array}$$

(content word)

$$\begin{array}{ccc}
 \text{Conj}_\vee & \xrightarrow{u} & \text{Conj} \\
 \downarrow ! & & \downarrow \chi_{\text{Conj}_\vee} \\
 1 & \xrightarrow{\top} & \Omega
 \end{array}$$

(semigrammatical word)

*Toposes already emerged in Asher's (2011) categorical model for TCL as suitable (and even necessary) for interpreting dot types, and Babonnaud (2019) further argues that toposes could be **the best categorical models** to interpret on a unified basis a large variety of semantic frameworks with subtyping.* (Babonnaud, 2021, p. 19)



Asher (2011) uses “dot types” to represent words with **inherent polysemy** (aka regular polysemy in WSD). For instance, *book* has the type  $P \cdot I$ , which has both a PHYSICAL and an INFORMATIONAL aspect. This idea can be traced back to Pustejovsky (1996).

Babonnaud (2019, 2021, 2022) treats dot types as **subtypes of product types**. On this view, the individual aspects of dot types can simply be retrieved via **categorical projections**.

$$\begin{array}{ccc} P \cdot I & \xrightarrow{u} & P \times I \\ \downarrow ! & \lrcorner & \downarrow \chi_{P \cdot I} \\ 1 & \xrightarrow{T} & \Omega \end{array}$$

( $P \cdot I$  is a relation between  $P$  and  $I$ )

$$\begin{array}{ccccc} & & P \cdot I & & \\ & & \downarrow u & & \\ P & \xleftarrow{\pi_1} & P \times I & \xrightarrow{\pi_2} & I \end{array}$$

( $\pi_1, \pi_2$  are projections)

Asher (2011) holds a more complex view involving power objects.



Now let’s combine the “dot type” view and the root syntax view. For a word with “inherent polysemy” like *book*, we can assign it the following syntactic and semantic representations:

- (9) a. Syntax:  $[_N n \sqrt{\text{BOOK}}]$   
b. Semantics:  $(\llbracket n \rrbracket, \{(n, \sqrt{\text{BOOK}})\})$  (an entity idiosyncratically characterized by  $\sqrt{\text{BOOK}}$ )

Root syntax does not specify what exactly this “idiosyncratic characterization” is. In fact, when it is just a single word,

$$(10) \quad \text{Type}(\llbracket n \rrbracket, \{(n, \sqrt{\text{BOOK}})\}) = \text{Type}(\llbracket n \rrbracket) \times \text{Type}(\{(n, \sqrt{\text{BOOK}})\}) \cong \text{Type}(\llbracket n \rrbracket) \times 1 \cong \text{Type}(\llbracket n \rrbracket)$$

This demonstrates that as far as pure functional composition is concerned, the root-contributed idiosyncrasy does not matter.



# Post-categorization ambiguity: where “dot types” meet root syntax



But that root-contributed idiosyncrasy is precisely what gives rise to **inherent polysemy**. Hence, the dot type corresponds to the root-tagging “log.” This brings us to the overall representation:

$$(11) \quad \text{Type}(\llbracket n \rrbracket, \{(n, \sqrt{\text{BOOK}})\}) = \text{Type}(\llbracket n \rrbracket) \times P \cdot I$$

The first component of this product is relevant to pure functional composition, while the second component is relevant to lexical semantic interpretation. NB both components may be part of some ontological structure (one grammatical and the other lexical-semantic):

$$\begin{array}{ccc} n & \xrightarrow{u} & \mathbf{EP}_N \\ \downarrow \lrcorner & & \downarrow \chi_n \\ 1 & \xrightarrow{\top} & \Omega \end{array}$$

(grammatical ontology)

$$\begin{array}{ccccc} P \cdot I & \xrightarrow{u} & P \times I & \xrightarrow{\pi_1} & P & \xrightarrow{v} & E \\ \downarrow \lrcorner & & \downarrow \chi_{P \cdot I} & & \downarrow \lrcorner & & \downarrow \chi_P \\ 1 & \xrightarrow{\top} & \Omega & & 1 & \xrightarrow{\top} & \Omega \end{array}$$

(semantic ontology)

$\mathbf{EP}_N$  represents a certain well-defined set of grammatical types that  $n$  is part of.



- 1 Introduction
- 2 Types of lexical ambiguity (NLP perspective)
- 3 Levels of lexical ambiguity (Linguistics perspective)
- 4 Lexical ambiguity representation via Category Theory
- 5 Conclusion**



In this study, I have

- **revisited** the established types of lexical ambiguity in NLP/NLU
  - POS ambiguity, homograph/homonymy, polysemy
- **reorganized** those types into two theoretical linguistic levels
  - root categorization level: homograph/homonymy, POS-based polysemy
  - post-categorization level: word sense polysemy (within the same POS)
- formally **represented** the two ambiguity levels in the language of Category Theory
  - respectively via monad and topos
  - with a tentative unification

**Takeaway: Theoretical linguistics can still be useful for next-generation NLU. Category Theory may be a useful channel.**

Future research: more details about the above unification

# Thank you!





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