

# Word Sense Disambiguation

LING 571 — Deep Processing for NLP

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# Distributional Similarity for Word Sense Induction + Disambiguation

# Word Sense Disambiguation

- We've looked at how to represent words
  - ...so far, ignored **homographs**
- Wrong senses can lead to poor performance in downstream tasks
  - Machine translation, text classification
- Now, how do we go about differentiating homographs?

# Word Senses

WordNet Sense	Spanish Translation	Roget Category	Word in Context
<b>bass</b> <sup>4</sup>	<i>lubina</i>	FISH/INSECT	...fish as Pacific salmon and striped <b>bass</b> and...
<b>bass</b> <sup>4</sup>	<i>lubina</i>	FISH/INSECT	...produce filets of smoked <b>bass</b> or sturgeon...
<b>bass</b> <sup>7</sup>	<i>bajo</i>	MUSIC	...exciting jazz <b>bass</b> player since Ray Brown...
<b>bass</b> <sup>7</sup>	<i>bajo</i>	MUSIC	...play <b>bass</b> because he doesn't have to solo...

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- ***First order*** vectors:
  - $\vec{w} = (f_1, f_2, f_3 \dots)$
  - Feature vector of word itself

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- We've covered how to create vectors for *words*, but how do we represent *senses*?
- **First order** vectors:
  - $\vec{w} = (f_1, f_2, f_3 \dots)$
  - Feature vector of word itself
- **Second order** vectors:
  - Context vector

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”



# Word Representation

- 2nd Order Representation:
- Identify words in context of  $w$
- For each  $x$  in context of  $w$ :
  - Compute  $x$  vector representation
- Compute centroid of these  $\vec{x}$  vector representations

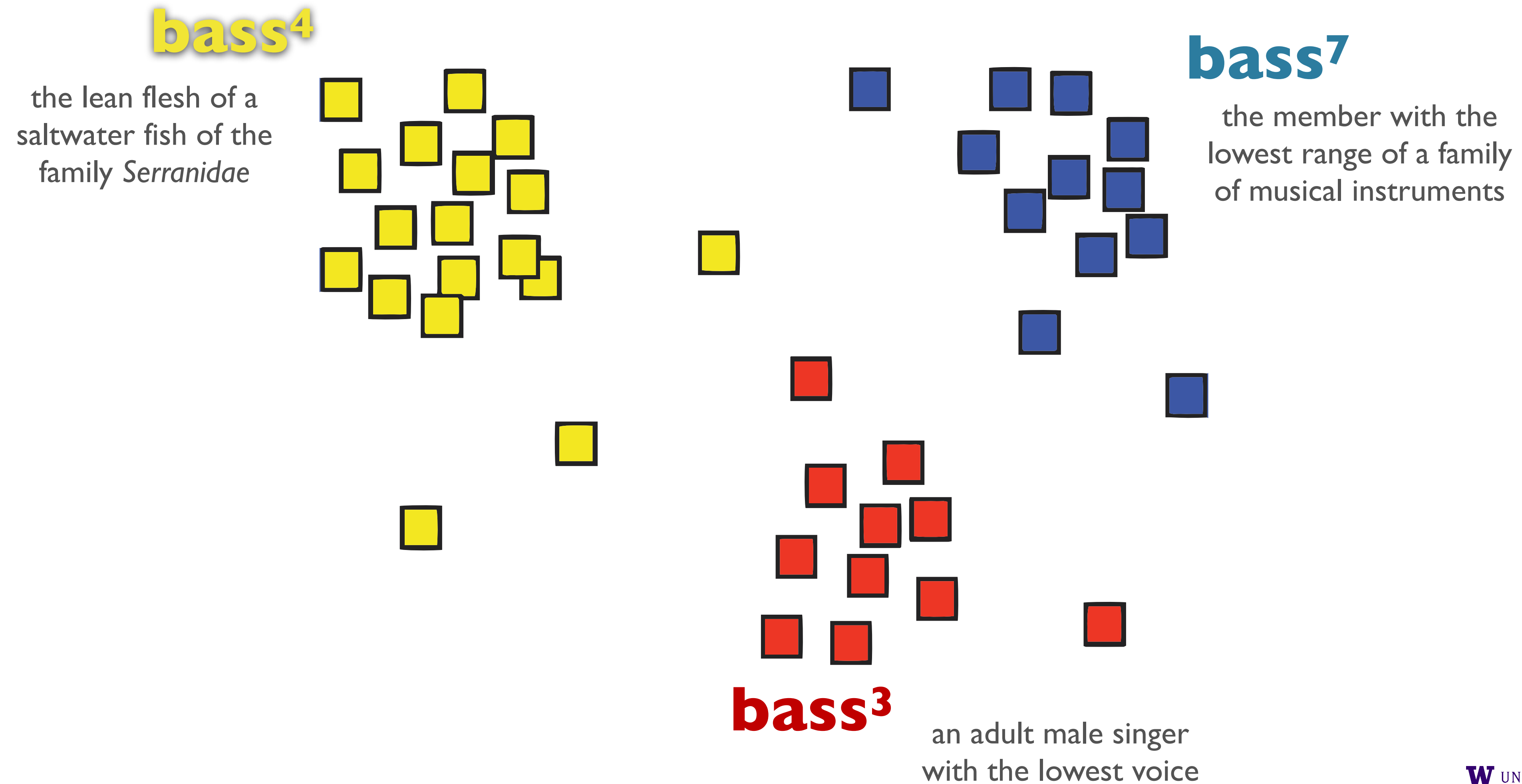
# Computing Word Senses

- Compute context vector for each occurrence of word in corpus
- Cluster these context vectors
  - # of clusters = # of senses
- Cluster centroid represents word sense
- Link to specific sense?
  - Pure unsupervised: no sense tag, just  $i^{\text{th}}$  sense
  - Some supervision: hand label clusters, or tag training

# Disambiguating Instances

- To disambiguate an instance  $t$  of  $w$ :
  - Compute context vector for instance
  - Retrieve all senses of  $w$
  - Assign  $w$  sense with closest centroid to  $t$

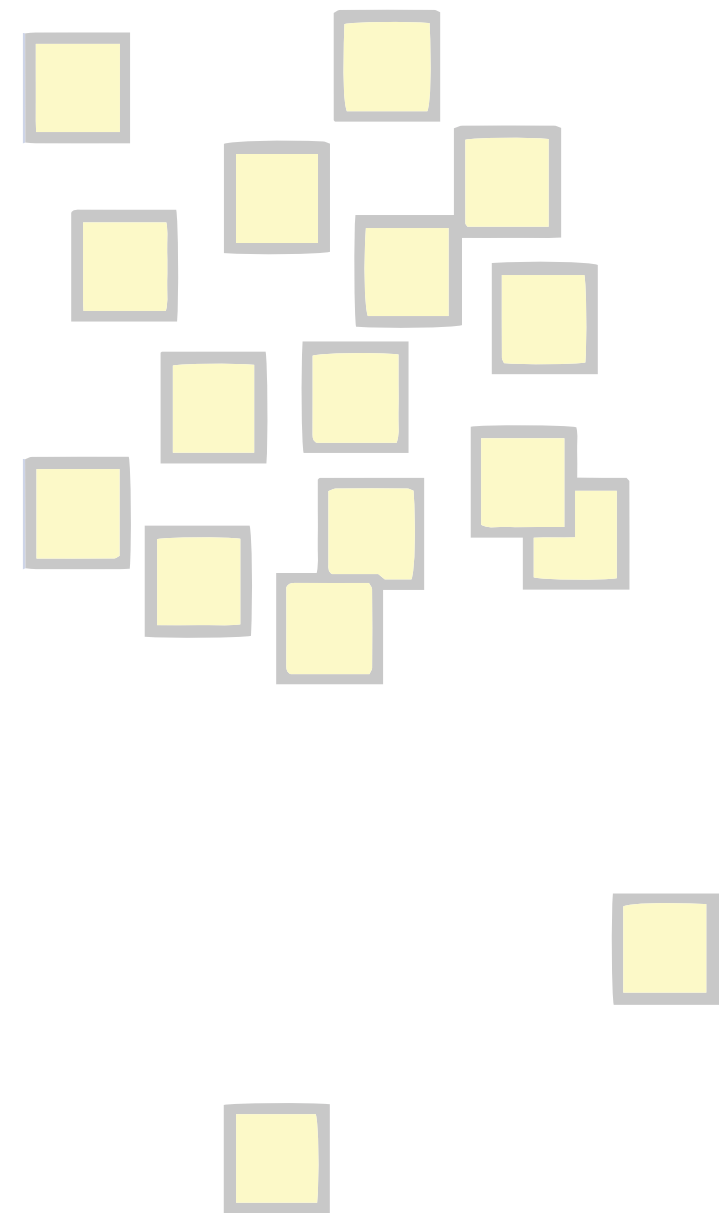
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# Computing Word Senses

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the lean flesh of a  
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family *Serranidae*



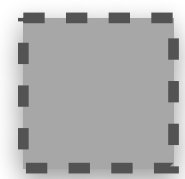
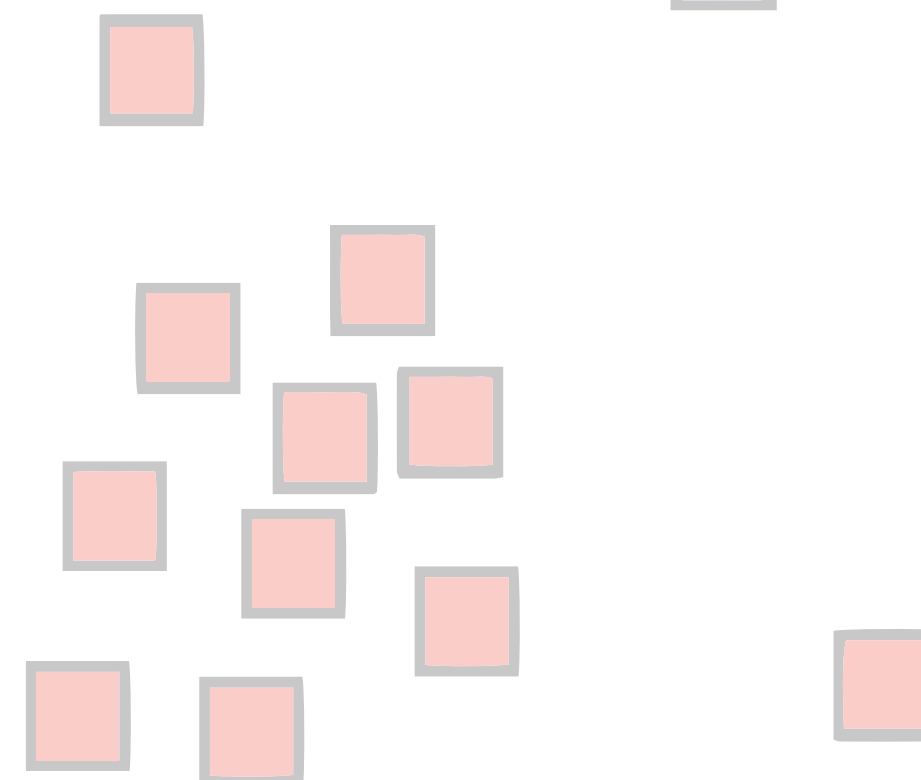
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the member with the  
lowest range of a family  
of musical instruments



**bass<sup>3</sup>**

an adult male singer  
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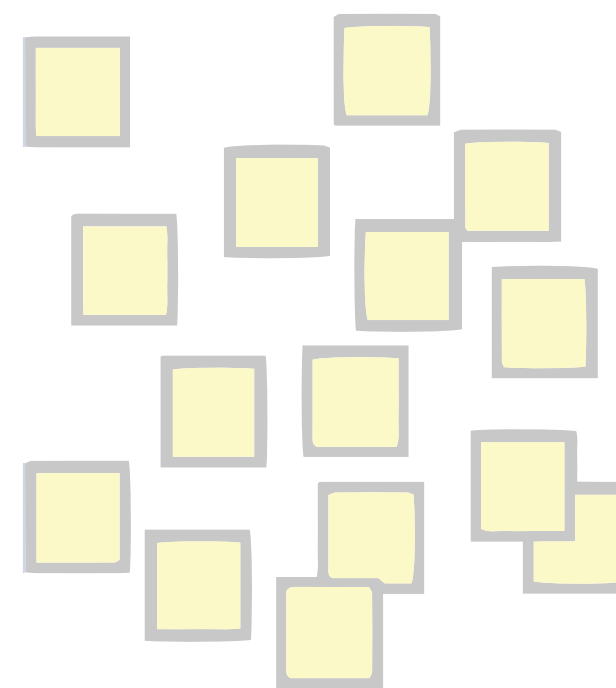


...and the **bass** covered the low notes

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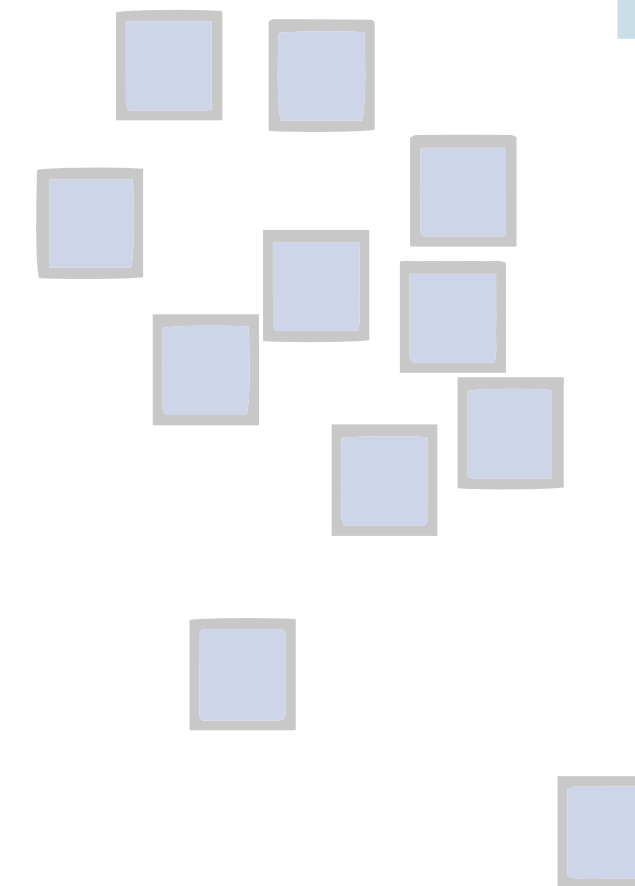
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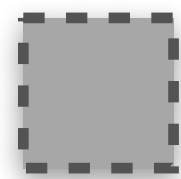
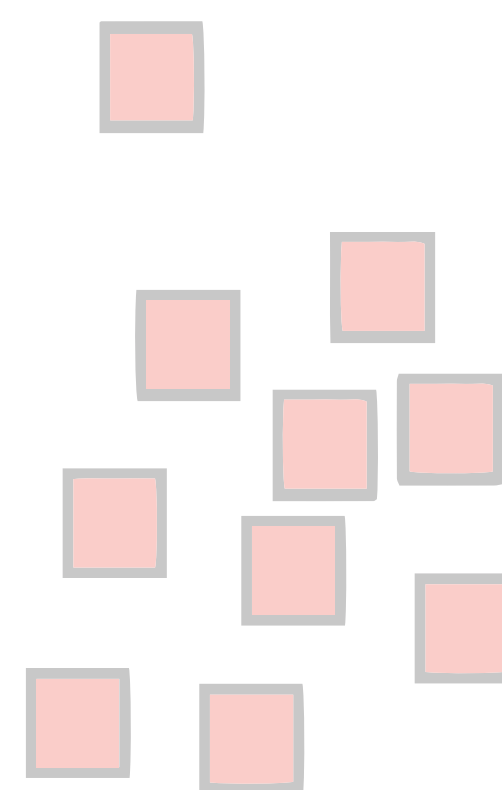
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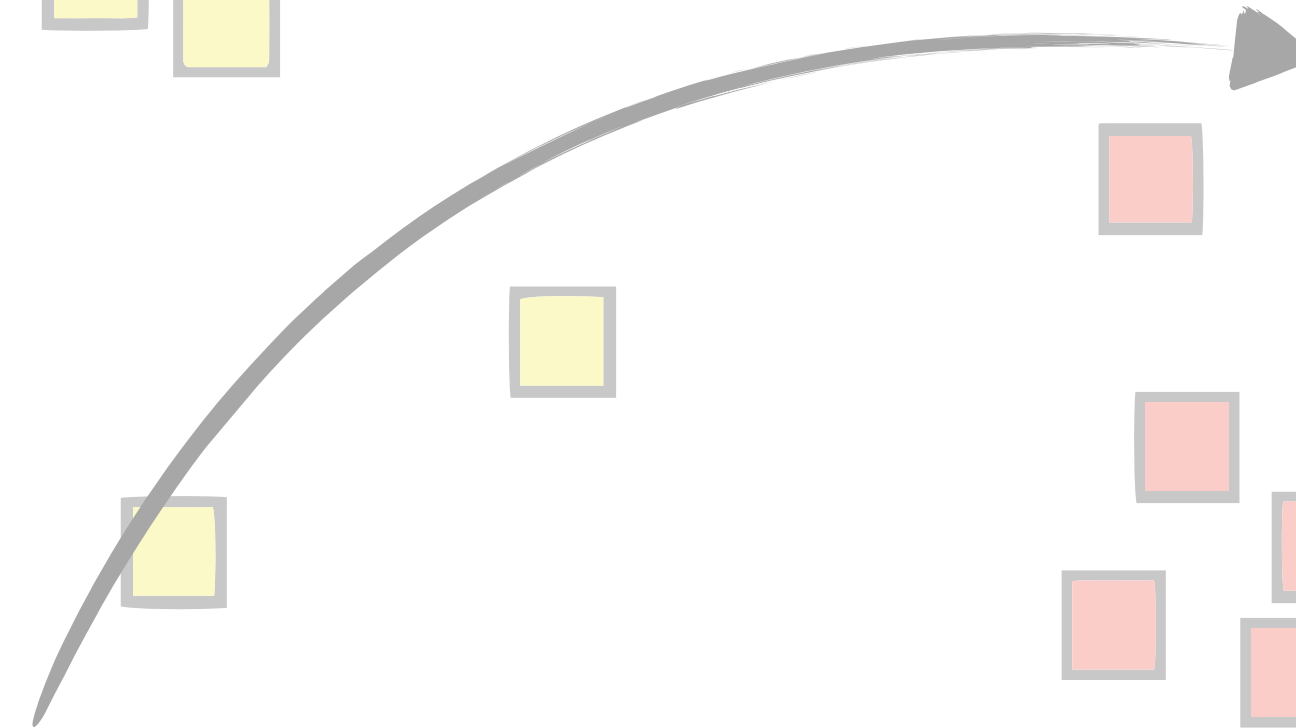


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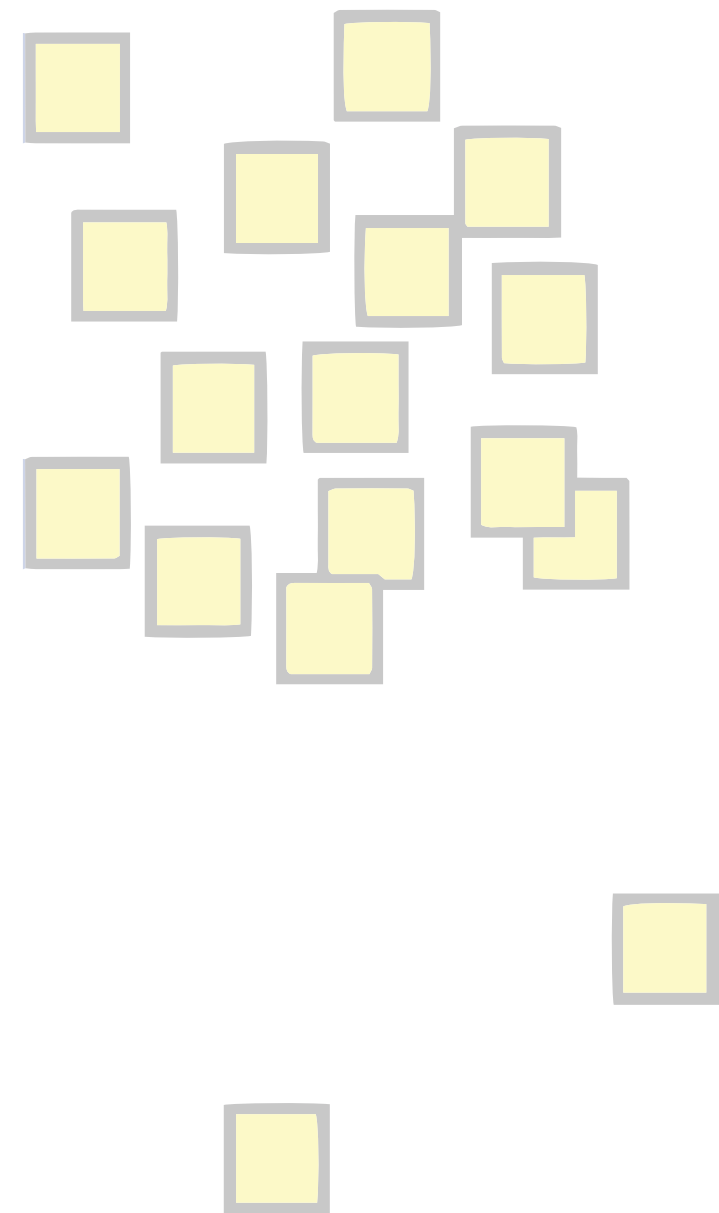
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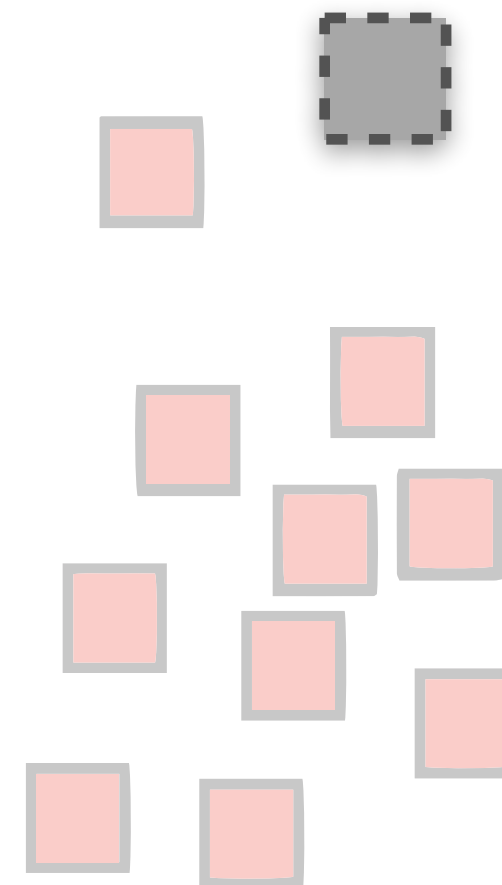
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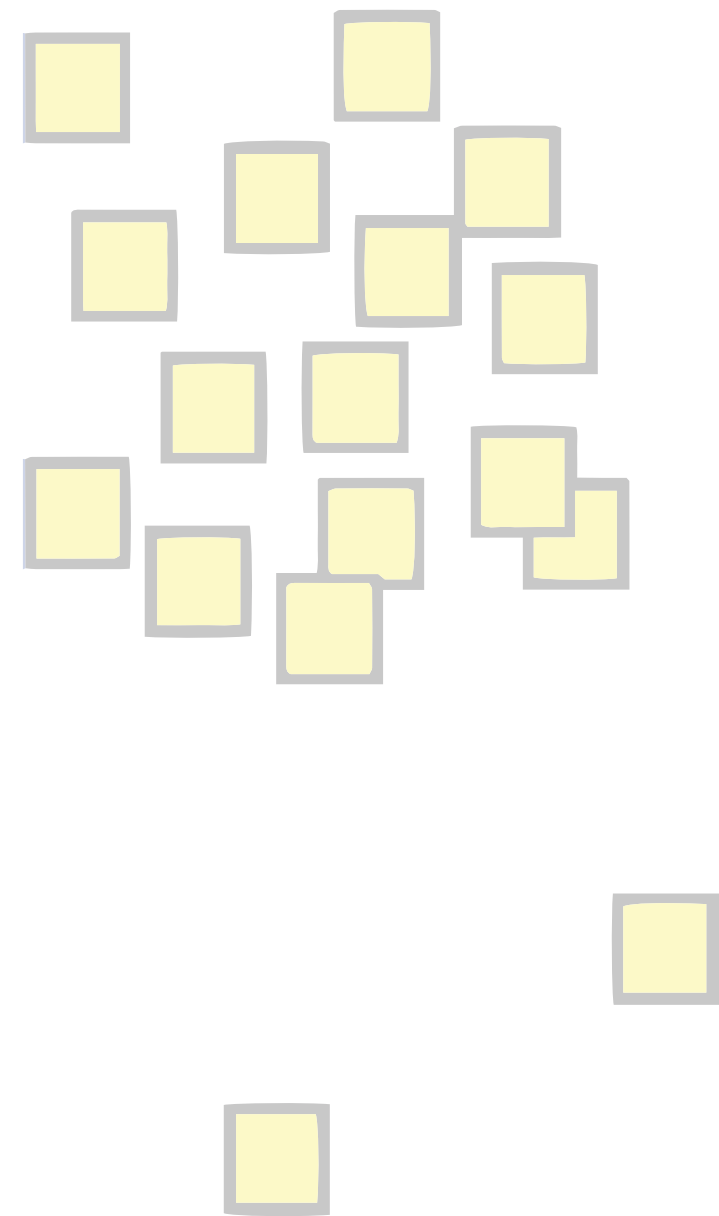


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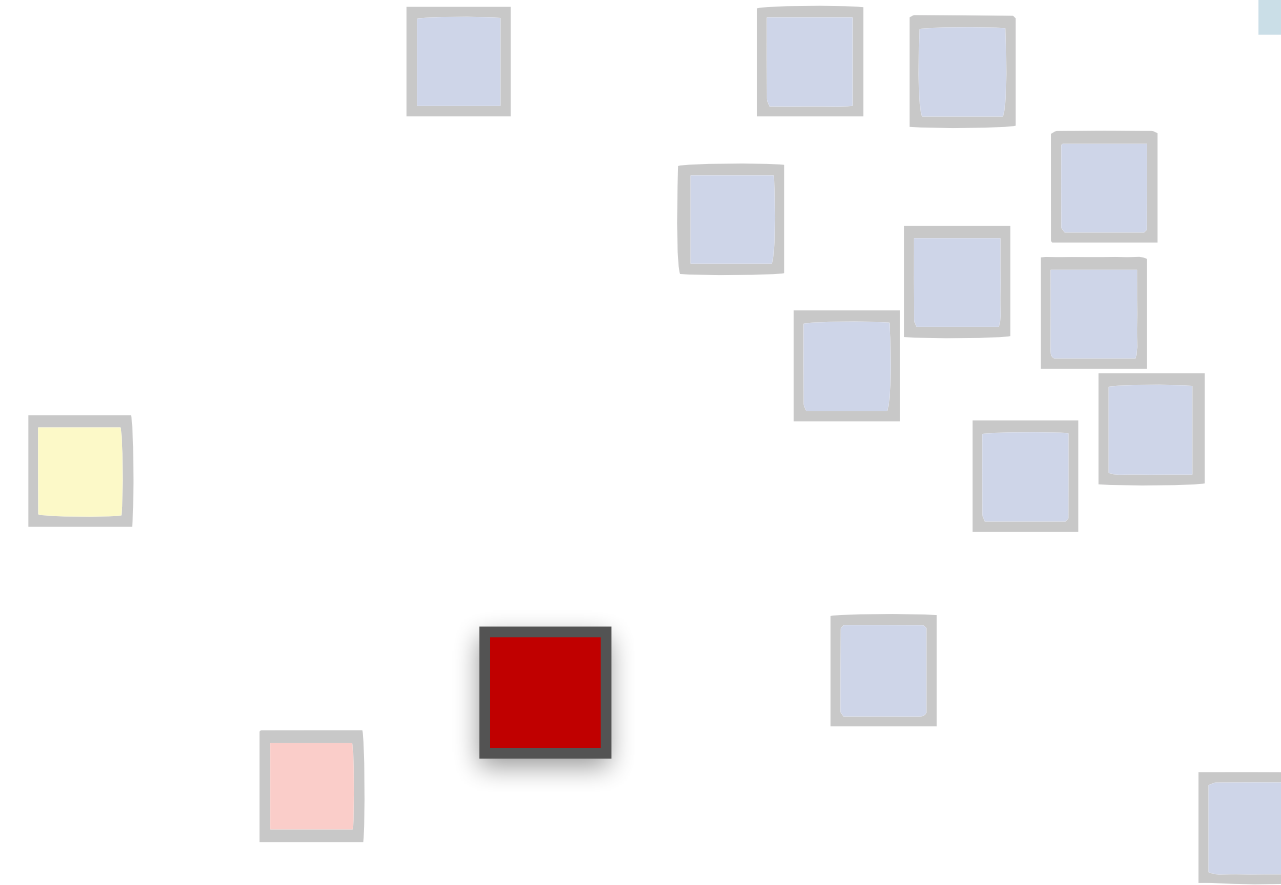
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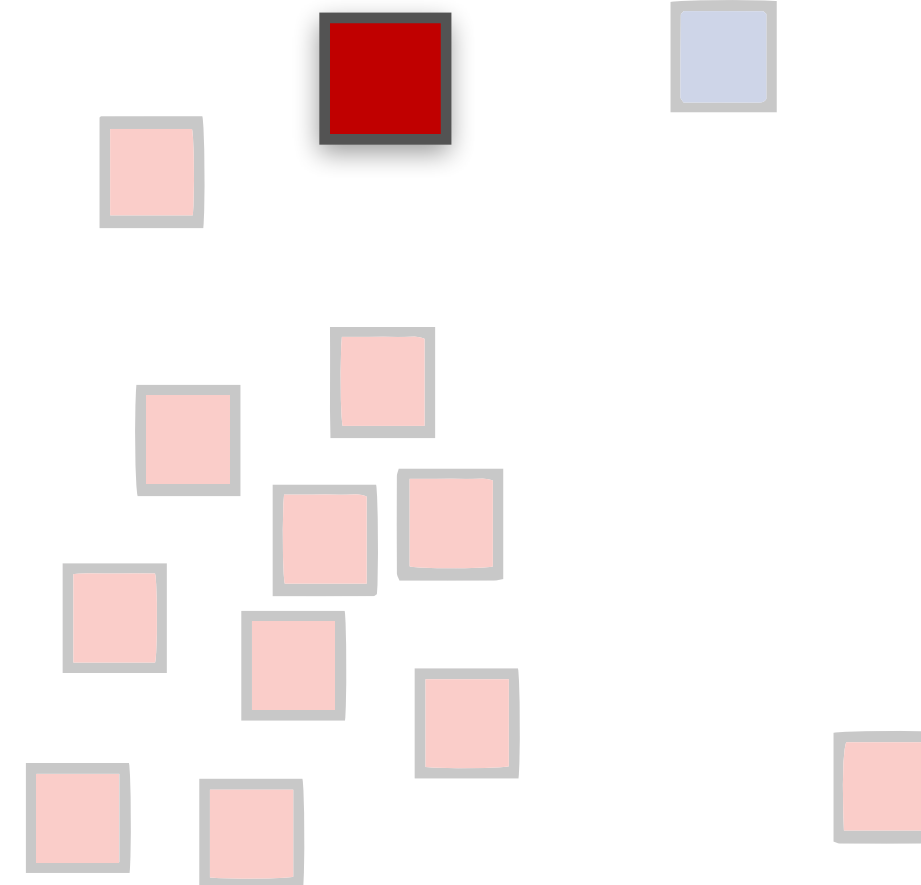
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# Resource-Based Models

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- Alternative to just clustering distributional representations
- What if we actually have some resources?
  - Dictionaries
  - Semantic sense taxonomy
  - Thesauri

# Dictionary-Based Approach

- (Simplified) Lesk algorithm
  - “How to tell a pine cone from an ice cream cone” ([Lesk, 1986](#))
- Compute “signature” of word senses:
  - Words in gloss and examples in dictionary

<b>bank (n.)</b>	1	a financial institution that accepts deposits and channels the money into lending activities. “he cashed a check at the bank,” “that bank holds the mortgage on my home.”
	2	sloping land (especially the slope beside a body of water). “they pulled the canoe up on the bank,” “he sat on the bank of the river and watched the currents.”

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- Compute context of word to disambiguate
- Compare overlap between signature and context
- Select sense with highest (non-stopword) overlap

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# Sense Taxonomy/Thesaurus Approaches

# WordNet Taxonomy

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    - Nouns (117K)
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  - 3 tree-structured hierarchies
    - Nouns (117K)
    - Verbs (11K)
    - Adjective+Adverb (27K)
  - Entries:
    - Synonym set (“*synset*”)
    - Gloss
    - Example usage

# WordNet Taxonomy

- Relations between entries:
  - Synonymy: in synset
  - Hyponym/Hypernym: *is-a* tree

# WordNet

The **noun** “bass” has 8 senses in WordNet. [[link](#)]

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

The **adjective** “bass” has 1 sense in WordNet.

1. **bass**<sup>1</sup> - deep<sup>6</sup> - (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	<i>breakfast</i> <sup>1</sup> → <i>meal</i> <sup>1</sup>
Hyponym	Subordinate	From concepts to subtypes	<i>meal</i> <sup>1</sup> → <i>lunch</i> <sup>1</sup>
Instance Hypernym	Instance	From instances to their concepts	<i>Austen</i> <sup>1</sup> → <i>author</i> <sup>1</sup>
Instance Hyponym	Has-Instance	From concepts to concept instances	<i>composer</i> <sup>1</sup> → <i>Bach</i> <sup>1</sup>
Member Meronym	Has-Member	From groups to their members	<i>faculty</i> <sup>2</sup> → <i>professor</i> <sup>1</sup>
Member Holonym	Has-Part	From members to their groups	<i>copilot</i> <sup>1</sup> → <i>crew</i> <sup>1</sup>
Part Meronym	Part-Of	From wholes to parts	<i>table</i> <sup>2</sup> → <i>leg</i> <sup>3</sup>
Part Holonym		From parts to wholes	<i>course</i> <sup>7</sup> → <i>meal</i> <sup>1</sup>
Substance Meronym		From substances to their subparts	<i>water</i> <sup>1</sup> → <i>oxygen</i> <sup>1</sup>
Substance Holonym		From parts of substances to wholes	<i>gin</i> <sup>1</sup> → <i>martini</i> <sup>1</sup>
Antonym		Semantic opposition between lemmas	<i>leader</i> <sup>1</sup> ⇔ <i>follower</i> <sup>1</sup>
Derivationally Related Form		Lemmas	<i>destruction</i> <sup>1</sup> ⇔ <i>destroy</i> <sup>1</sup>



# 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

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=> entity

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  - The shorter path length in thesaurus, smaller semantic distance
  - Words similar to parents, siblings in tree
- `pathlength` = #edges in shortest route through graph between nodes
  - $sim_{path} = -\log pathlen(c_1, c_2)$  [[Leacock & Chodorow, 1998](#)]

# Problem #1

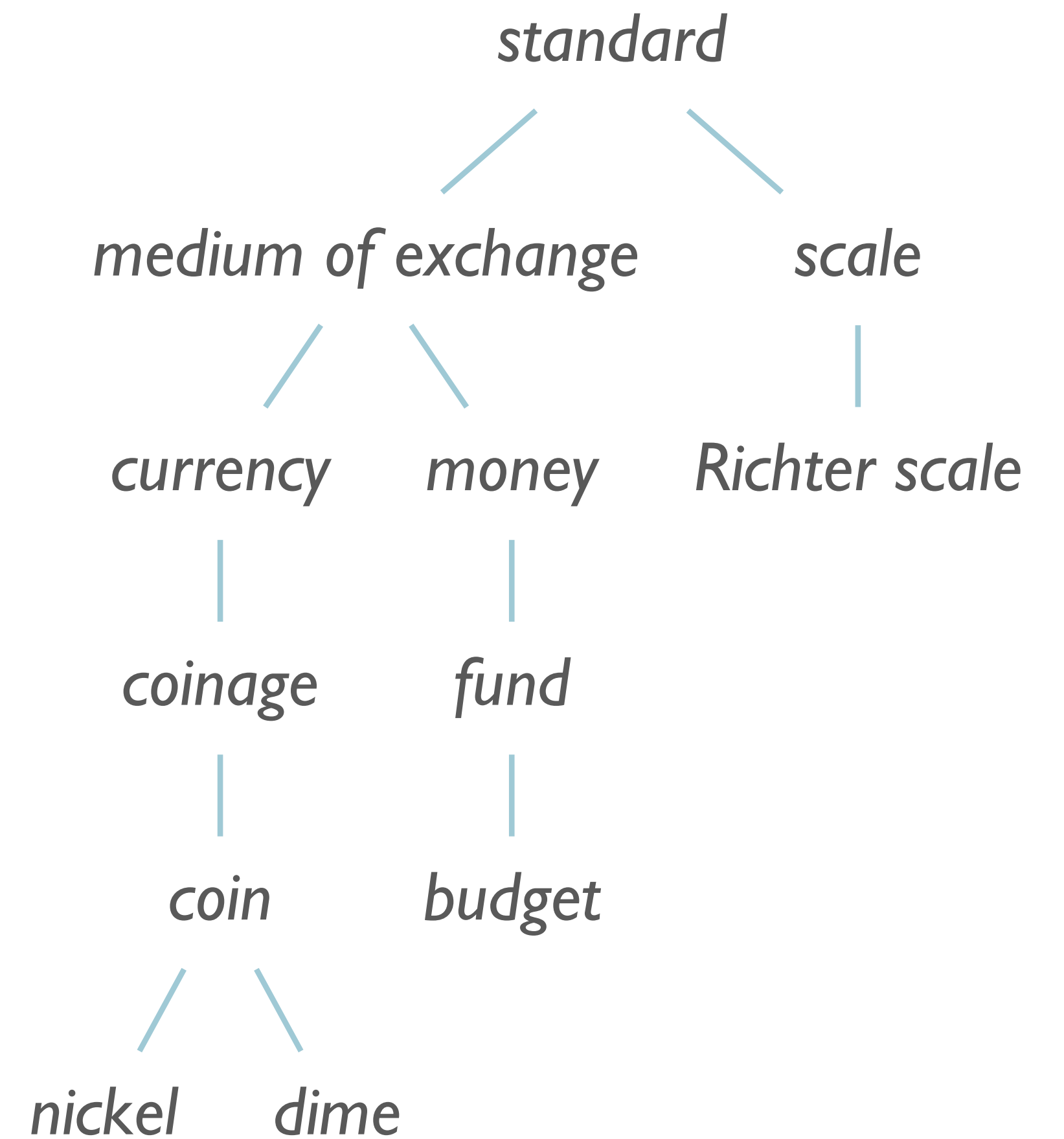
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# Problem #1

- Rarely know *which sense*, thus rarely know *which node*
- **Solution**
  - assume most similar senses as an estimate
  - $wordsim(w_1, w_2) = \max sim(c_1, c_2)$

# Problem #2

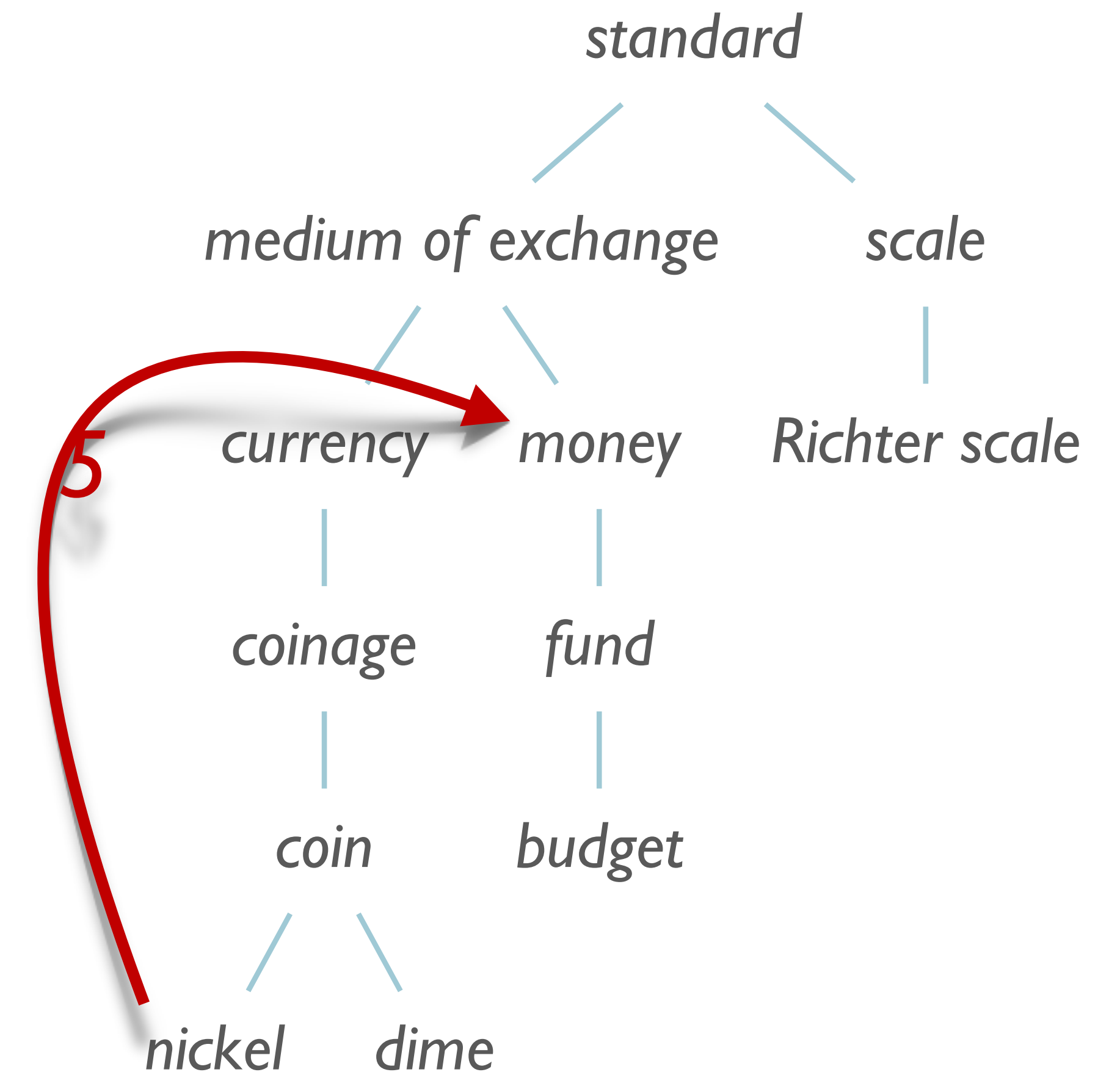
- Links in WordNet not uniformly different





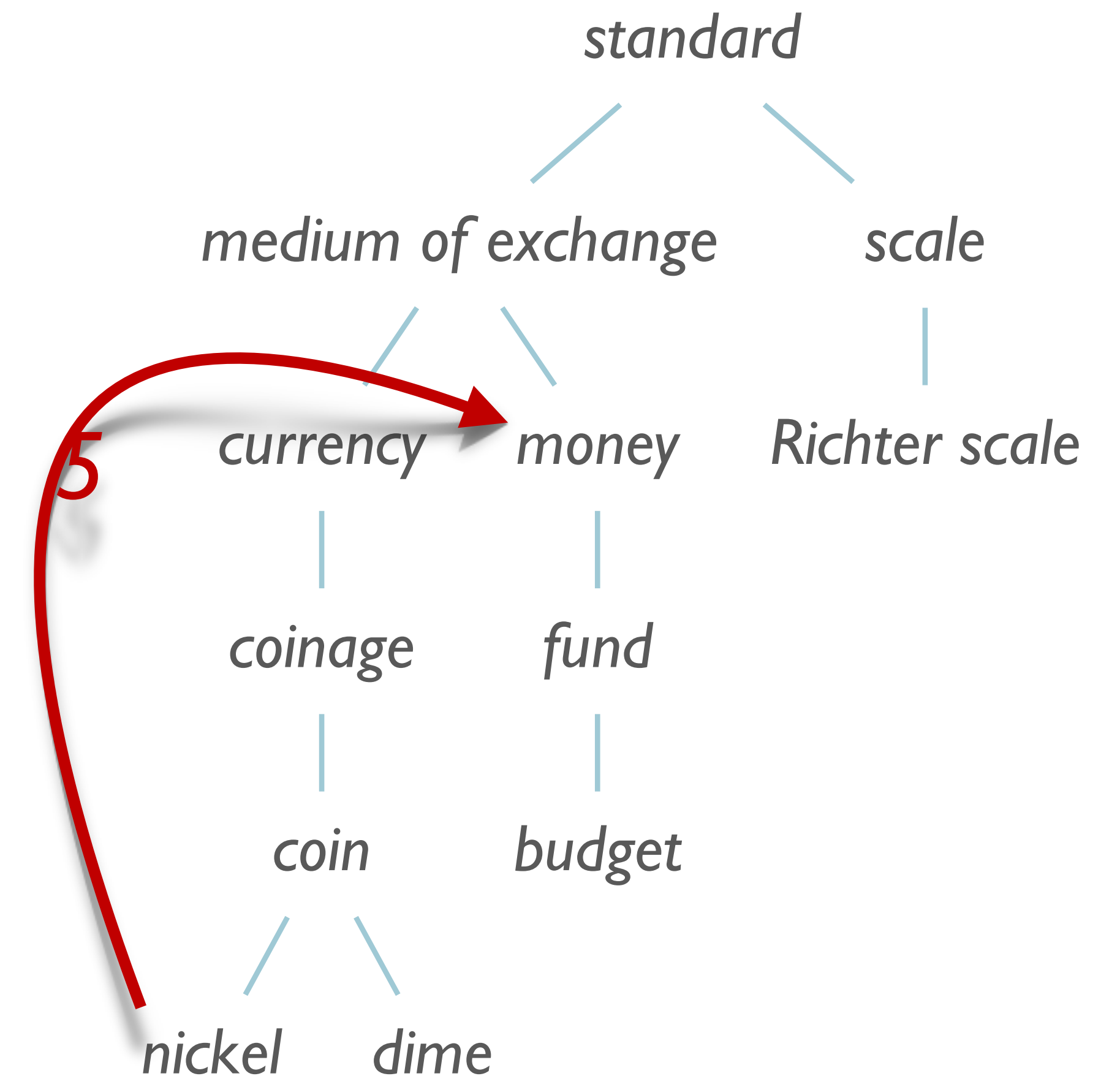
# Problem #2

- Links in WordNet not uniformly different
  - |Nickel → Money| = 5



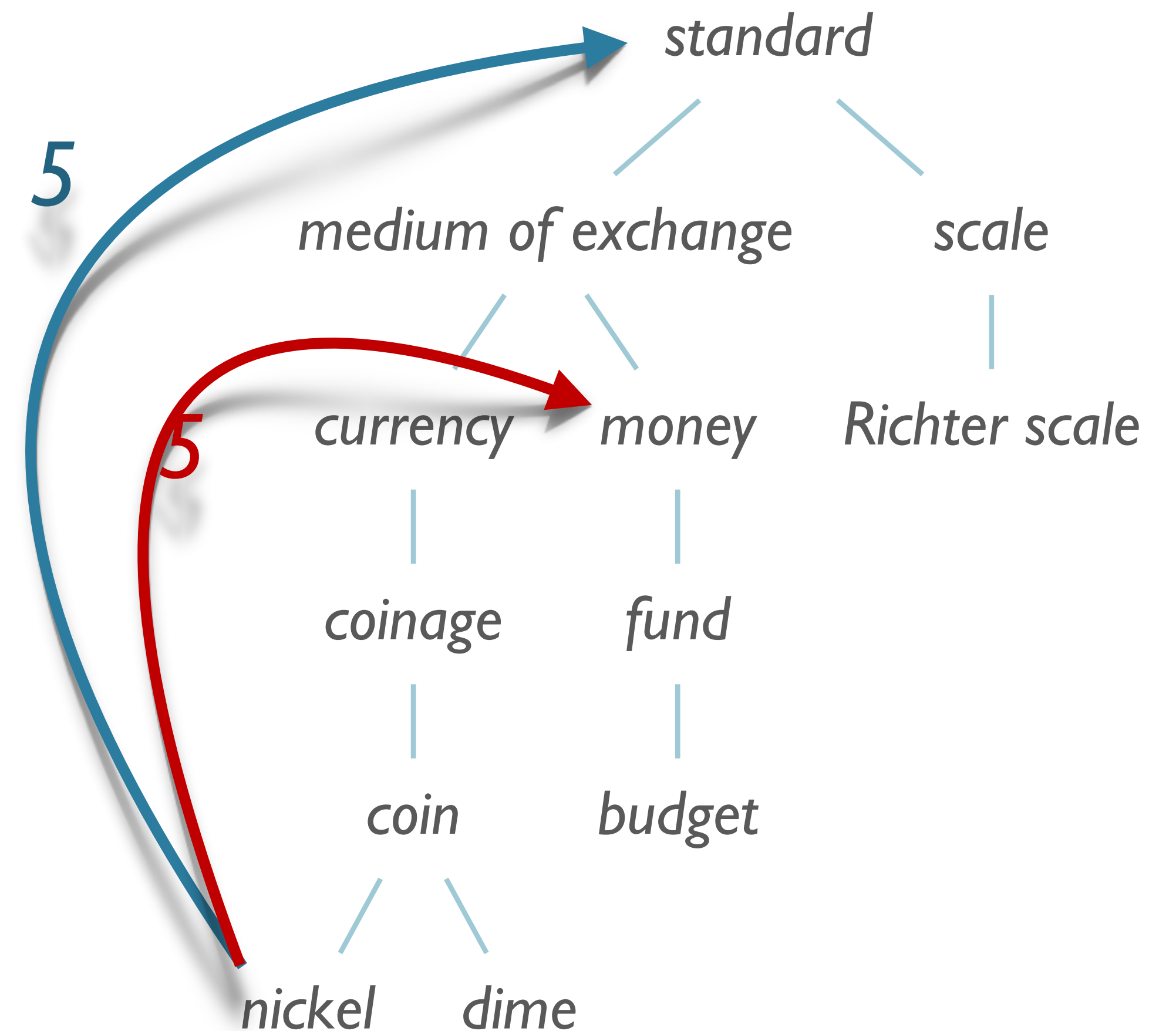
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# Problem #2

- Links in WordNet not uniformly different
  - |Nickel → Money| = 5
  - |Nickel → Standard| = 5
- How to capture?



# Thesaurus-based Techniques: A Solution

- Add *information content* from a corpus ([Resnik, 1995](#))
- $P(c)$ : probability that a word is instance of concept  $c$
- $words(c)$ : words subsumed by concept  $c$ ;
- $N$ : words in corpus

$$P(c) = \frac{\sum_{w \in words(c)} count(w)}{N}$$

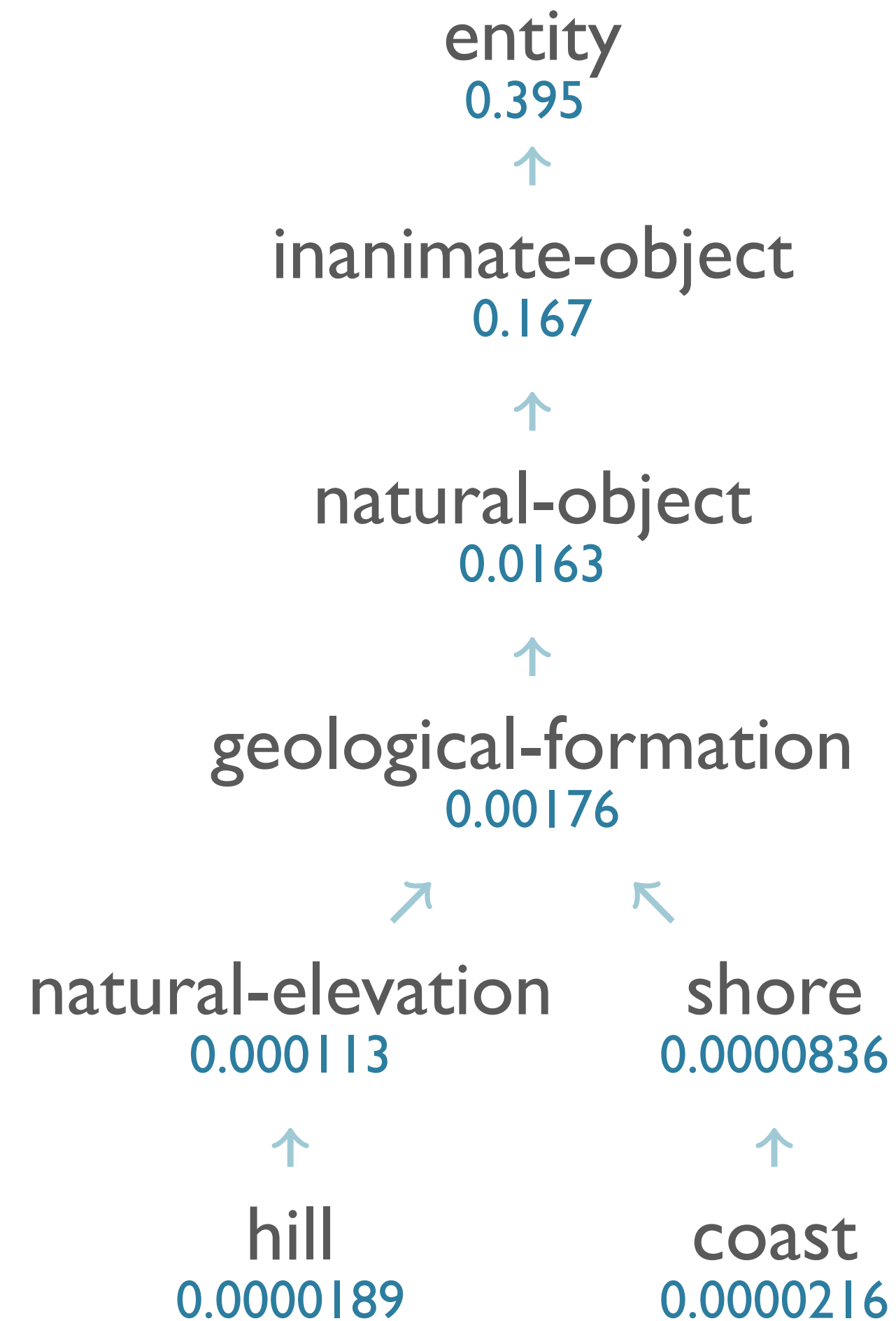
# Information Content

- Using a sense-tagged corpus (like SemCor)

```
...
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<wf cmd="done" pos="VB" lemma="be" wnsn="1" lexsns="2:42:03::">was</wf>
<wf cmd="done" pos="JJ" lemma="gay" wnsn="6" lexsns="5:00:00:homosexual:00">gay</wf>
<punc>,</punc>
<wf cmd="done" pos="JJ" lemma="witty" wnsn="1" lexsns="5:00:00:humorous:00">witty</wf>
<punc>,</punc>
<wf cmd="done" pos="JJ" lemma="mercurial" wnsn="1" lexsns="5:00:00:changeable:00">mercurial</wf>
<punc>,</punc>
<wf cmd="done" pos="JJ" lemma="full" wnsn="1" lexsns="3:00:00::">full</wf>
<wf cmd="done" pos="JJ" ot="notag">of</wf>
<wf cmd="done" pos="NN" lemma="prank" wnsn="1" lexsns="1:04:01::">pranks</wf>
<wf cmd="ignore" pos="CC">and</wf>
<wf cmd="done" pos="NN" ot="foreignword">bonheur</wf>
...
```

*“The Serge Prokofieff whom we knew in the United States of America was gay, witty, mercurial, full of pranks and bonheur—*

# Concept Probability Example



# Information Content-Based Similarity Measures

- Information content of node (concept  $c$ )
  - $IC(c) = -\log P(c)$
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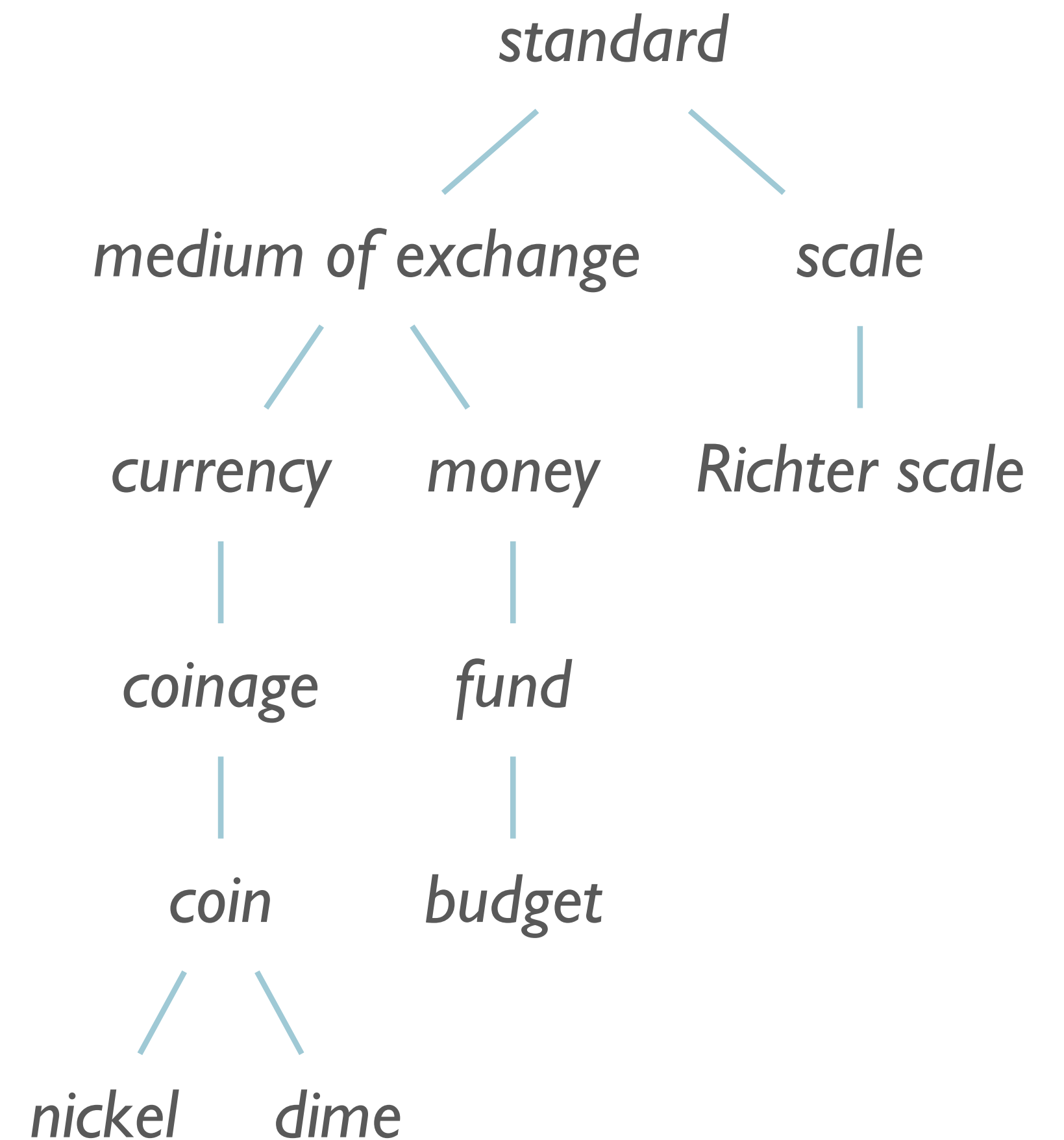


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- Least common subsumer (LCS):
  - Lowest node in hierarchy subsuming 2 nodes
- Similarity measure
  - $sim_{resnik}(c_1, c_2) = -\log P(LCS(c_1, c_2))$
  - The more specific the LCS concept, the more similar  $c_1, c_2$ .

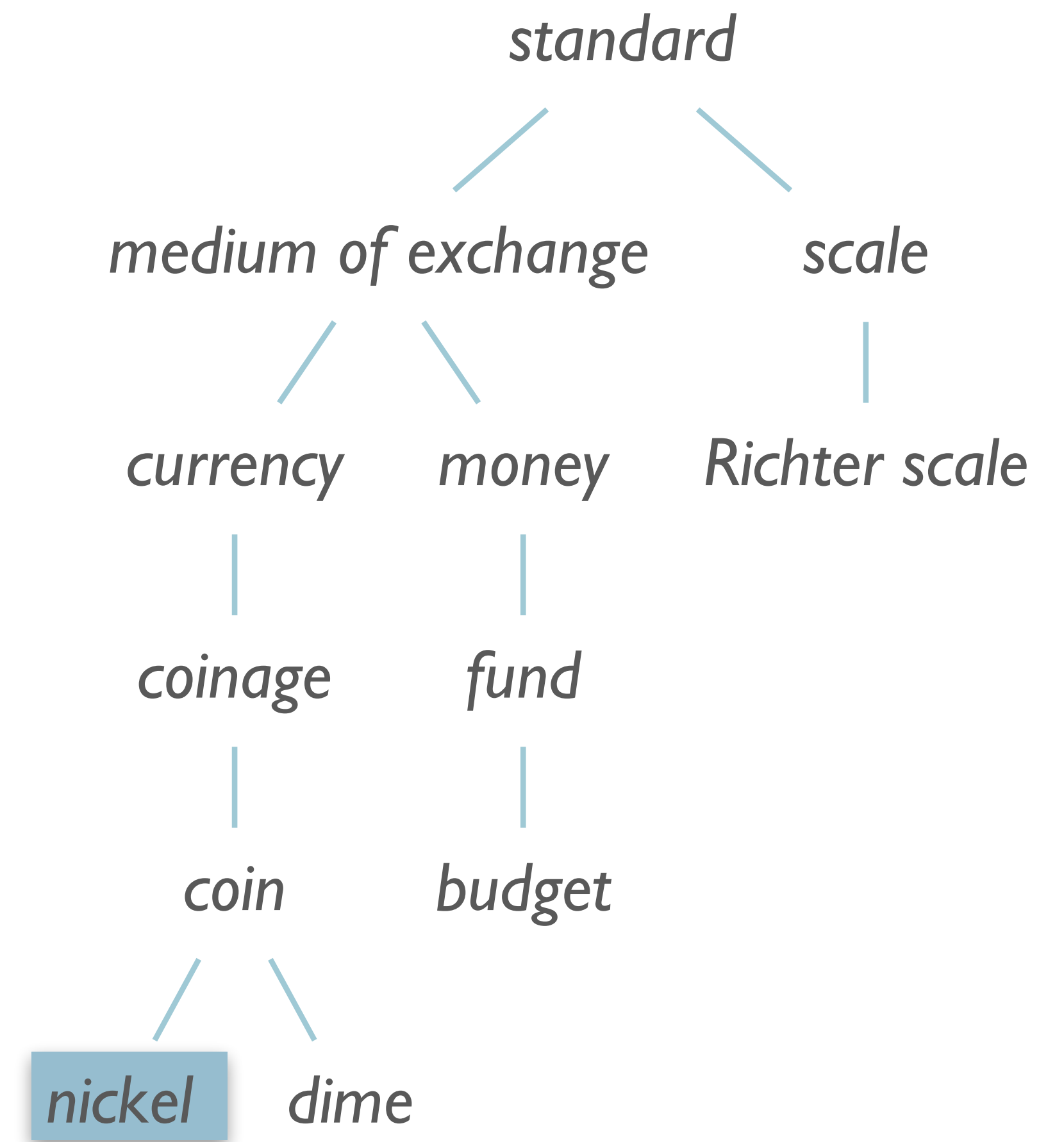
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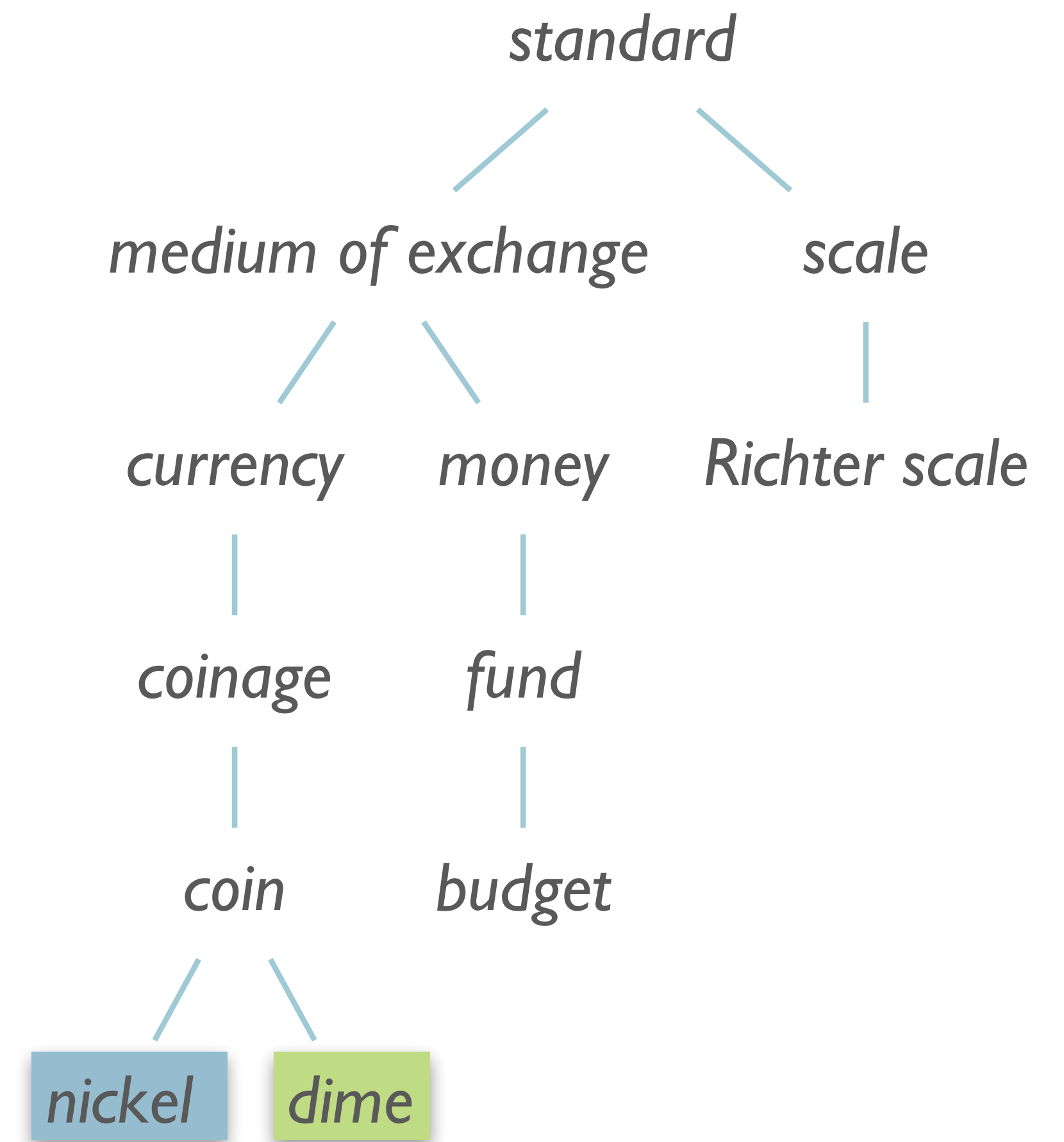
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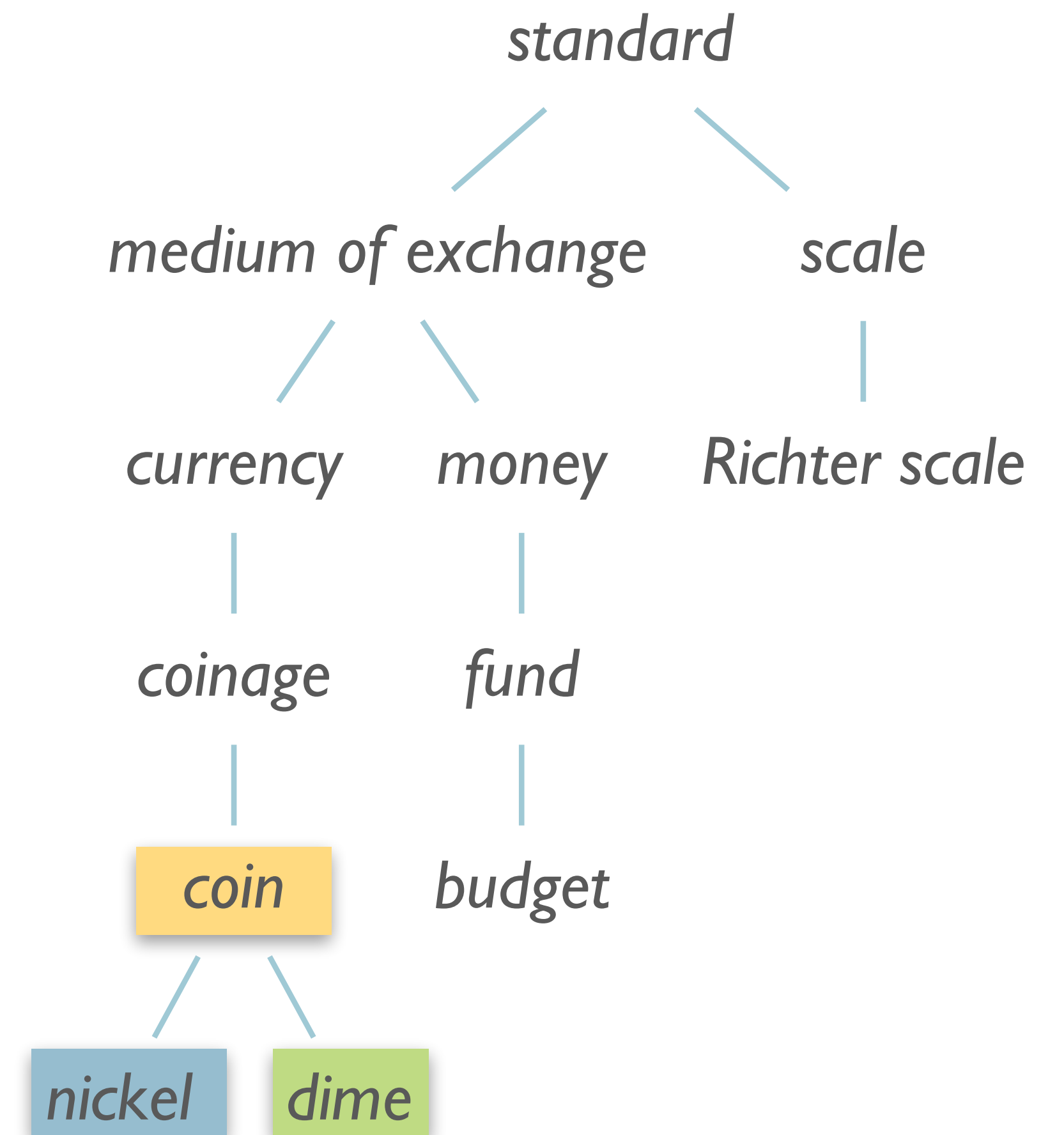
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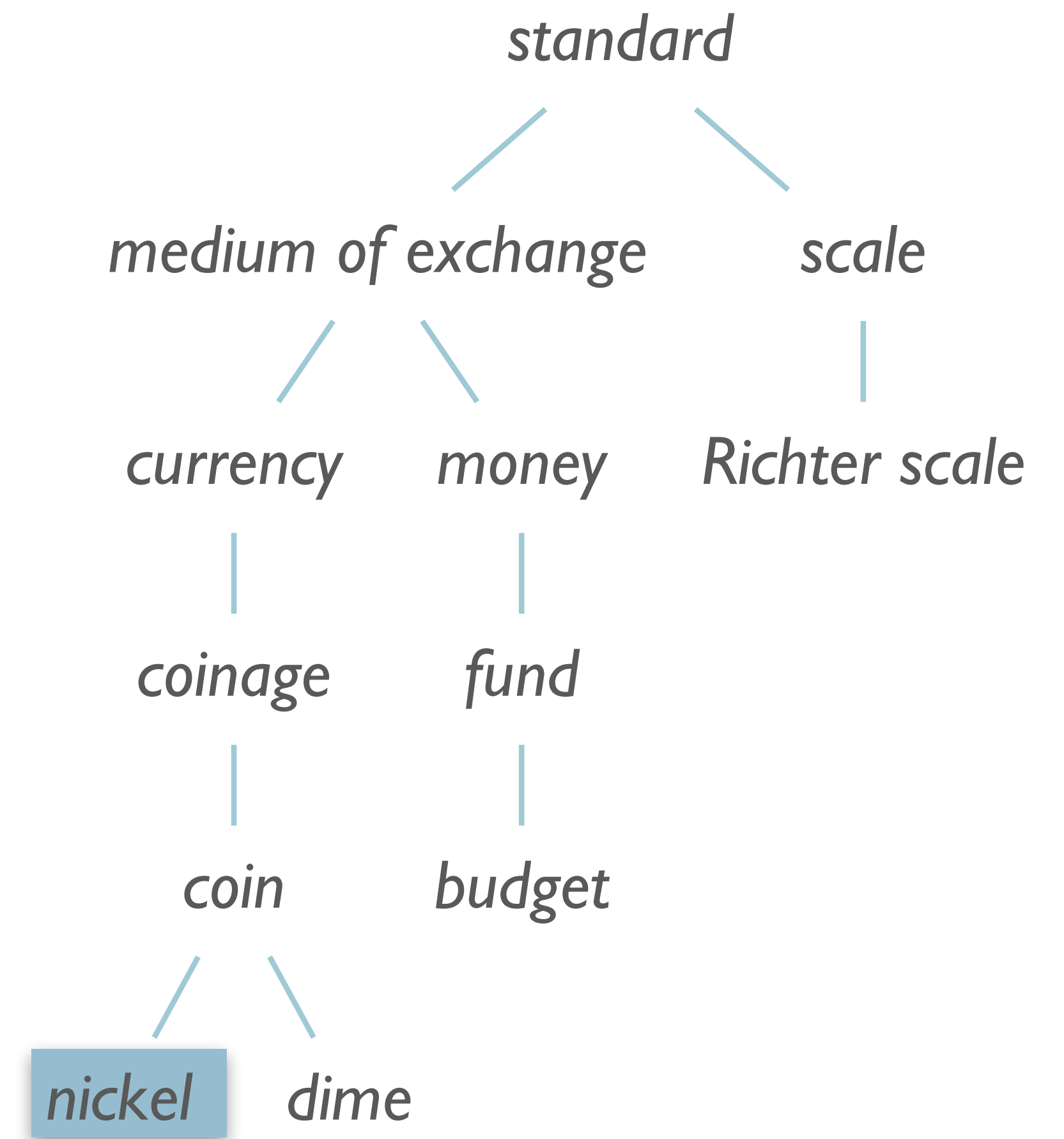
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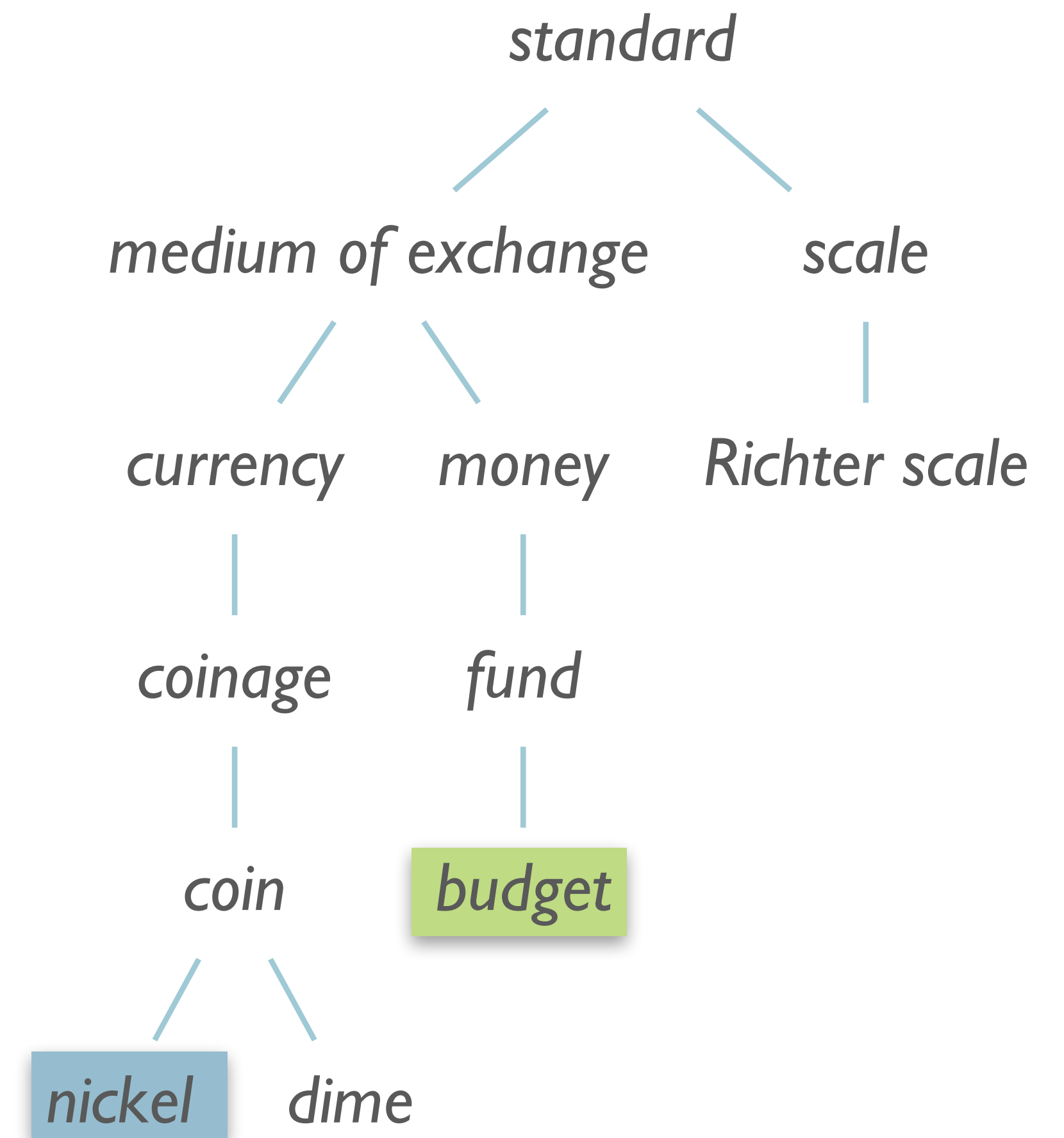
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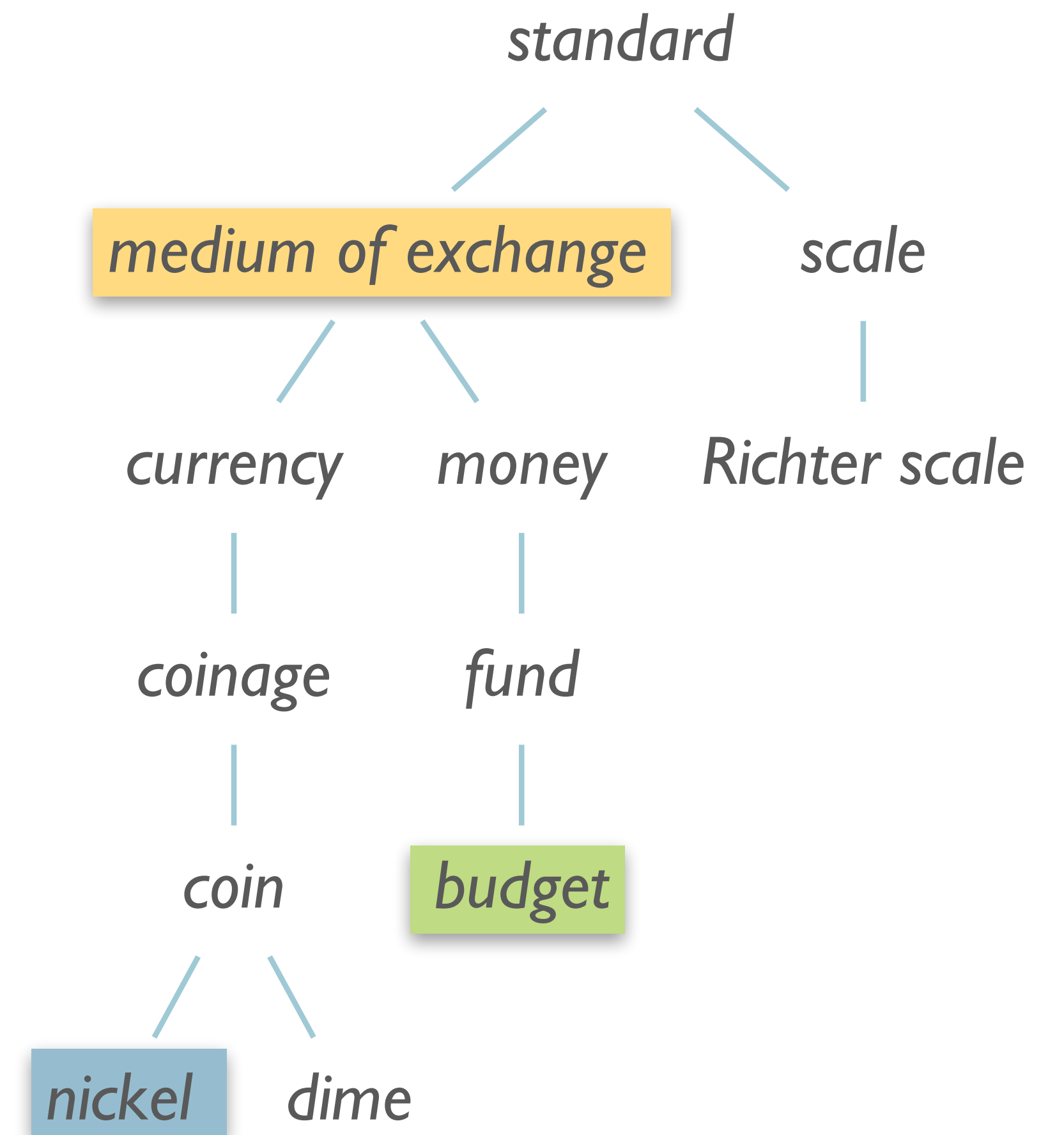
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# The Plant Example Again

- 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.

# Application to WSD

- **Calculate Informativeness**
  - For each node in WordNet:
    - Sum occurrences of concept and all children
    - Compute *Information Content* for each node of WordNet

# Application to WSD

- **Disambiguate with WordNet**
  - Assume set of words in context: {*animals*, *rainforest*, *species*}
  - Find **Most Informative** Least Common Subsumer
    - for **target word**, **context word**
  - Increment count for sense subsumed by this concept
  - Select sense with highest vote

# Thesaurus Similarity Issues

- Coverage:
  - Few languages have large thesauri
  - Few languages have large sense-tagged corpora
- Thesaurus design:
  - Works well for noun */S-A* hierarchy
  - Verb hierarchy shallow, bushy, less informative

# Resnik Similarity

# Algorithm

Given  $W=\{w_i, \dots, w_n\}$ , a set of nouns

for  $i$  and  $j=1$  to  $n$ , with  $i < j$

$v_{i,j} = \text{wsim}(w_i, w_j)$

$c_{i,j}$  = the most informative subsumer for  $w_i$  and  $w_j$

for  $k=1$  to  $\text{num\_senses}(w_i)$

if  $c_{i,j}$  is an ancestor of  $\text{sense}_{i,k}$

increment  $\text{support}[i,k]$  by  $v_{i,j}$

for  $k'=1$  to  $\text{num\_senses}(w_j)$

if  $c_{i,j}$  is an ancestor of  $\text{sense}_{j,k'}$

increment  $\text{support}[j,k']$  by  $v_{i,j}$

increment  $\text{normalization}[i]$  by  $v_{i,j}$

increment  $\text{normalization}[j]$  by  $v_{i,j}$

for  $i=1$  to  $n$

for  $k=1$  to  $\text{num\_senses}(w_i)$

if ( $\text{normalization}[i] > 0.0$ )

$\gamma_{i,k} = \text{support}[i,k] / \text{normalization}[i]$

else

$\gamma_{i,k} = 1 / \text{num\_senses}[w_i]$

Resnik 1999, sec 5.1  
[also on website]

# Algorithm

Given  $W=\{w_i, \dots, w_n\}$ , a set of nouns

for  $i=1$  to  $n$ , **and input word**  $w_0$

$v_{0,i}$  =  $\text{wsim}(w_0, w_i)$

$c_{0,i}$  = the most informative subsumer for  $w_0$  and  $w_i$

for  $k=1$  to  $\text{num\_senses}(w_i)$

if  $c_{0,i}$  is an ancestor of  $\text{sense}_{i,k}$

increment  $\text{support}[i,k]$  by  $v_{0,i}$

for  $k'=1$  to  $\text{num\_senses}(w_0)$

if  $c_{0,i}$  is an ancestor of  $\text{sense}_{k'}$

increment  $\text{support}[0,k']$  by  $v_{0,i}$

increment  $\text{normalization}[i]$  by  $v_{0,i}$

for  $i=1$  to  $n$

for  $k=1$  to  $\text{num\_senses}(w_i)$

if ( $\text{normalization}[i] > 0.0$ )

$\gamma_{i,k} = \text{support}[i,k] / \text{normalization}[i]$

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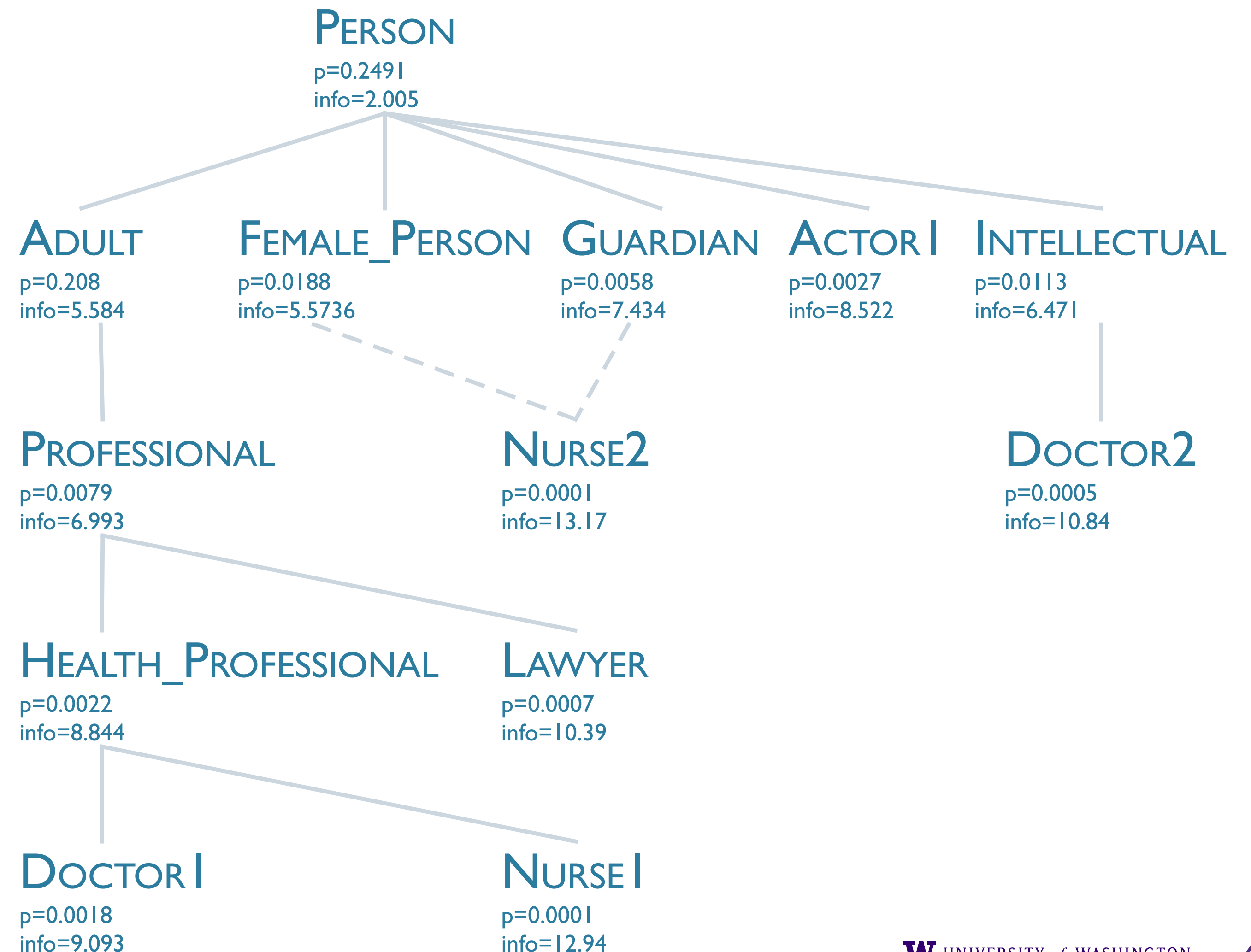
# Resnik Similarity

- Calculate:

$$sim_{word}(w_1, w_2) = \max_{c_1, c_2} (sim_{concept}(c_1, c_2))$$

- Let's try

- $sim_{word}(doctor, nurse)$





# Resnik Similarity

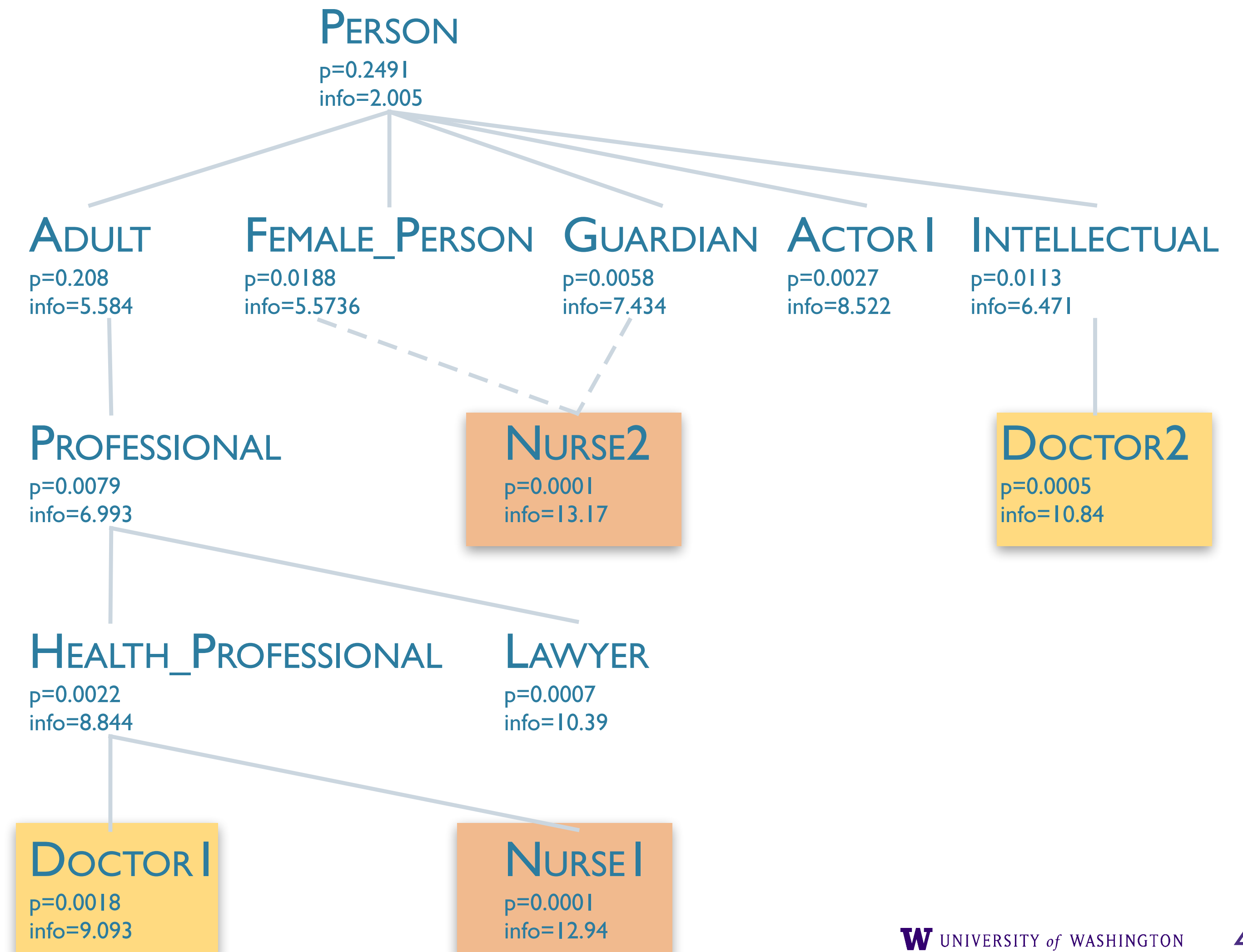
- Calculate:

$$sim_{word}(w_1, w_2) = \max_{c_1, c_2} (sim_{concept}(c_1, c_2))$$

- Let's try

- $sim_{word}(\text{doctor}, \text{nurse})$
- $sim_{concept}(c_1, c_2)$
- Get IC of LCS

$c_1$	$c_2$	LCS	$sim(c_1, c_2)$



# Resnik Similarity

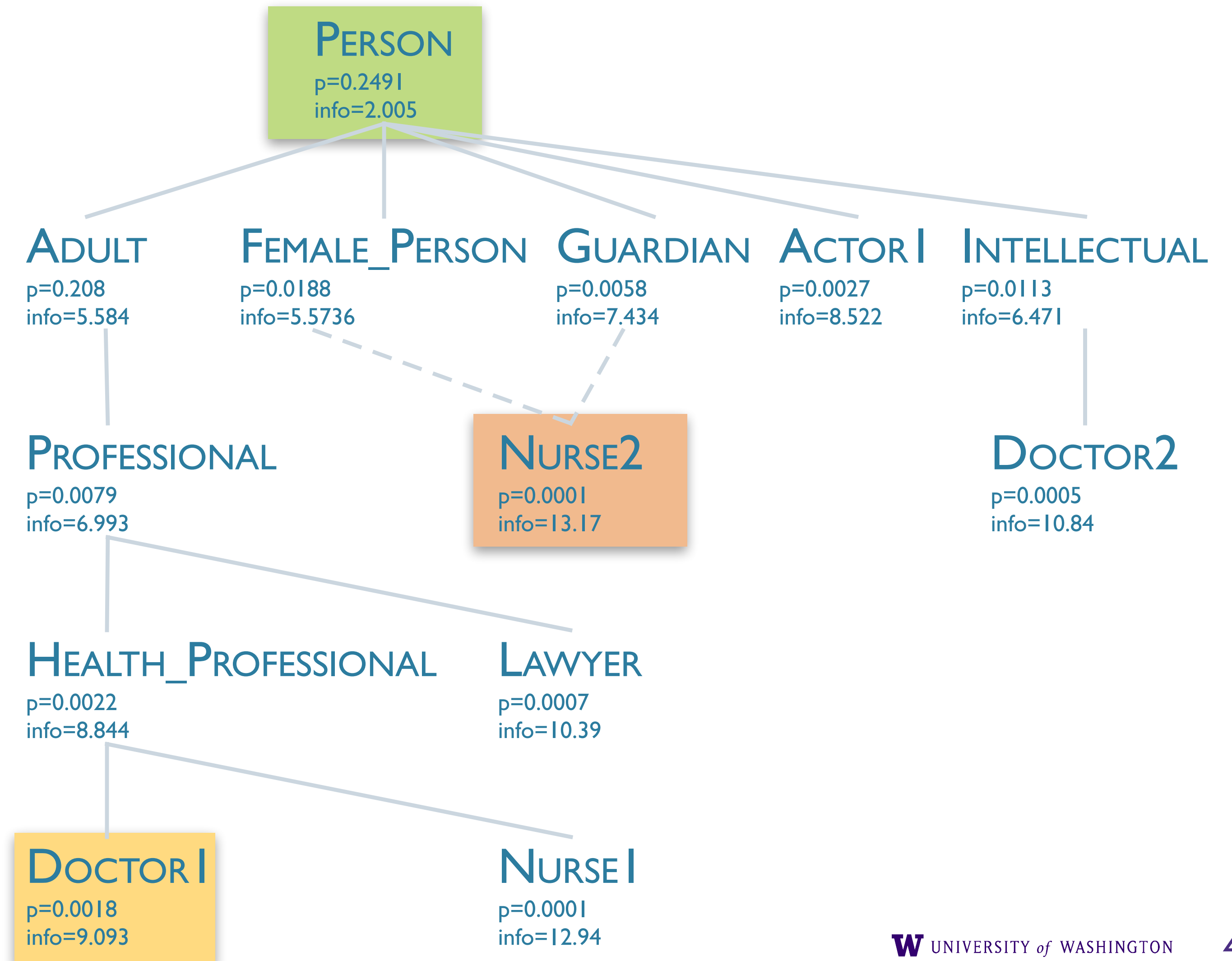
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- $sim_{concept}(c_1, c_2)$
- Get IC of LCS

$c_1$	$c_2$	LCS	$sim(c_1, c_2)$
DOCTOR <sub>1</sub>	NURSE <sub>2</sub>	PERSON	2.005



# Resnik Similarity

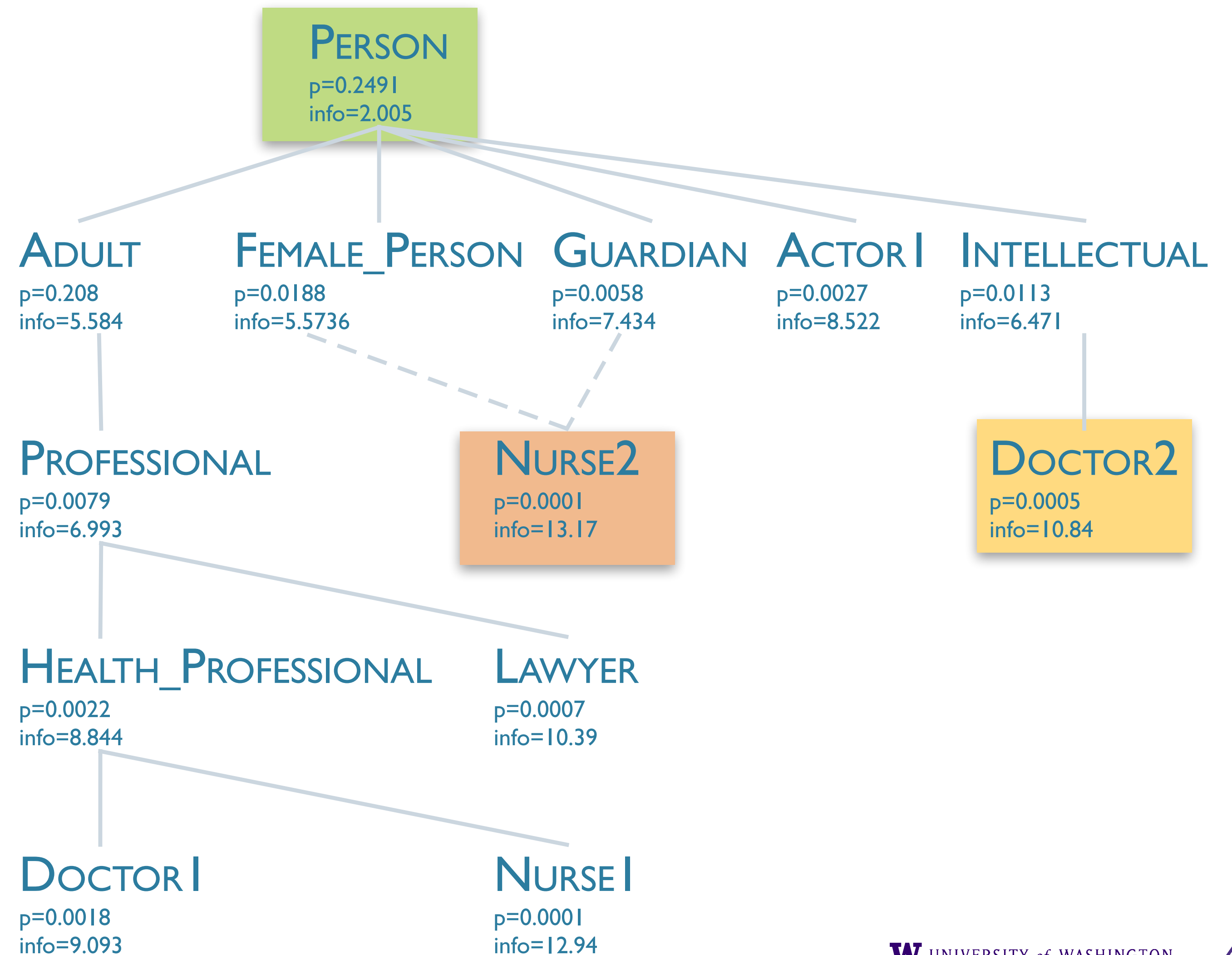
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- Let's try

- $sim_{word}(\text{doctor}, \text{nurse})$
- $sim_{concept}(c_1, c_2)$
- Get IC of LCS

$c_1$	$c_2$	LCS	$sim(c_1, c_2)$
DOCTOR <sub>1</sub>	NURSE <sub>2</sub>	PERSON	2.005
DOCTOR <sub>2</sub>	NURSE <sub>2</sub>	PERSON	2.005



# Resnik Similarity

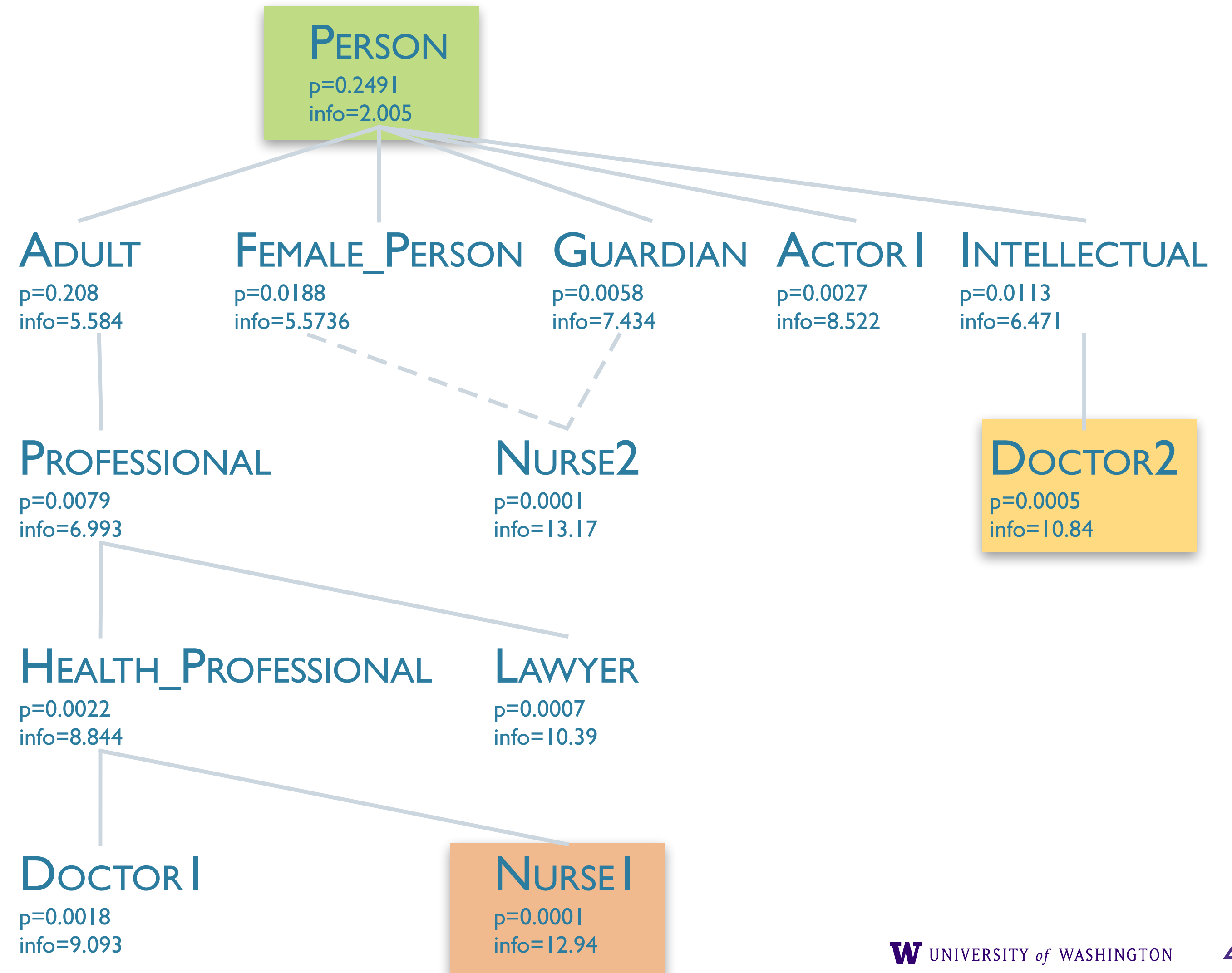
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- Let's try

- $sim_{word}(\text{doctor}, \text{nurse})$
- $sim_{concept}(c_1, c_2)$
- Get IC of LCS

$c_1$	$c_2$	LCS	$sim(c_1, c_2)$
DOCTOR <sub>1</sub>	NURSE <sub>2</sub>	PERSON	2.005
DOCTOR <sub>2</sub>	NURSE <sub>2</sub>	PERSON	2.005
DOCTOR <sub>2</sub>	NURSE <sub>1</sub>	PERSON	2.005



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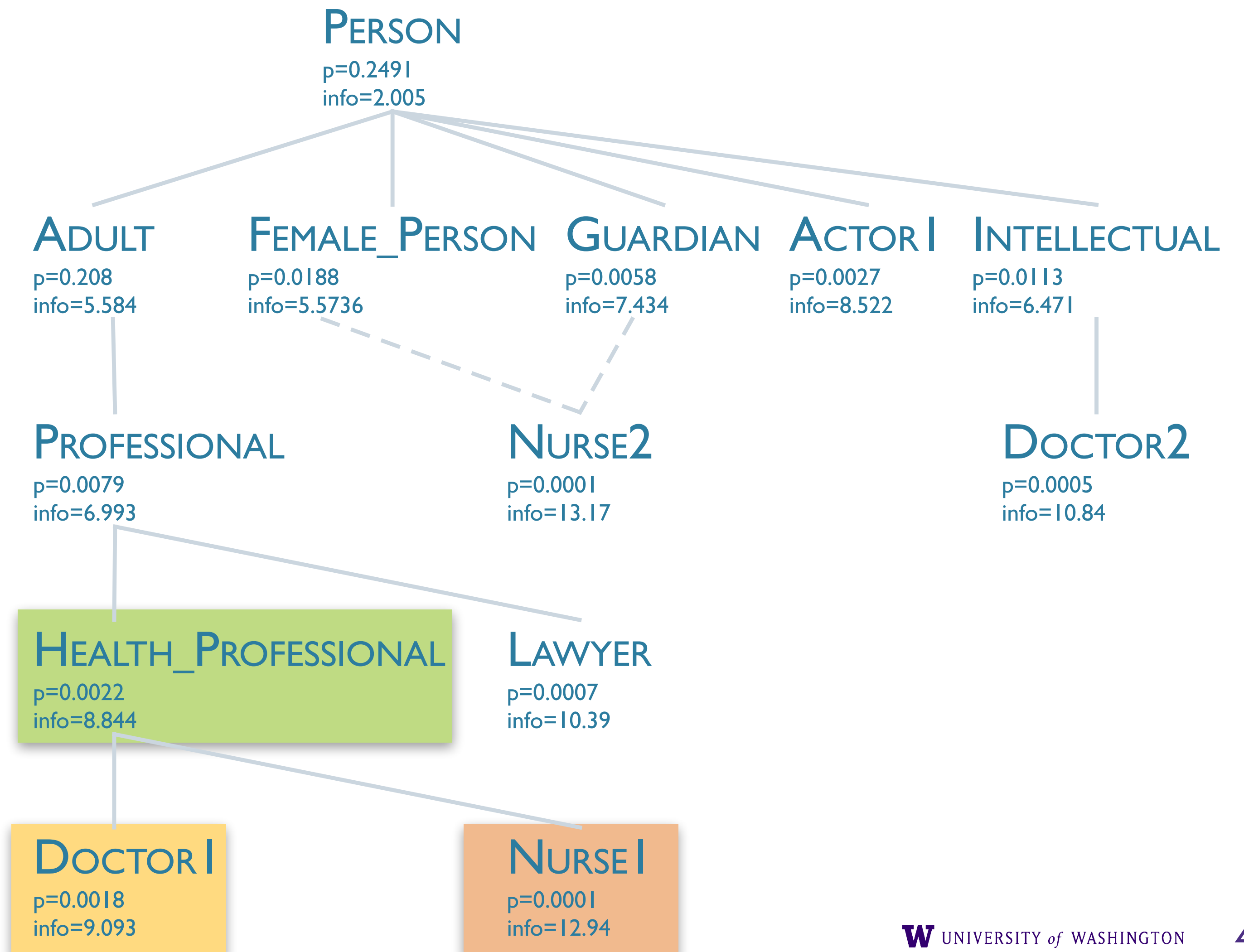
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$$sim_{word}(w_1, w_2) = \max_{c_1, c_2} (sim_{concept}(c_1, c_2))$$

- Let's try

- $sim_{word}(\text{doctor}, \text{nurse})$
- $sim_{concept}(c_1, c_2)$
- Get IC of LCS

$c_1$	$c_2$	LCS	$sim(c_1, c_2)$
DOCTOR <sub>1</sub>	NURSE <sub>2</sub>	PERSON	2.005
DOCTOR <sub>2</sub>	NURSE <sub>2</sub>	PERSON	2.005
DOCTOR <sub>2</sub>	NURSE <sub>1</sub>	PERSON	2.005
DOCTOR <sub>1</sub>	NURSE <sub>1</sub>	HEALTH_PROFESSIONAL	8.844



# Resnik WSD: Choosing a Sense

- doctor — nurse, lawyer, accountant, scholar, minister
- We'll get:
  - {**DOCTOR**<sub>1</sub>, NURSE<sub>1</sub>}  $\subset$  HEALTH\_PROFESSIONAL = 8.844
  - {**DOCTOR**<sub>1</sub>, LAWYER<sub>1</sub>}  $\subset$  PROFESSIONAL + 6.993 = 15.837
  - {**DOCTOR**<sub>1</sub>, ACCOUNTANT<sub>1</sub>}  $\subset$  PROFESSIONAL + 6.993 = **22.83**
  - {**DOCTOR**<sub>2</sub>, SCHOLAR<sub>1</sub>}  $\subset$  INTELLECTUAL = 6.471
  - {**DOCTOR**<sub>2</sub>, MINISTER<sub>1</sub>}  $\subset$  INTELLECTUAL + 6.471 = **12.942**
- **DOCTOR**<sub>1</sub> with **22.83** of “support”
- **DOCTOR**<sub>2</sub> with **12.942** of “support”
  - Select **DOCTOR**<sub>1</sub> by majority vote.



# Compositional and Lexical Semantics

# The Meaning of “Life”

## Foreword

In the spring of 1976, Terry Parsons and Barbara Partee taught a course on Montague grammar, which I attended. On the second to the final day of class, Terry went around the room asking the students if there were any questions at all that remained unanswered, and promised to answer them on the last day of class. I asked if he really meant ANY question at all, which he emphatically said that he meant. As I had encountered a few questions in my lifetime that remained at least partially unresolved, I decided to ask one of them. What is life? What is the meaning of life? After all, Barbara and Terry had promised to provide answers to any question at all.

On the final day of class Barbara wore her Montague grammar T-shirt, and she and Terry busied themselves answering our questions. At long last, they came to my question. I anticipated a protracted and involved answer, but their reply was crisp and succinct. First Barbara, chalk in hand, showed me the meaning of life.

^life'

Terry then stepped up and showed me what life really is.

^}life'

As we were asked to show on a homework assignment earlier in the year, this is equivalent to: life'.

Leaving me astounded that I had been living in such darkness for all these years, the class then turned to the much stickier problem of pronouns.

Carlson 1977



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Life ← `\w.\x.life(w,x)`

Terry then stepped up and showed me what life really is.

^A life

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## Carlson 1977

# Two “Approaches” to Meaning

- Compositional / logical semantics:
  - Verb  $\rightarrow$  ‘booked’  $\{\lambda W.\lambda z.W(\exists e \text{Booked}(e) \wedge \text{Booker}(e,z) \wedge \text{BookedThing}(e,y))\}$
- Lexical semantics:
  - booked: [0.1234, 0.4, 0.269, ...]
- Generating good *sentence representations*, either by integrating these two approaches or enriching the distributional approach, is a major area of current work in computational semantics.