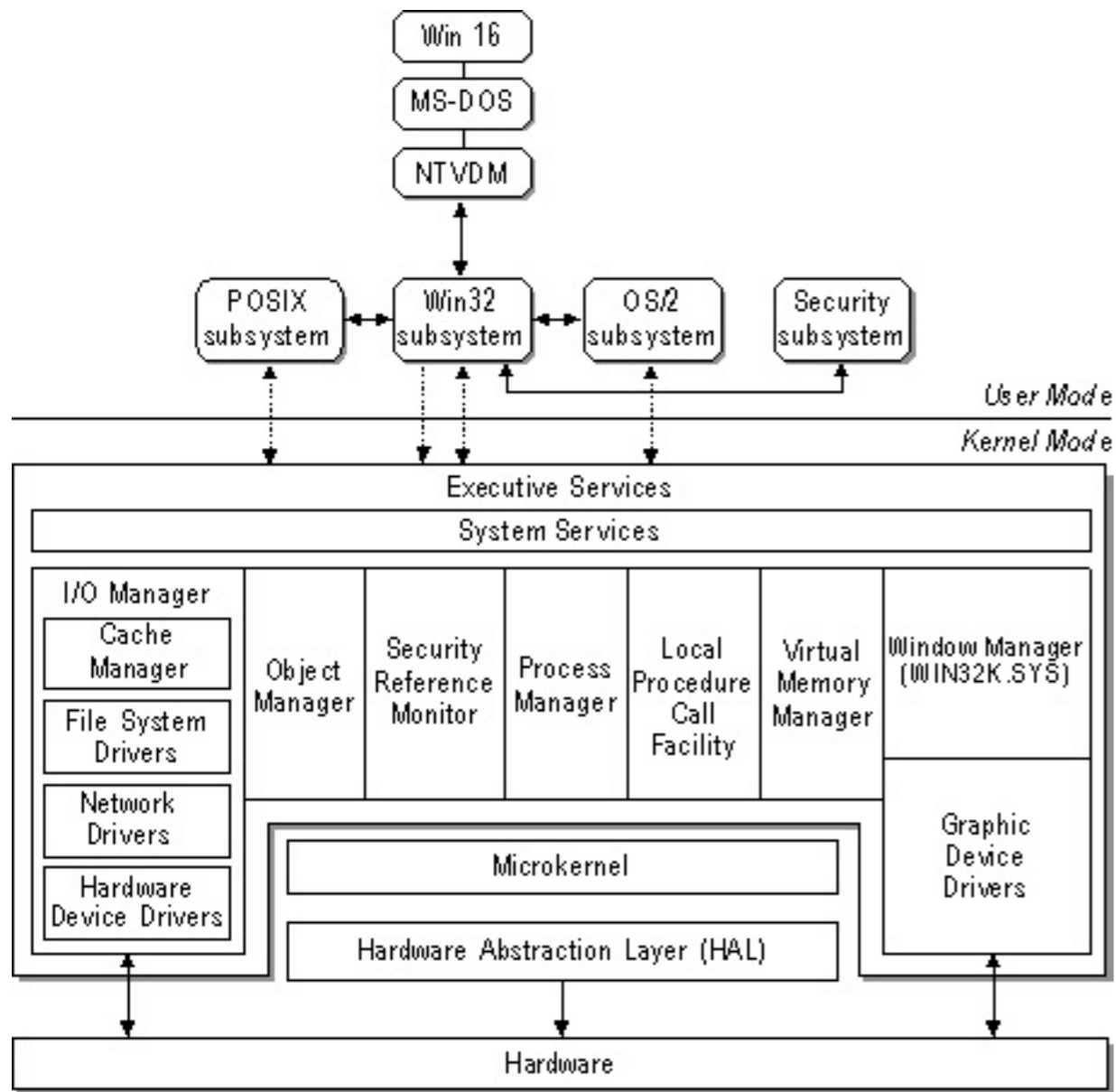


Natural Language Processing (aka NLP, Computational Linguistics, Human Language Technology)



Benjamin Snyder



```

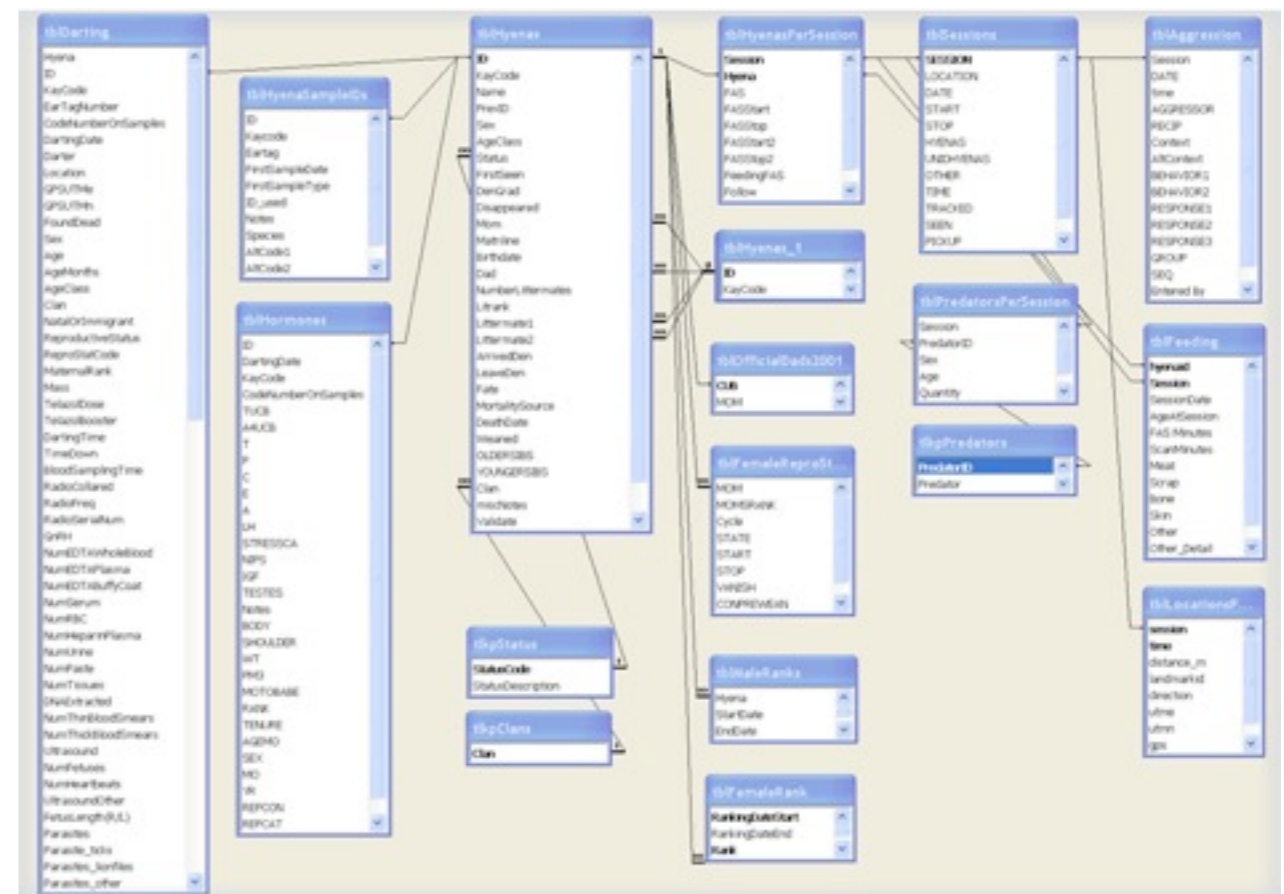
Windows

A fatal exception 0E has occurred at 0020:C0011E36 in UXD UHM(01) +
00010E36. The current application will be terminated.

- Press any key to terminate the current application.
- Press CTRL-ALT-BEL again to restart your computer. You will
lose any unsaved information in all applications.

Press any key to continue ...

```



All that stuff is
important, but...

What can computers
do with human
language?

A Dream

A Dream

- Make computers more useful by getting them to ...

A Dream

- Make computers more useful by getting them to ...
 - Answer questions using the Web

A Dream

- Make computers more useful by getting them to ...
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 - Translate documents from one language to another

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 - Do library research (what papers to read? summarize!)

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A Dream

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 - Fix your spelling or grammar
 - Write poems or novels

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 - Fix your spelling or grammar
 - Write poems or novels
 - Give advice, psychotherapy

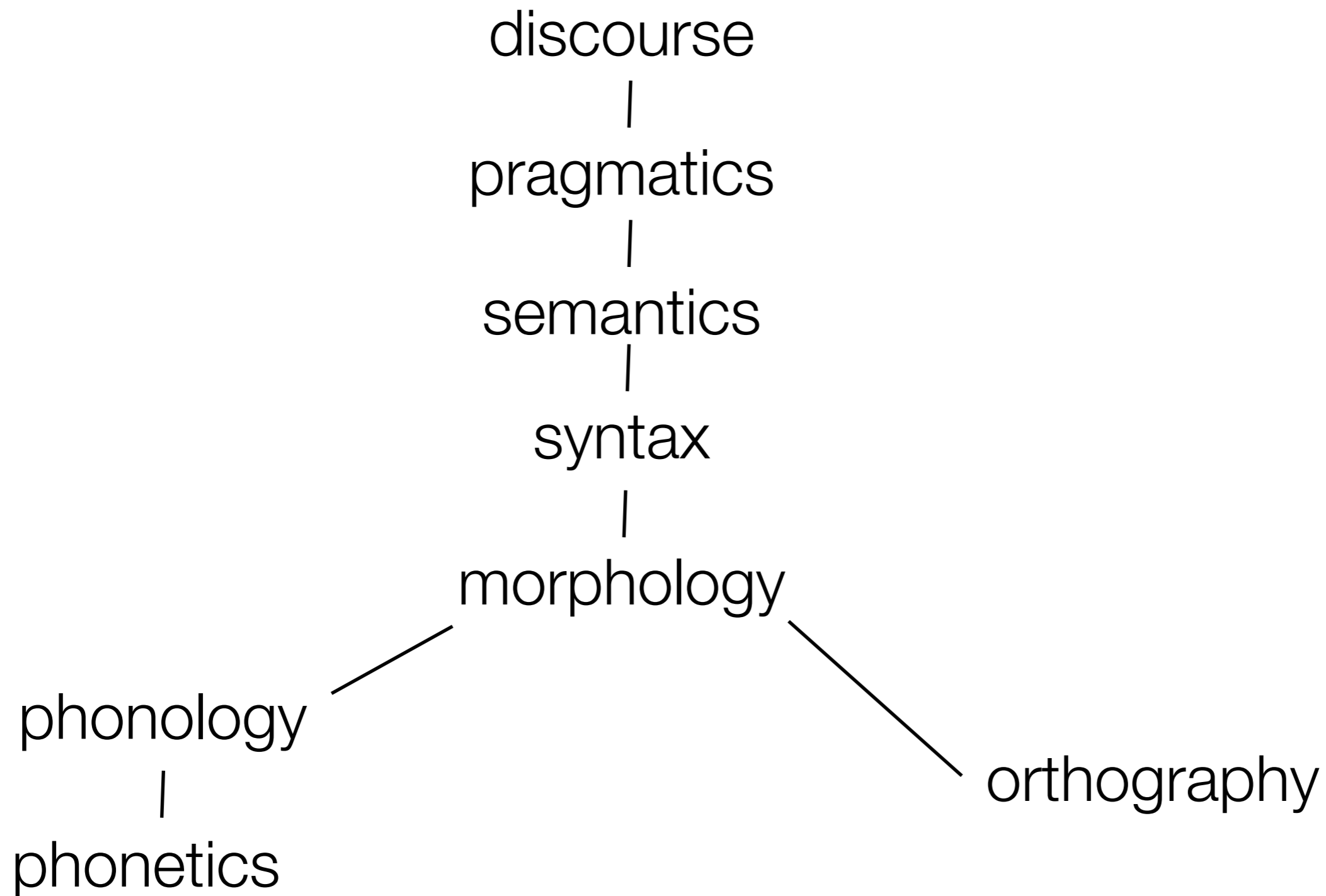
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 - Follow directions given by any user (your Grandma)
 - Fix your spelling or grammar
 - Write poems or novels
 - Give advice, psychotherapy
 - Predict world events (elections, financial markets)

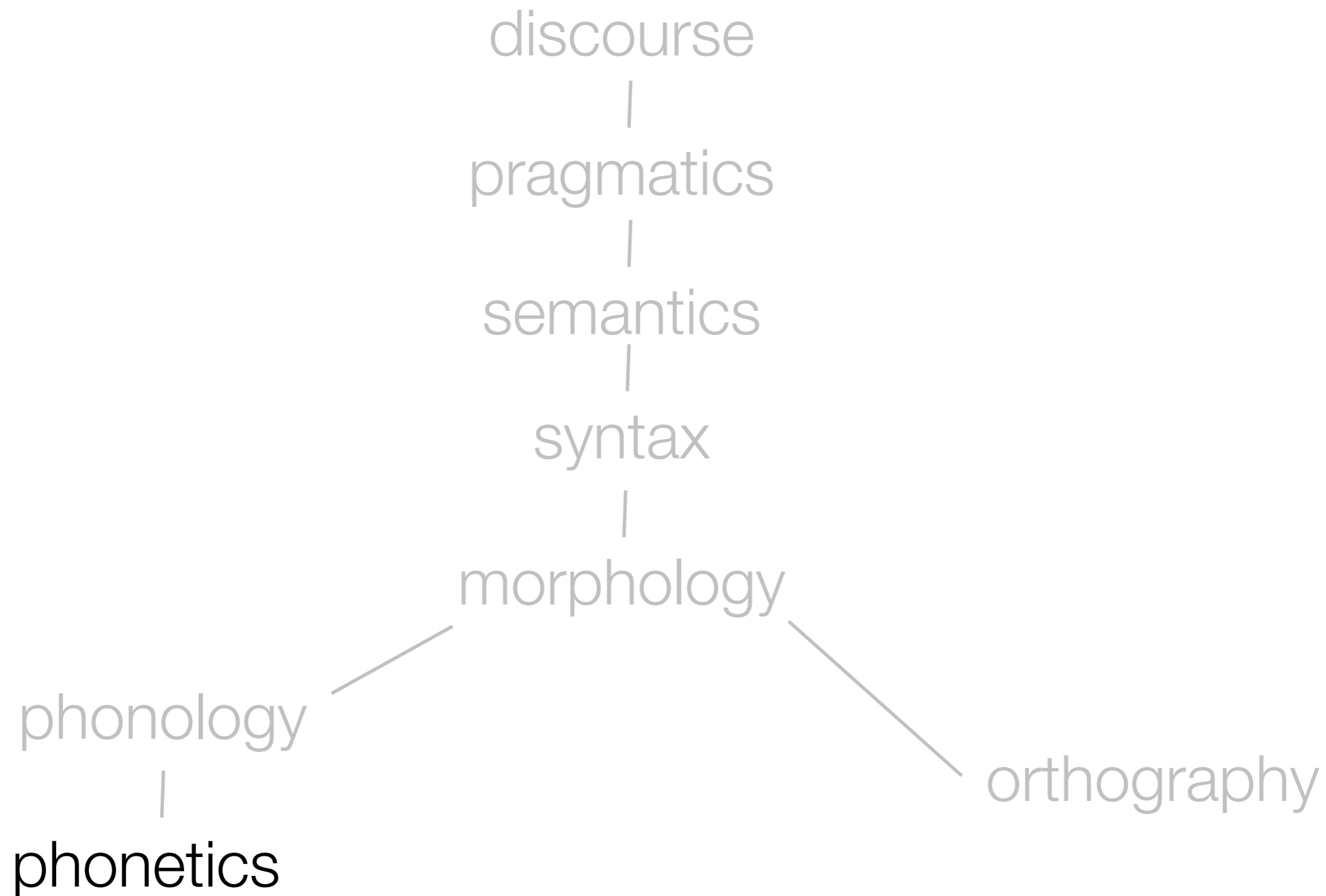
A Dream

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 - Fix your spelling or grammar
 - Write poems or novels
 - Give advice, psychotherapy
 - Predict world events (elections, financial markets)
- **Major obstacle to this fantasy: language!**

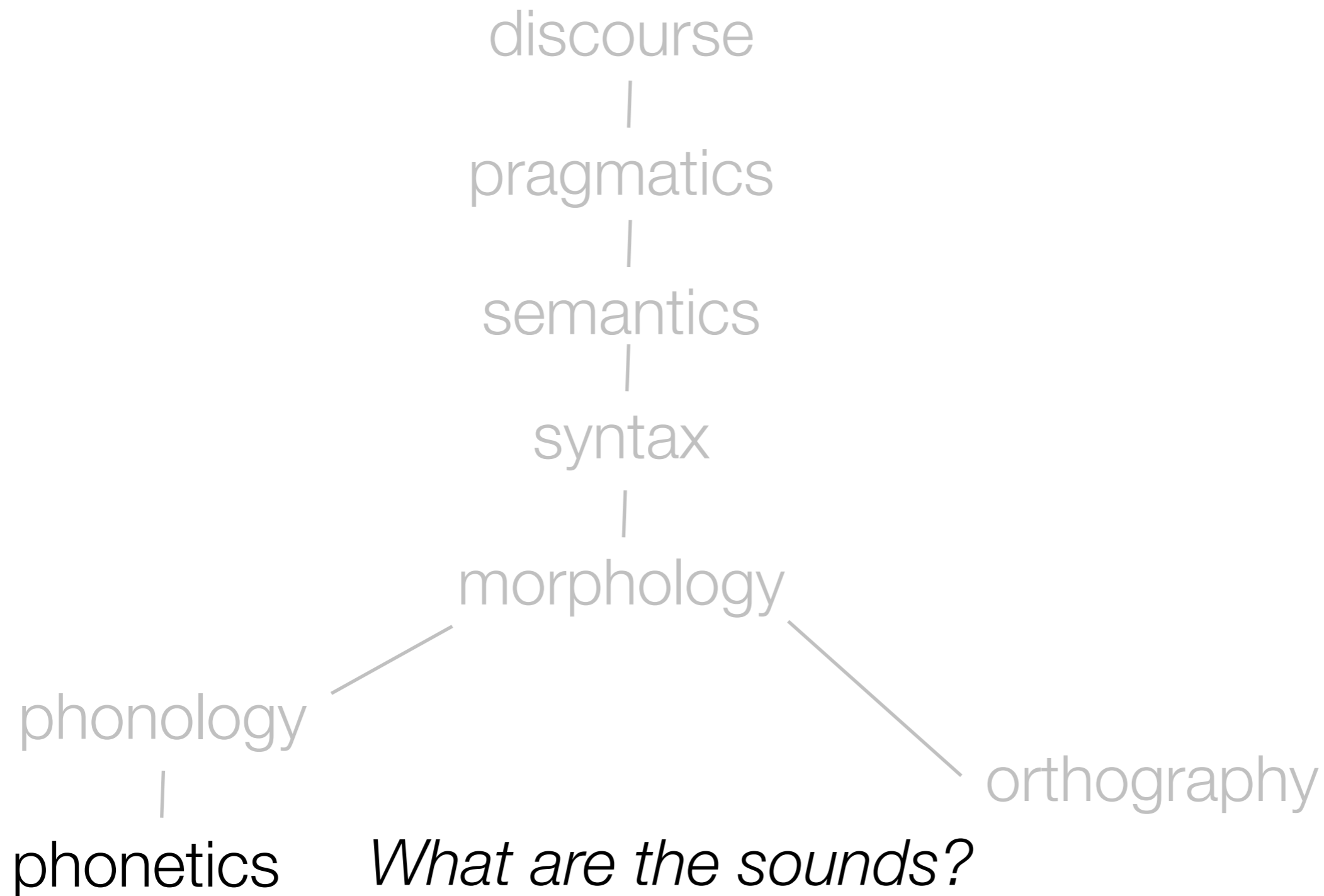
Different Levels of Linguistic Knowledge



Different Levels of Linguistic Knowledge



Different Levels of Linguistic Knowledge



phonetics

What are the sounds?

The sound of air moving through my larynx while my tongue is raised in the back of my throat is i_y (as in **teach**).

phonetics *What are the sounds?*

The sound of air moving through my larynx while my tongue is raised in the back of my throat is i_y (as in **teach**).

The sound of air gurgling up from my stomach is not speech.

phonetics *What are the sounds?*

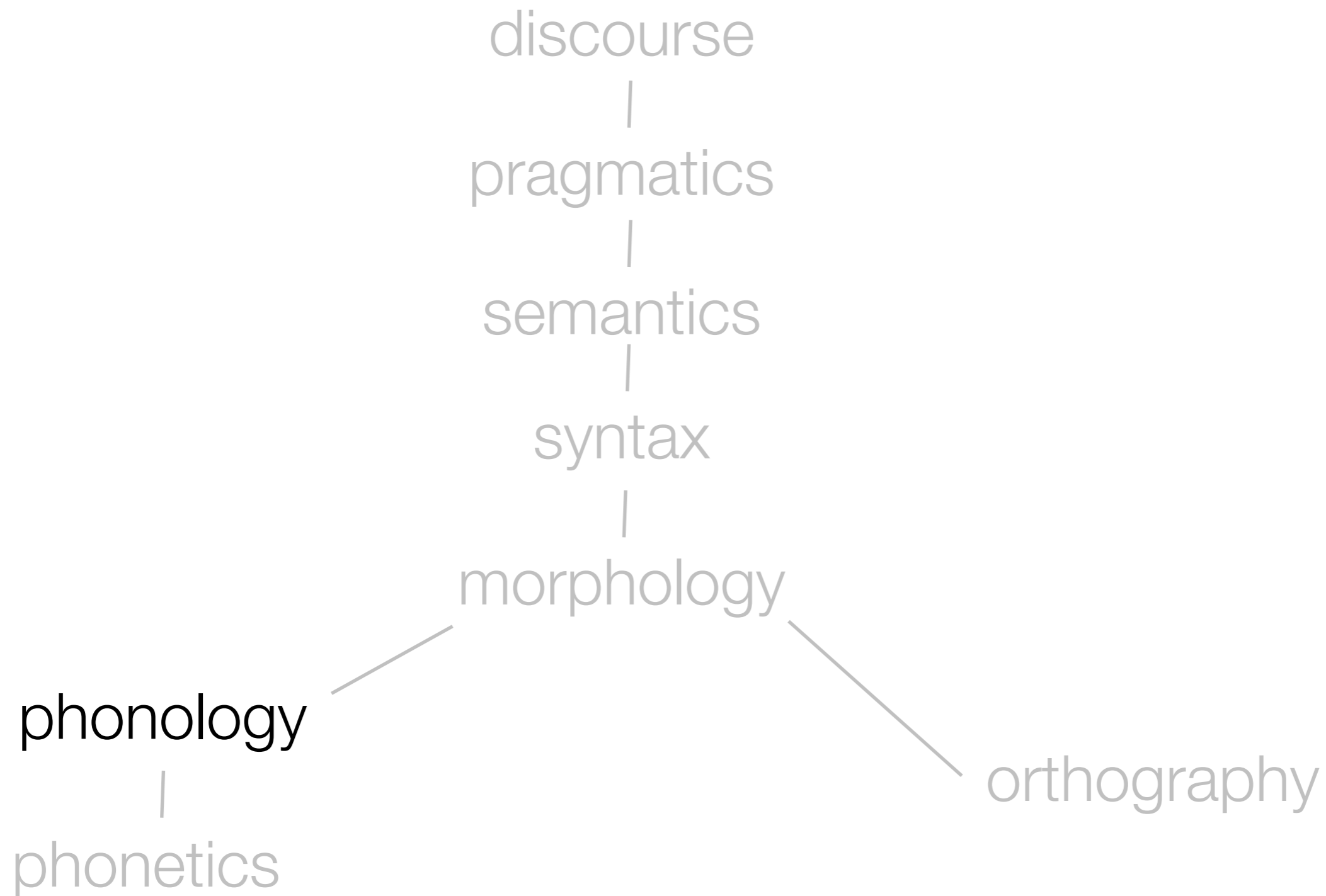
The sound of air moving through my larynx while my tongue is raised in the back of my throat is i_y (as in **teach**).

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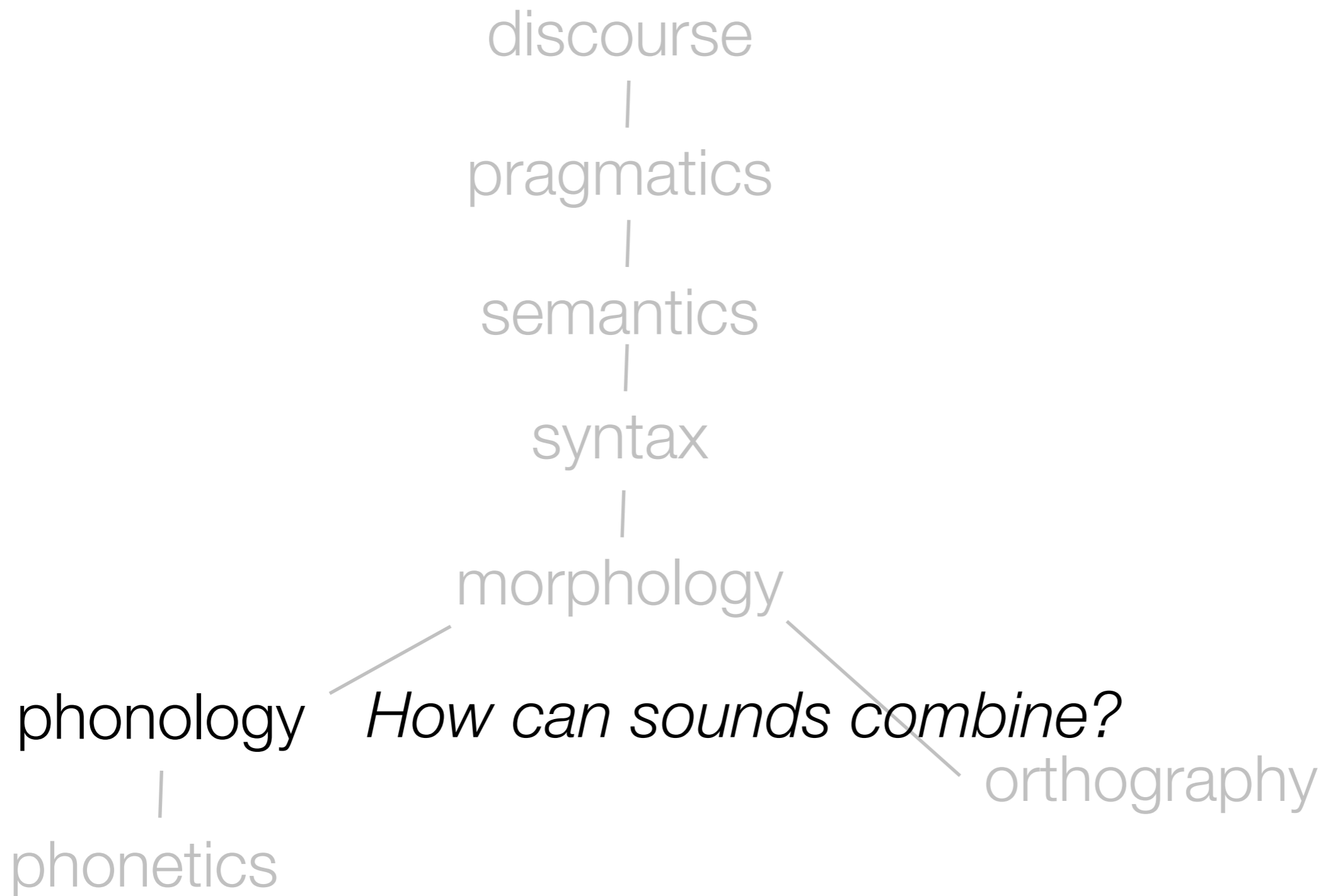
How to distinguish/generate the waveforms for speech sounds?

phonetics *What are the sounds?*

Different Levels of Linguistic Knowledge



Different Levels of Linguistic Knowledge



phonology *How can sounds combine?*

“Let’s pee in the corner. Let’s pee
in the spotlight.”

phonology *How can sounds combine?*

“Let’s pee in the corner. Let’s pee
in the spotlight.”

“I left my brains down in Africa”

phonology *How can sounds combine?*

“Let’s pee in the corner. Let’s pee
in the spotlight.”

www.kissthisguy.com

“I left my brains down in Africa”

phonology *How can sounds combine?*

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in the spotlight.”

www.kissthisguy.com

Sociological factors:

- merry/marry/Mary
- pin/pen/pan/paeon
- caught/cot
- goin’/going
- something/suttin’/
sumpin’/sumthin’

“I left my brains down in Africa”

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“Let’s pee in the corner. Let’s pee
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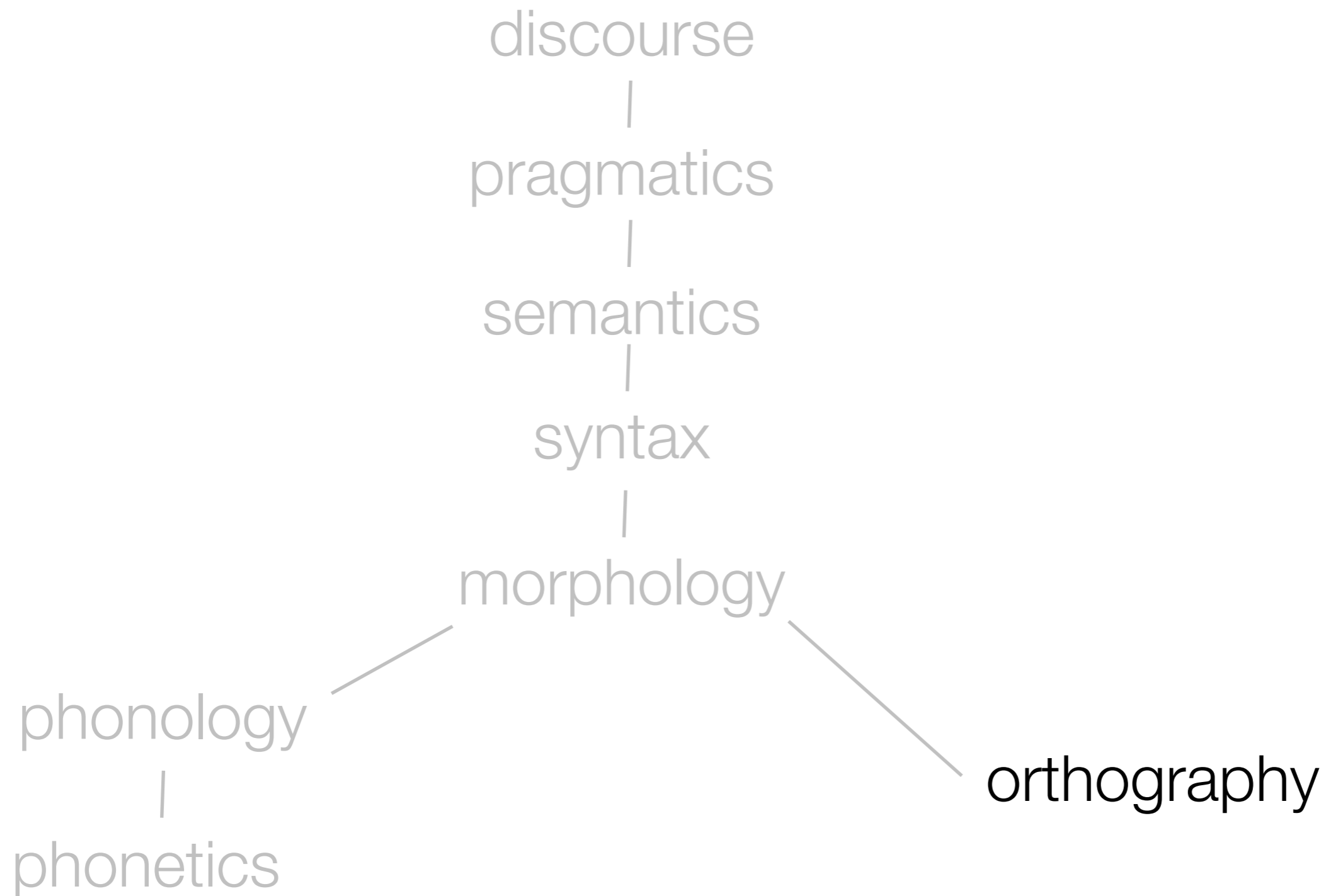
- merry/marry/Mary
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sumpin’/sumthin’

“I left my brains down in Africa”

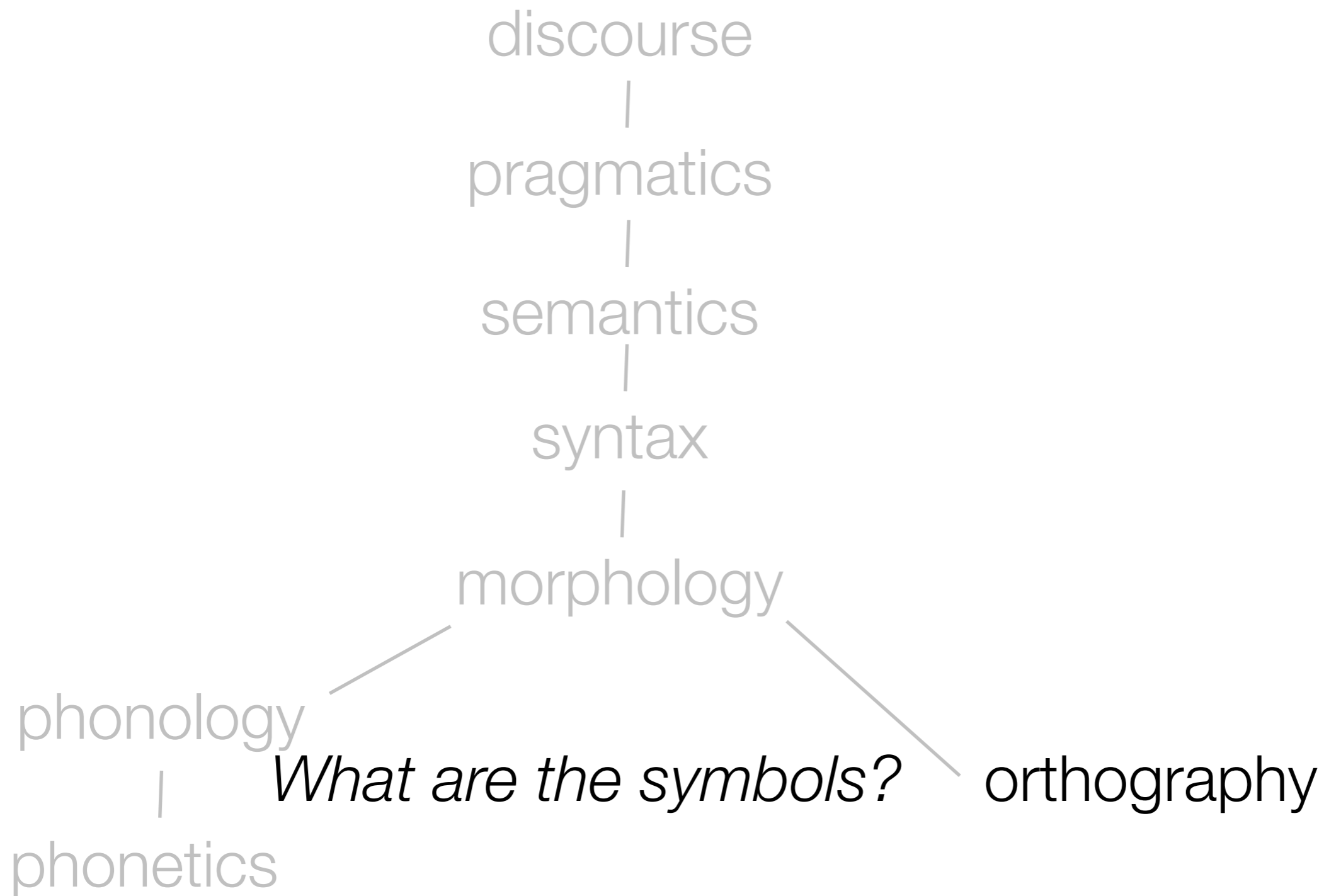
Words like **because**
and **about** can be
realized many
different ways.

phonology *How can sounds combine?*

Different Levels of Linguistic Knowledge



Different Levels of Linguistic Knowledge



What are the symbols? orthography

第二阶段的奥运会体育比赛门票与残奥会开闭幕式门票的预订工作已经结束,现在进入门票分配阶段。在此期间,我们不再接受新的门票预订申请。

What are the symbols? orthography

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NATRL LNGUAG PRCSSNG

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NATRL LNGUAG PRCSSNG

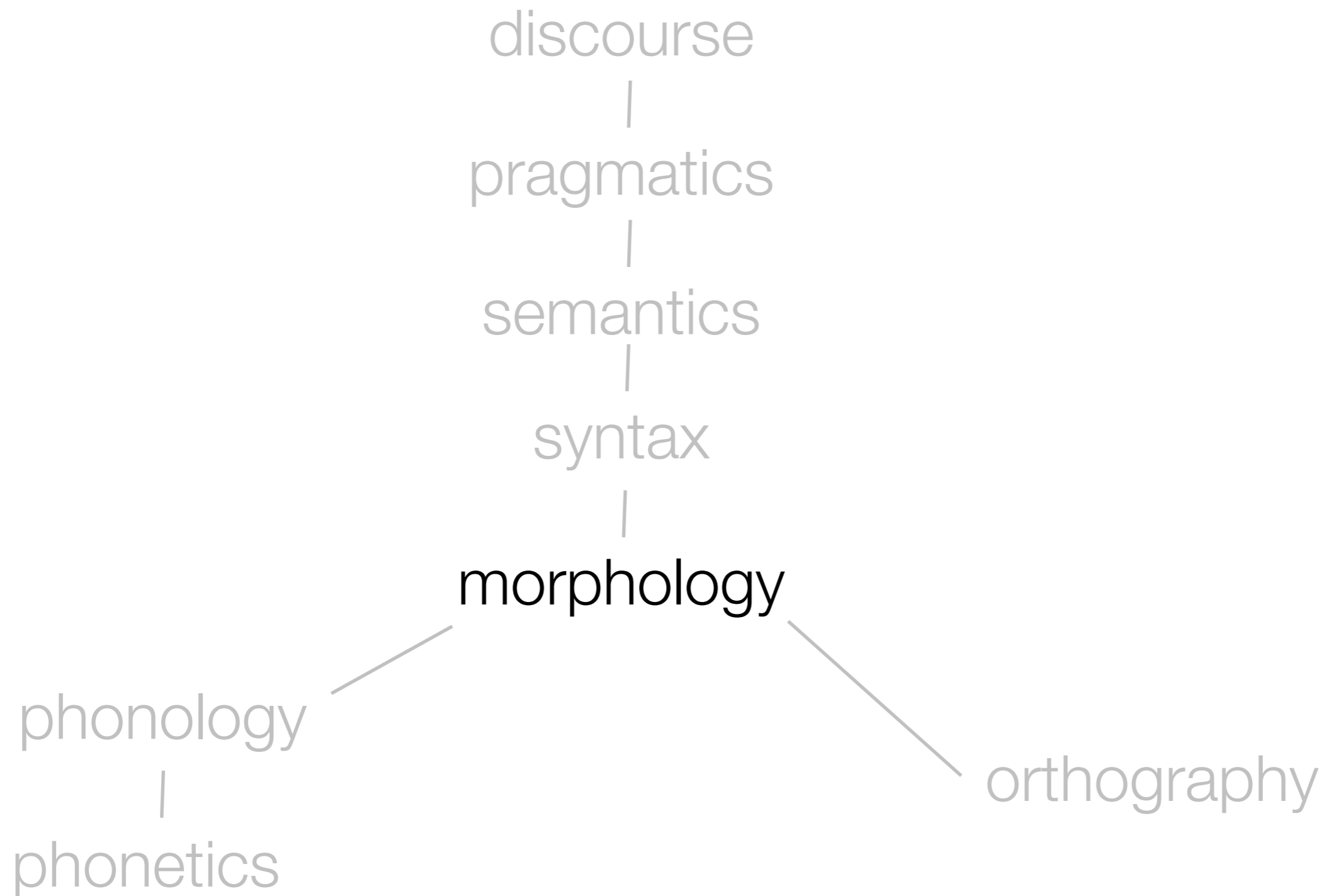
“Let’s go see the **praade!**”

“They have a mouse in **they’re** house.”

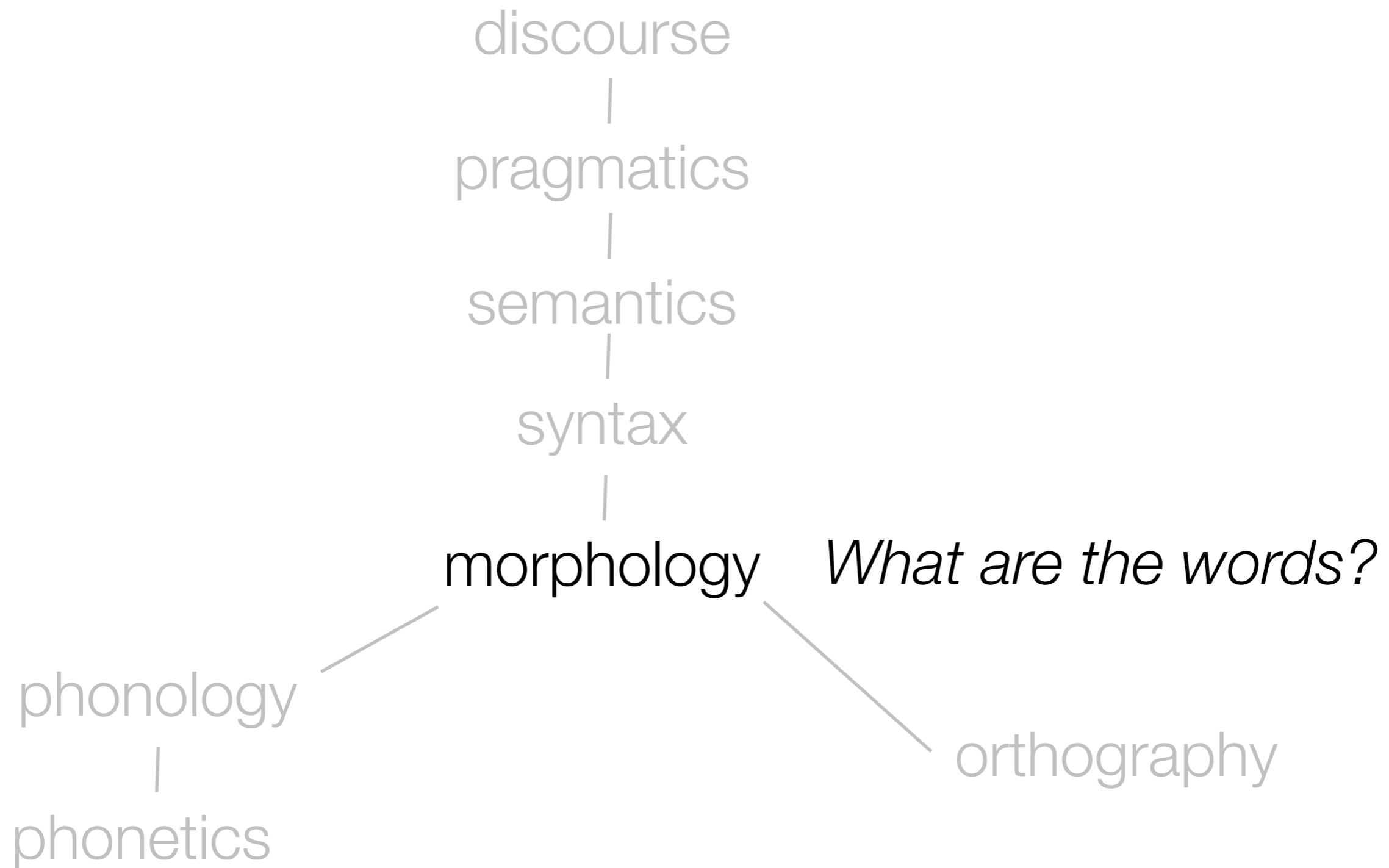
“What do you want for **desert?**”

What are the symbols? orthography

Different Levels of Linguistic Knowledge



Different Levels of Linguistic Knowledge



morphology *What are the words?*

fax, google, w00t, OMG, Man-fucking-hattan, lol, lolz,
unfriend, tweet, Obamacare, coo af

morphology *What are the words?*

fax, google, w00t, OMG, Man-fucking-hattan, lol, lolz,
unfriend, tweet, Obamacare, coo af

After it sorts each sub-part, it **merges** them.

After they sort each sub-part, they **merge** them.

How many **merges** are needed?

One **merge**.

Merging is fast.

To split is human, to **merge** divine.

morphology *What are the words?*

fax, google, w00t, OMG, Man-fucking-hattan, lol, lolz,
unfriend, tweet, Obamacare, coo af

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morphology *What are the words?*

One house among many houses

One mouse among many **mouses**

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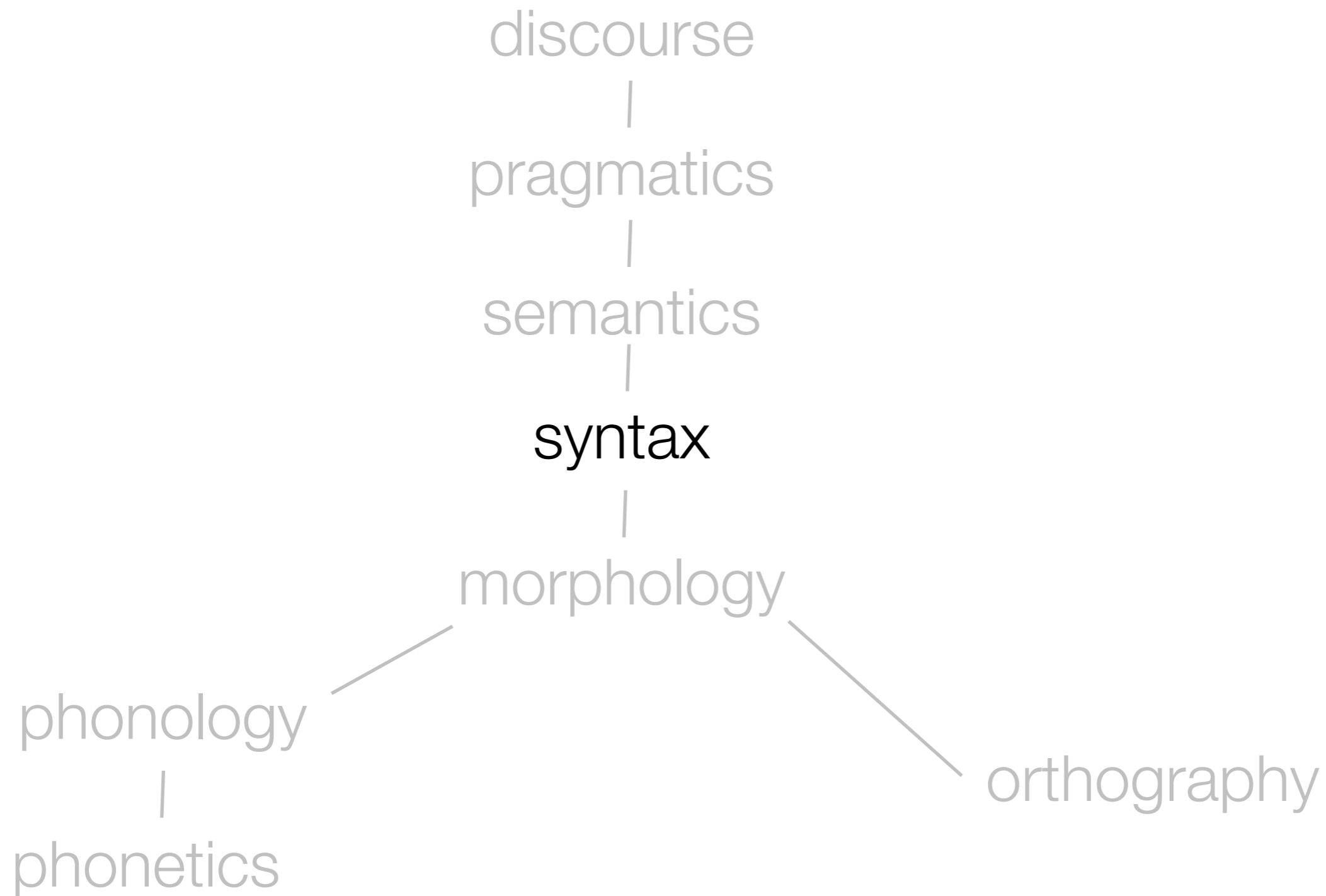
One house among many houses

One mouse among many **mouses**

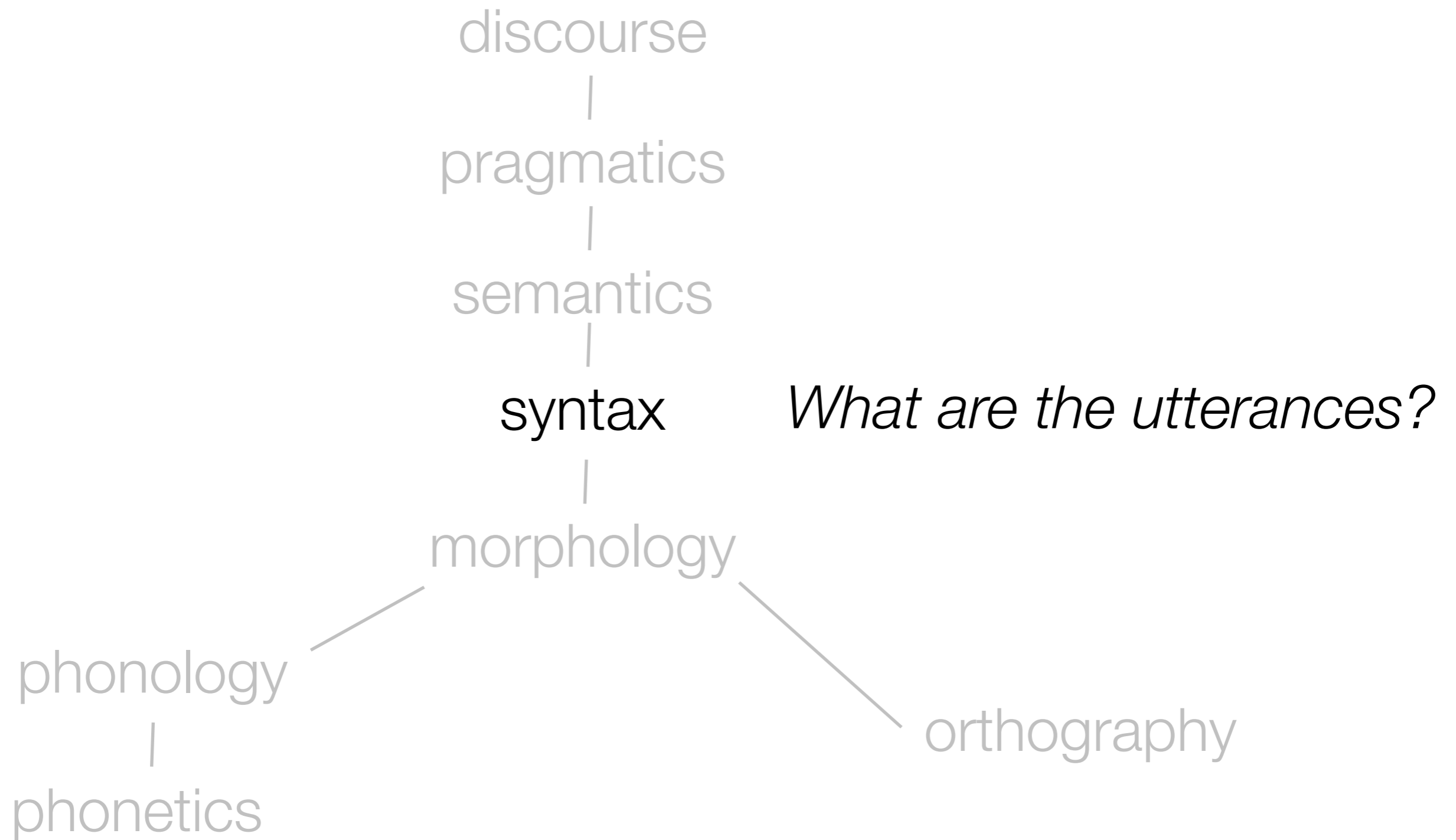
uygarlaştıramadıklarımızdanmışsınızcasına

“(behaving) as if you are among those whom we could not civilize”

Different Levels of Linguistic Knowledge



Different Levels of Linguistic Knowledge



syntax

What are the utterances?

Noah gave Kevin the book.

= Noah gave the book to Kevin.

= The book was given to Kevin by Noah.

= The book was given by Noah to Kevin.

*Gave Noah Kevin the book.

syntax

What are the utterances?

Noah gave Kevin the book.

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syntax

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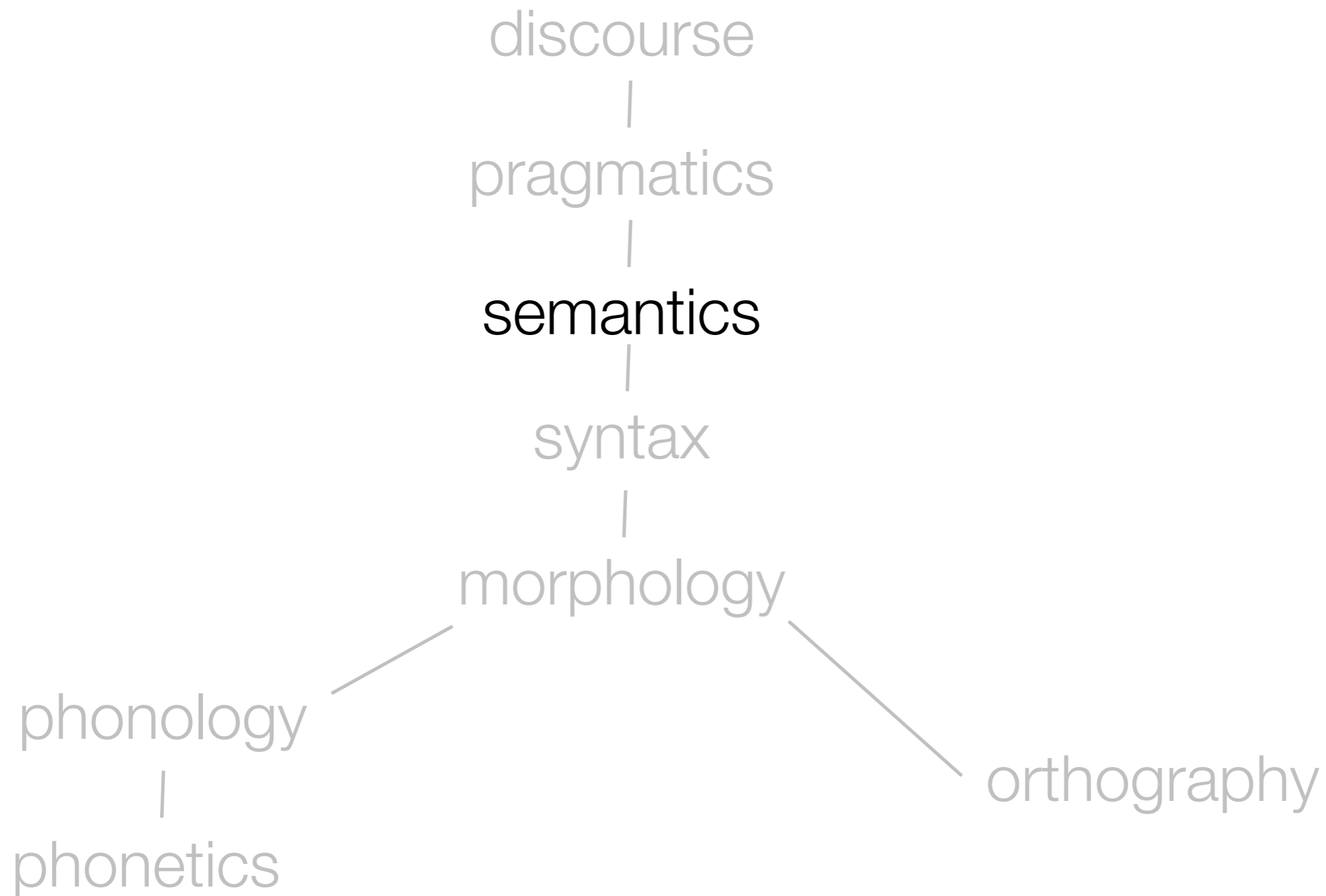
I want a flight to Tokyo.

I want to fly to Tokyo.

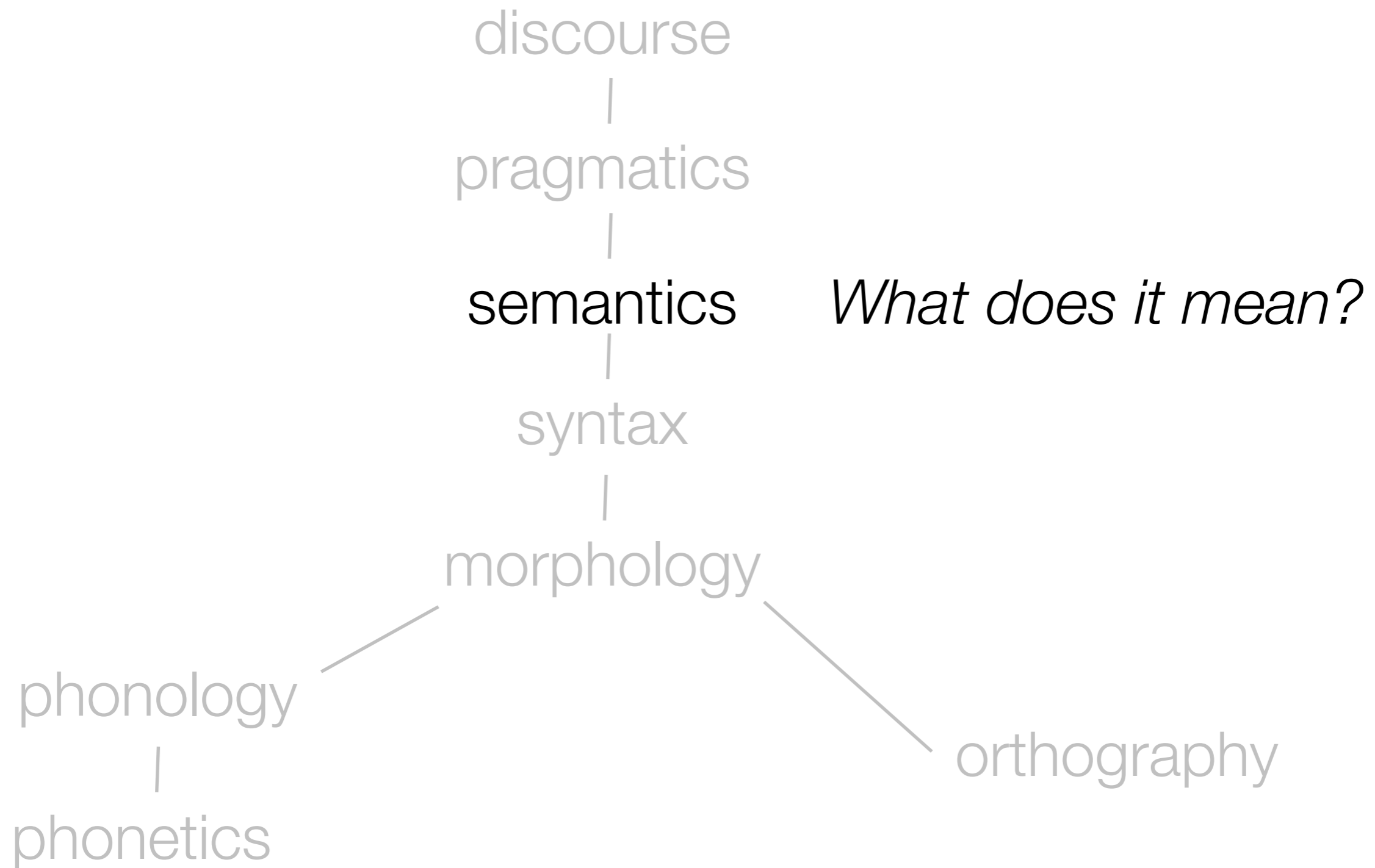
I found a flight to Tokyo.

*I found to fly to Tokyo.

Different Levels of Linguistic Knowledge



Different Levels of Linguistic Knowledge



semantics *What does it mean?*

“Jerusalem - there is no such city!”

semantics *What does it mean?*

“Jerusalem - there is no such city!”

In this country a woman gives birth **every** fifteen minutes.
Our job is to find that woman and stop her.

semantics *What does it mean?*

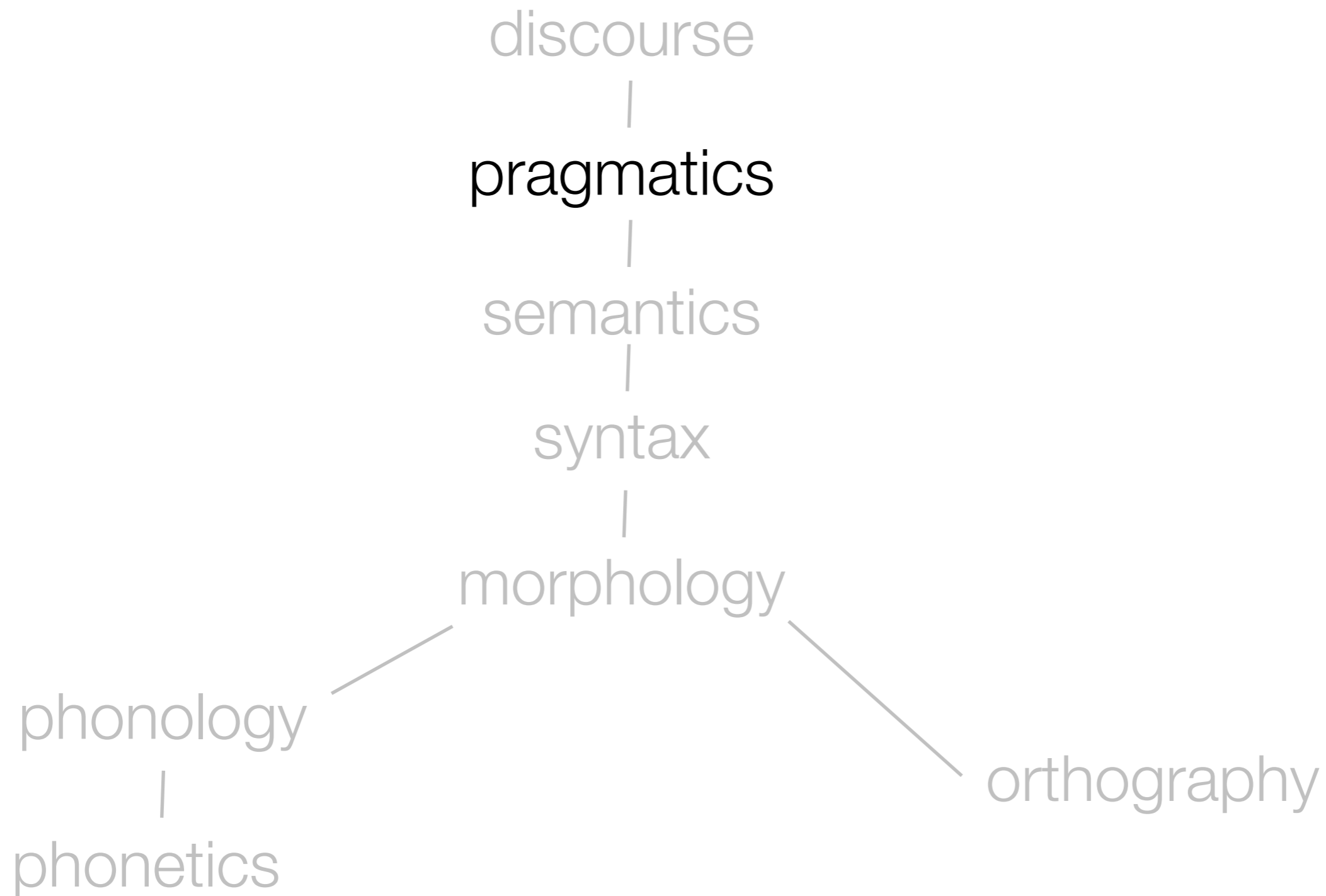
“Jerusalem - there is no such city!”

In this country a woman gives birth **every** fifteen minutes.
Our job is to find that woman and stop her.

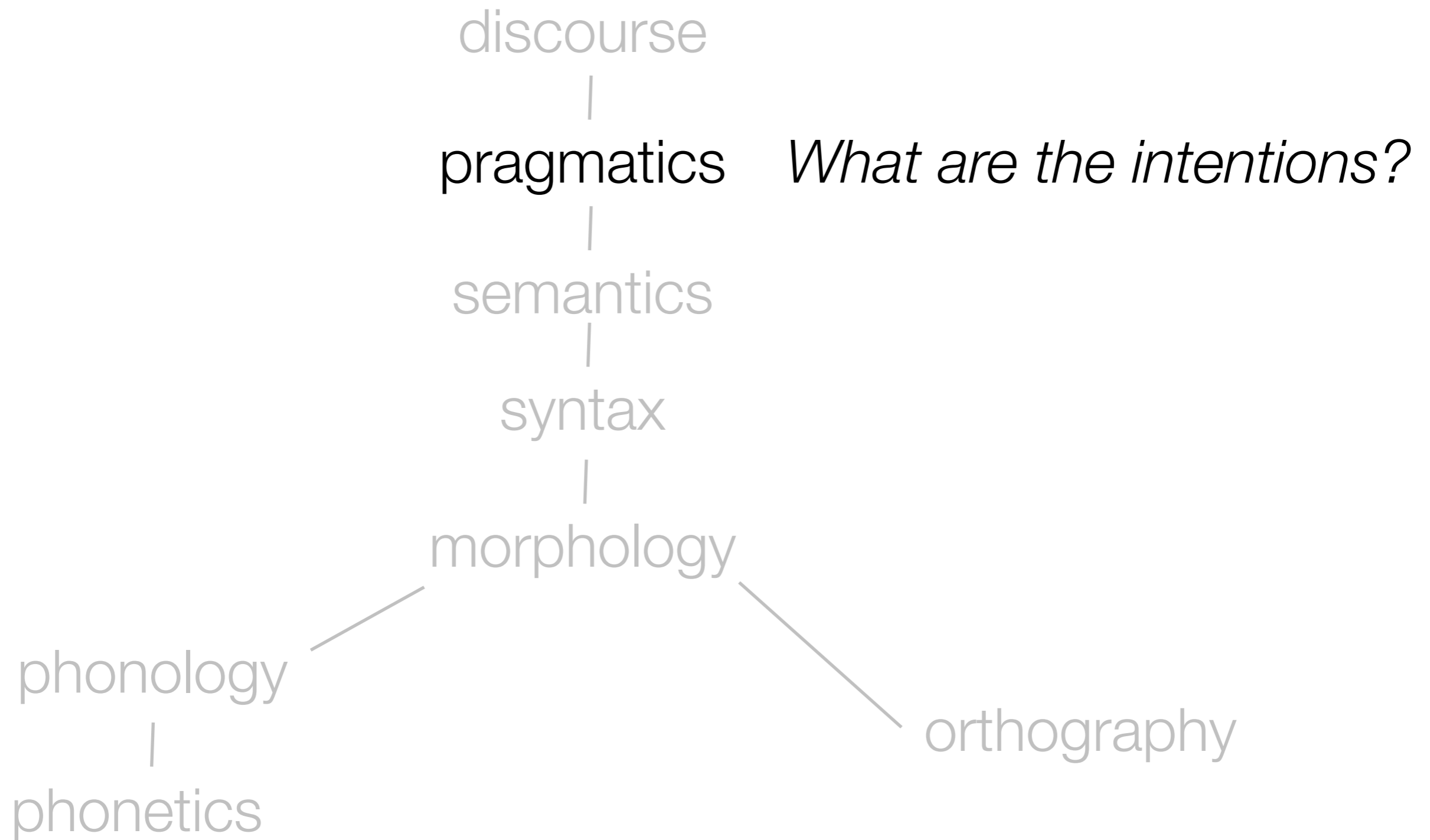
semantics *What does it mean?*

Colorless green ideas sleep furiously.

Different Levels of Linguistic Knowledge



Different Levels of Linguistic Knowledge



pragmatics *What are the intentions?*

“Would you mind passing the salt?”

pragmatics *What are the intentions?*

“Would you mind passing the salt?”

pragmatics *What are the intentions?*

“I’m sorry Dave, I’m afraid I can’t do that.”

“Would you mind passing the salt?”

pragmatics *What are the intentions?*

“I’m sorry Dave, I’m afraid I can’t do that.”

“You’re so funny.”

“Would you mind passing the salt?”

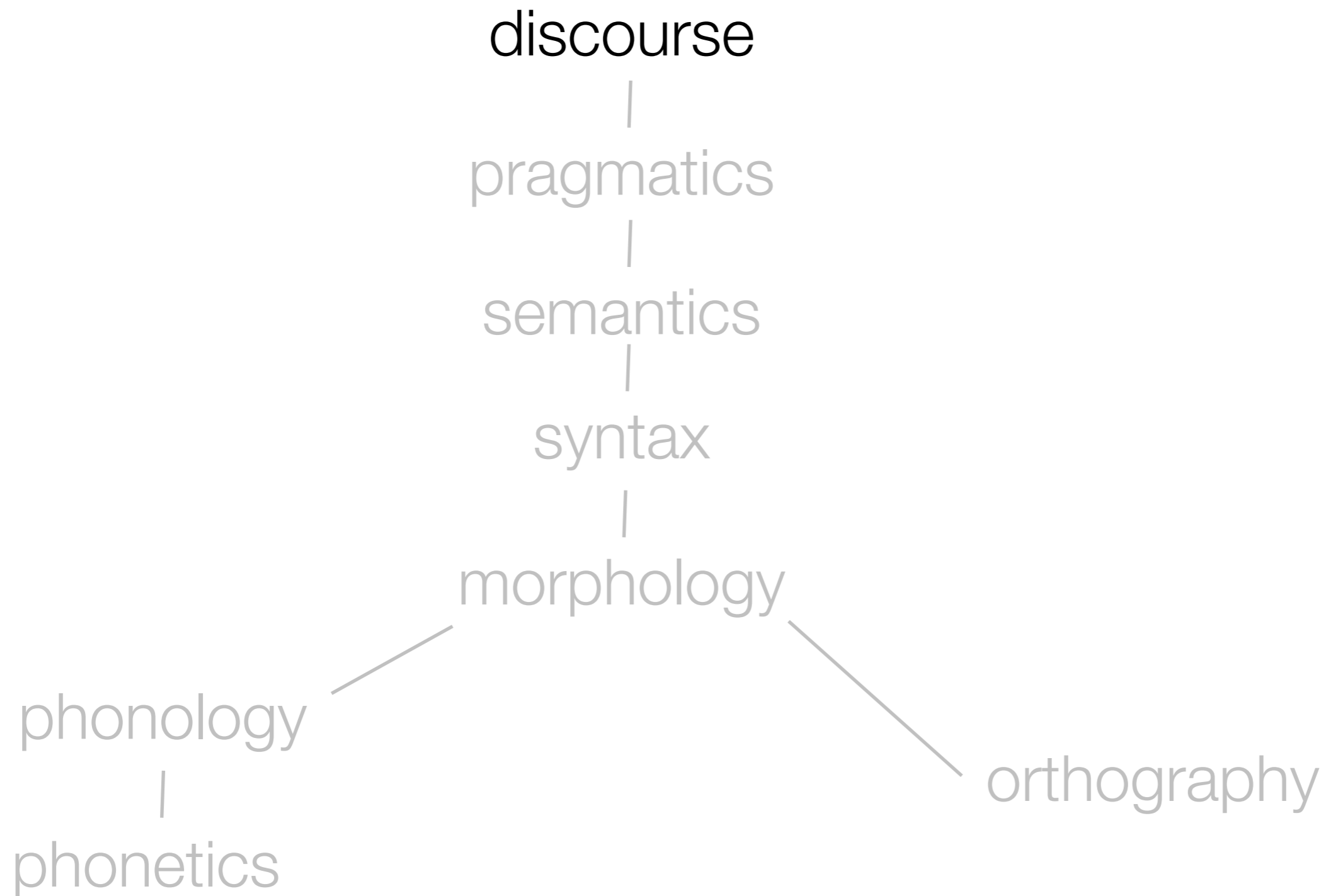
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“I’m sorry Dave, I’m afraid I can’t do that.”

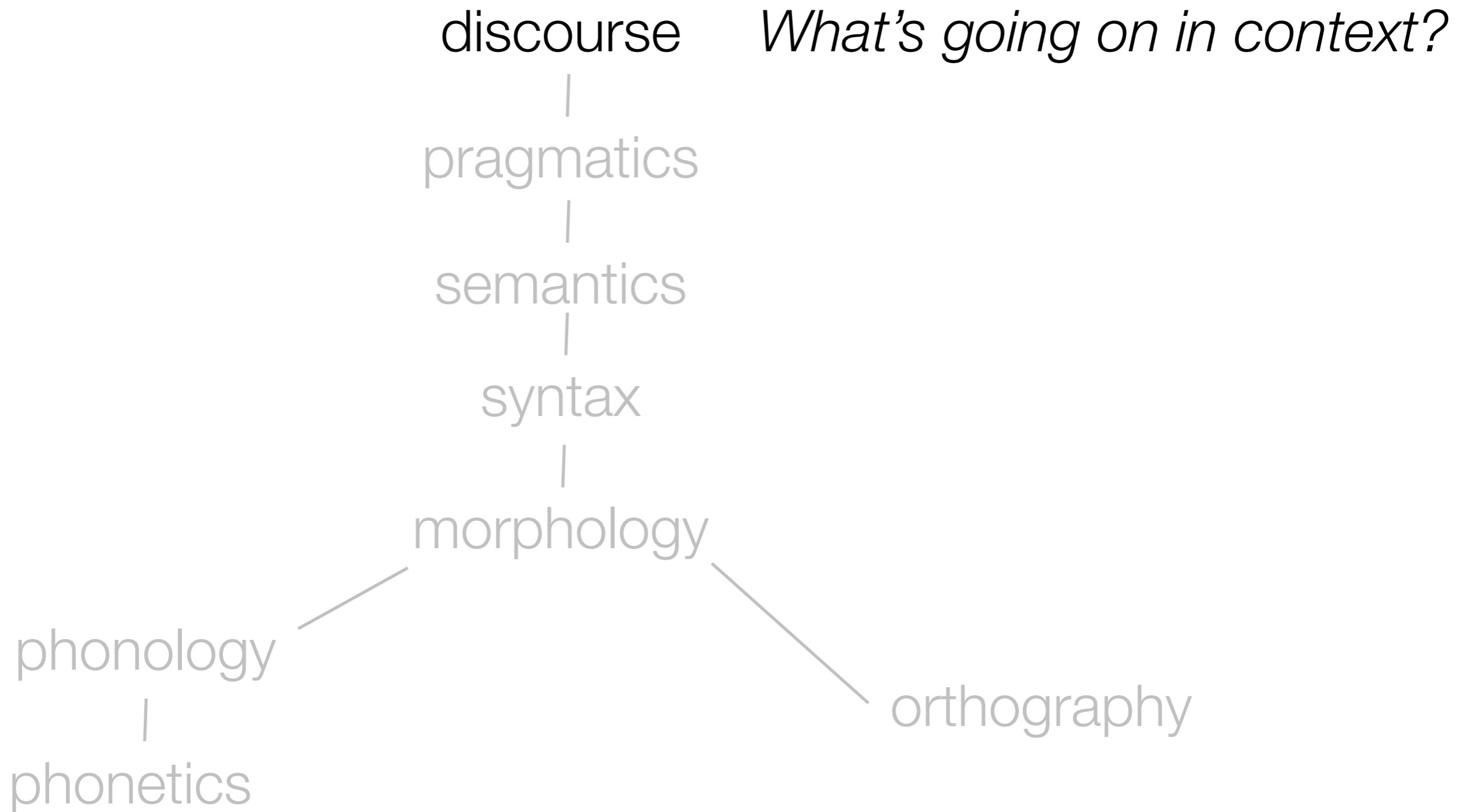
“You’re so funny.”

“I can’t believe I ate the whole thing.”

Different Levels of Linguistic Knowledge



Different Levels of Linguistic Knowledge



discourse *What's going on in context?*

discourse *What's going on in context?*

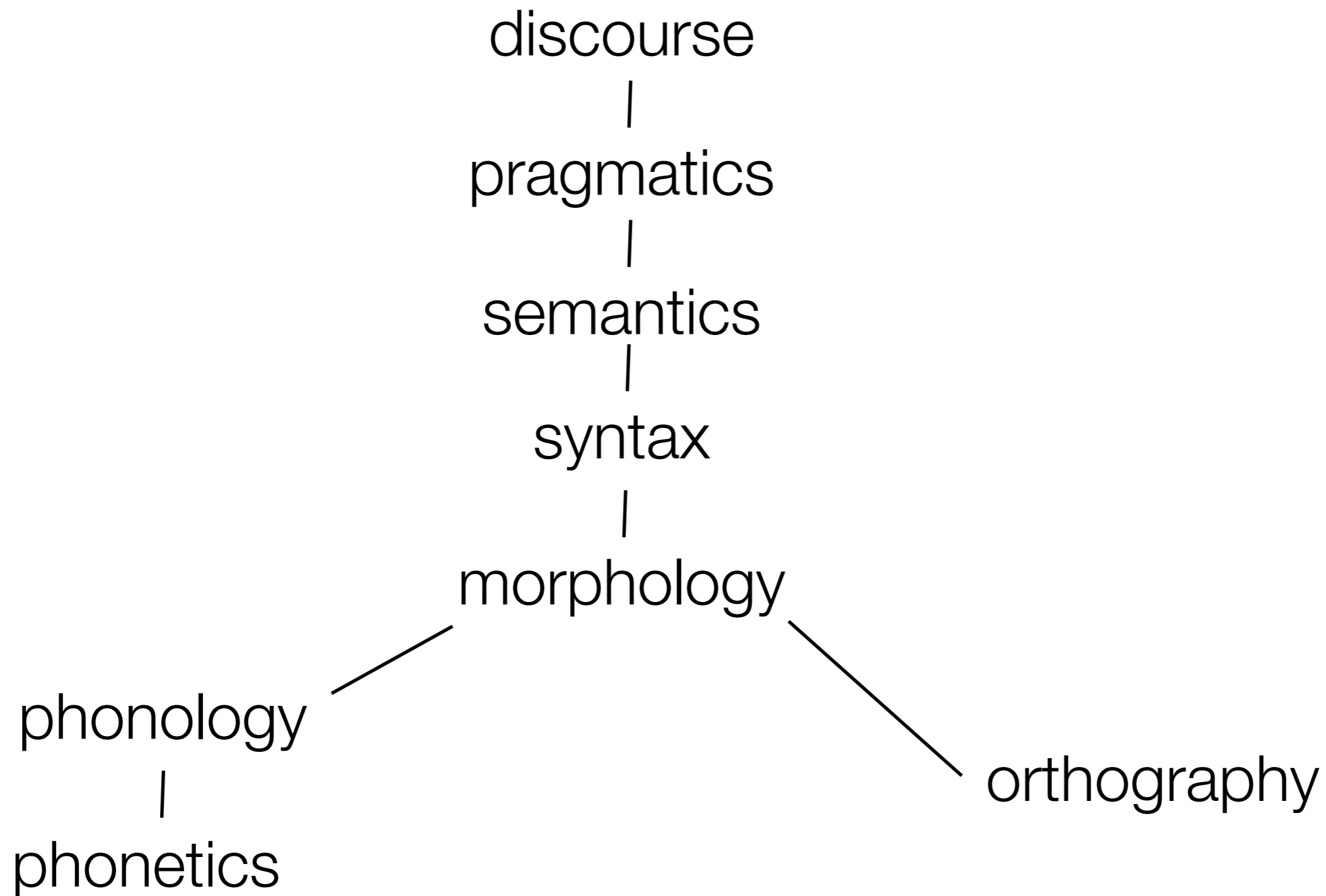
The Tin Woodman went to the Emerald City to see the Wizard of Oz and ask for a heart. After **he** asked for **it**, the Woodman waited for the Wizard's response.

discourse *What's going on in context?*

The Tin Woodman went to the Emerald City to see the Wizard of Oz and ask for a heart. After **he** asked for **it**, the Woodman waited for the Wizard's response.

Any time
you got
nothing to
do - and
lots of time
to do **it** -
come on
up.

Different Levels of Linguistic Knowledge



Ambiguity Students hate annoying professors

Headlines:

From Facebook:

- I'd rather have Kissed a Girl stuck in my head than the Girl from Ipanema.

Ambiguity Students hate annoying professors

From Groucho:

Headlines:

From Facebook:

- I'd rather have Kissed a Girl stuck in my head than the Girl from Ipanema.

Ambiguity

Students hate annoying professors

From Groucho:

- Last night I shot an elephant in my pajamas. What he was doing in my pajamas I'll never know.

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- Kids Make Nutritious Snacks

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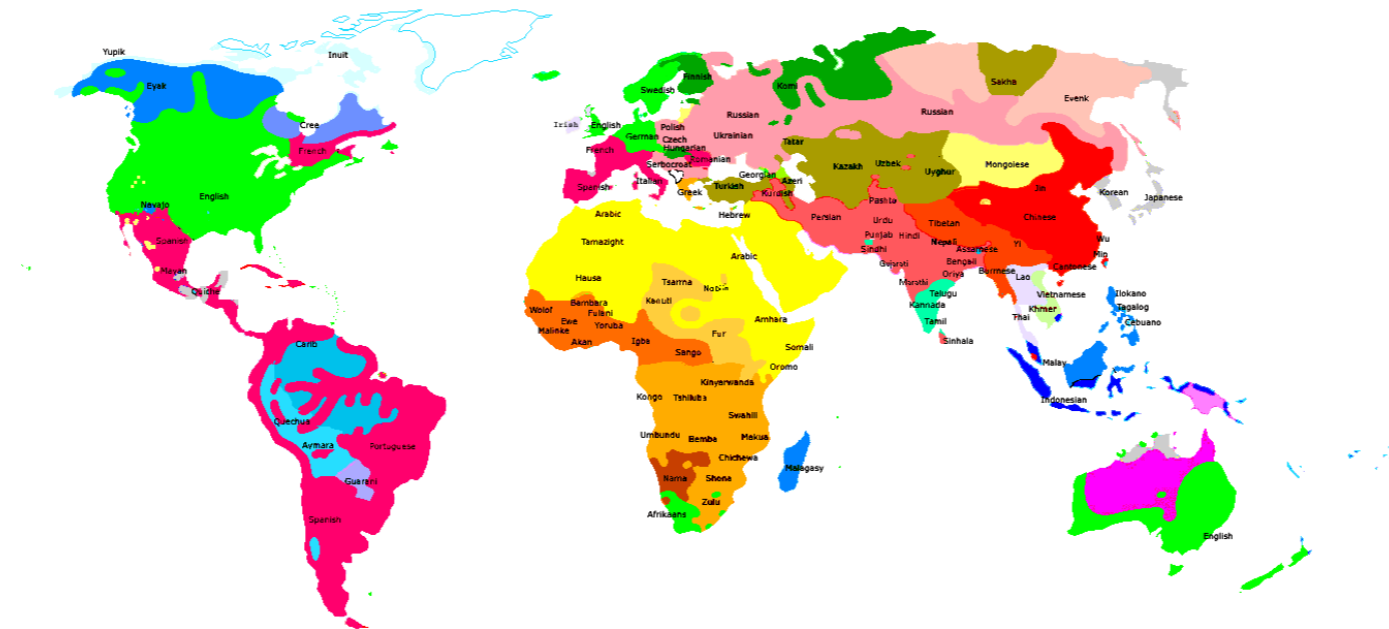
Headlines:

- Kids Make Nutritious Snacks
- British Left Waffles on Falkland Islands
- Red Tape Holds Up New Bridges
- Iraqi Head Seeks Arms

From Facebook:

- I'd rather have Kissed a Girl stuck in my head than the Girl from Ipanema.

4,000 living languages



- Research has focused on English
- Most languages beyond reach of NLP:
 - ▶ Lack of data
 - ▶ Variations in linguistic structure

Linguistic Typology:

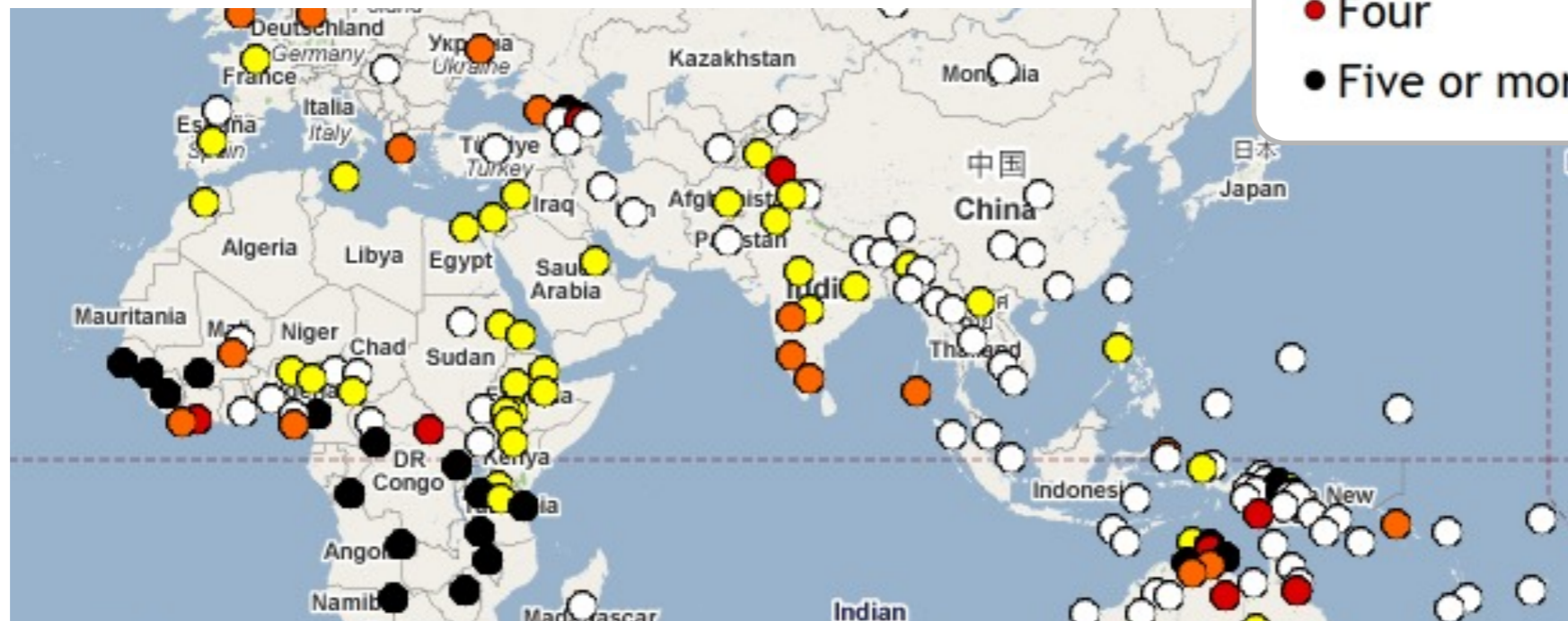
The study of language difference

Subject Verb Object Positioning

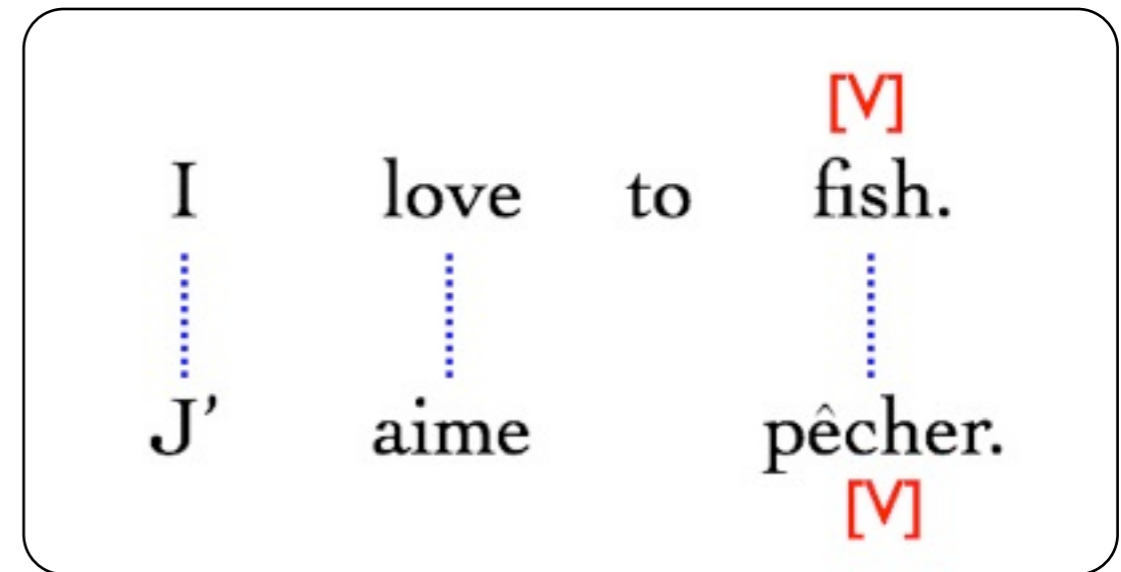
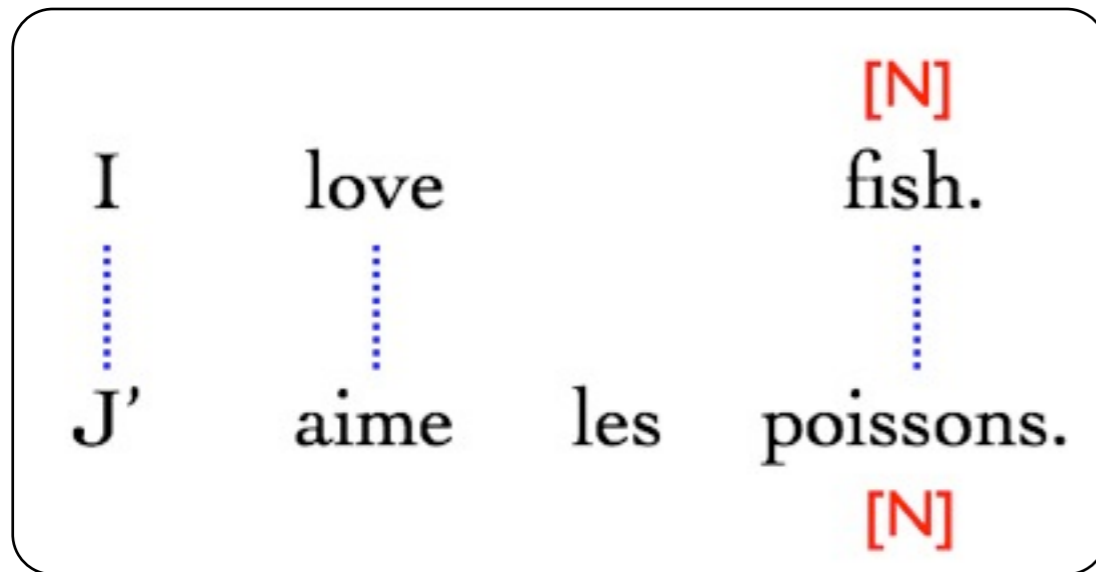
Number of Genders ←

Definite Article

- None (145 languages)
- Two (50 languages)
- Three (26 languages)
- Four (12 languages)
- Five or more (24 languages)



Variations in Ambiguity



English: fish (noun) / fish (verb)

French: poissons (noun) / pêcher (verb)

Variations in Ambiguity

- Differences in morphology

English: **in my country**

separate words

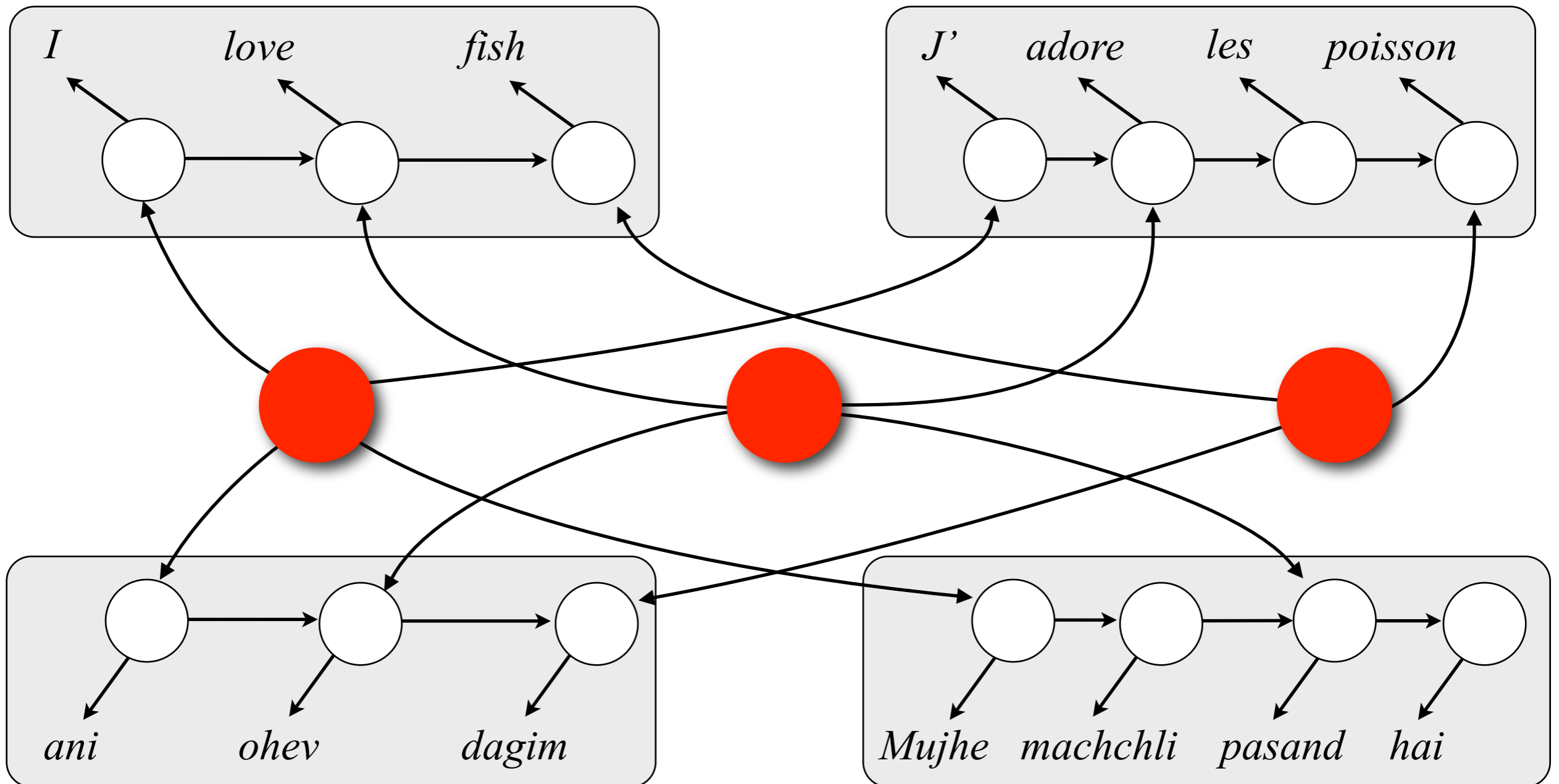
Hebrew: בארץ

- Differences in syntax

Japanese: チーズのスパゲティを食べた *genitive marker*

English: **I ate pasta with cheese.**

A Multilingual Probabilistic Model



Corpus



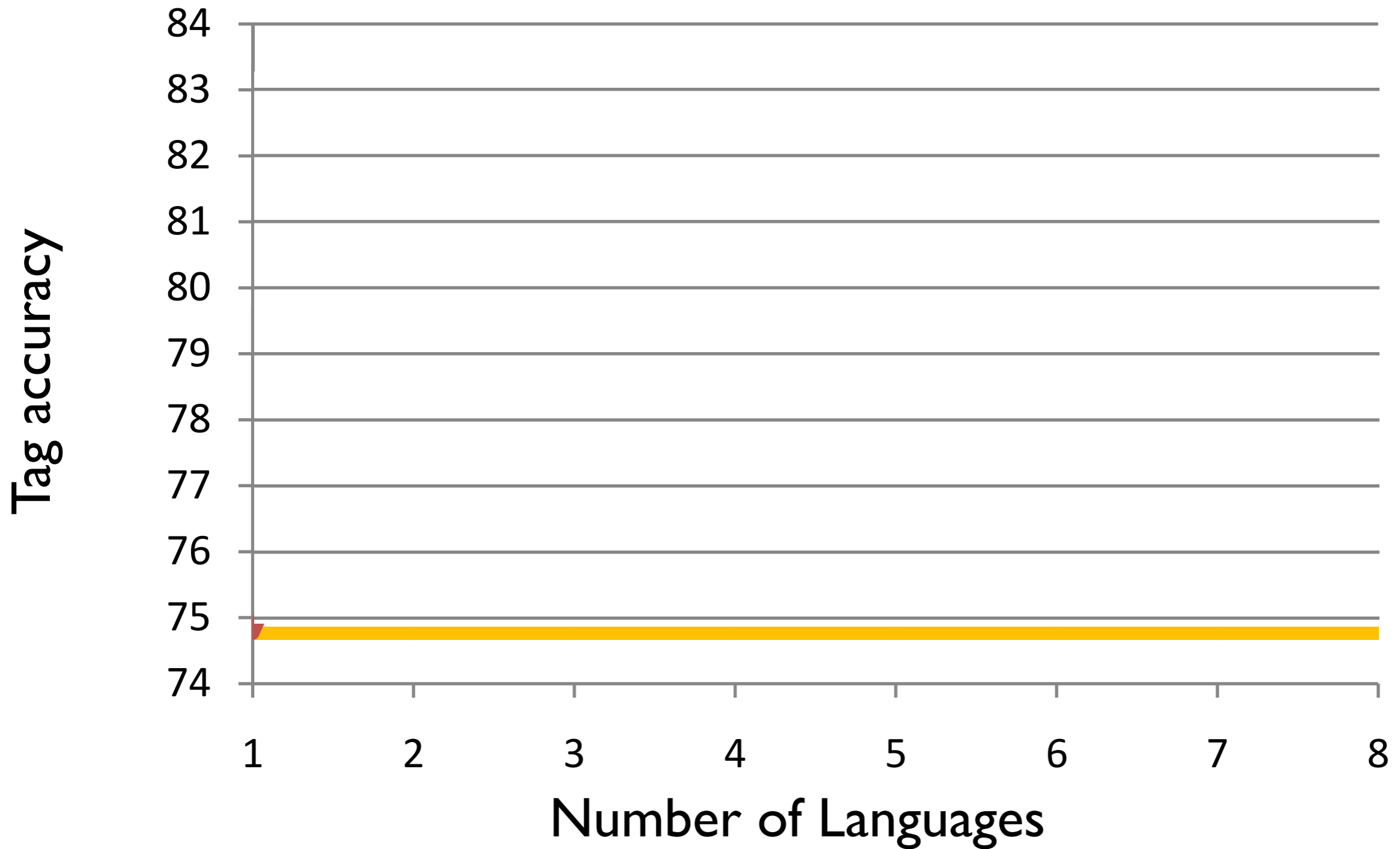
Orwell's *Nineteen Eighty Four* (~100k words)

<u>Slavic:</u>	Bulgarian, Czech, Serbian, Slovene
<u>Uralic:</u>	Hungarian, Estonian
<u>Romance:</u>	Romanian
<u>Germanic:</u>	English

Task: Part-of-speech Induction

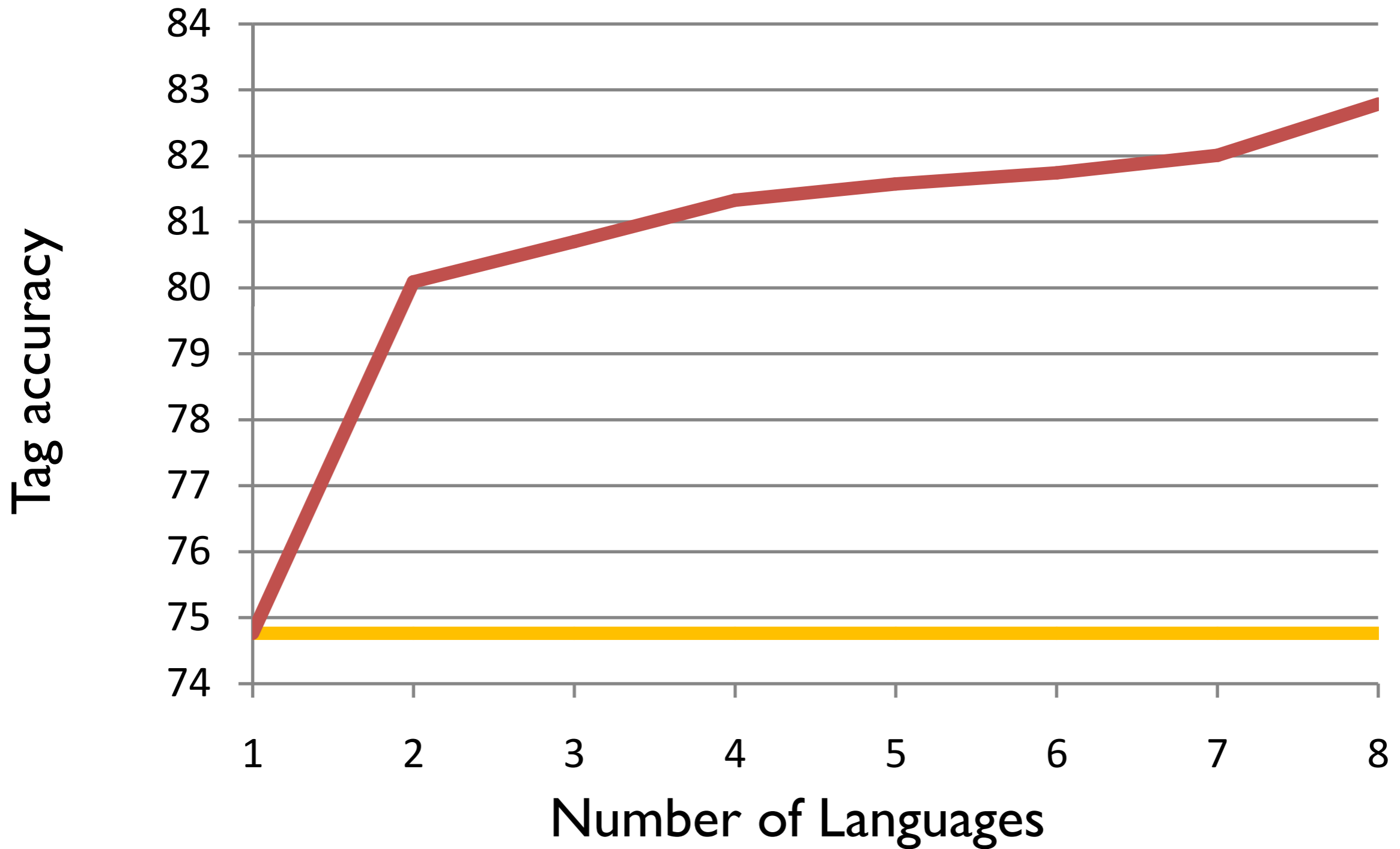
As we add Languages...

— Mono



As we add Languages...

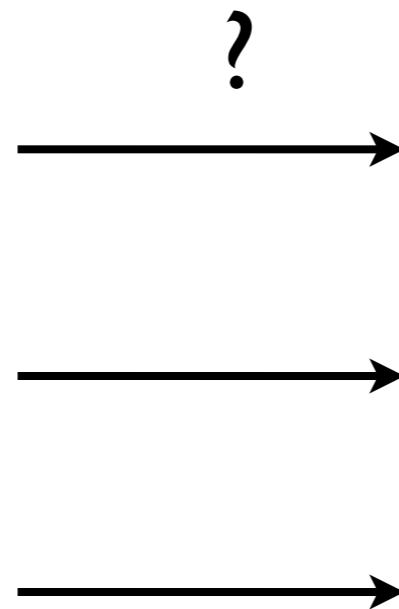
— Mono — Multi



Archeological Decipherment



lost language



known languages

Linguistic Assumptions

- Related languages have *cognates*

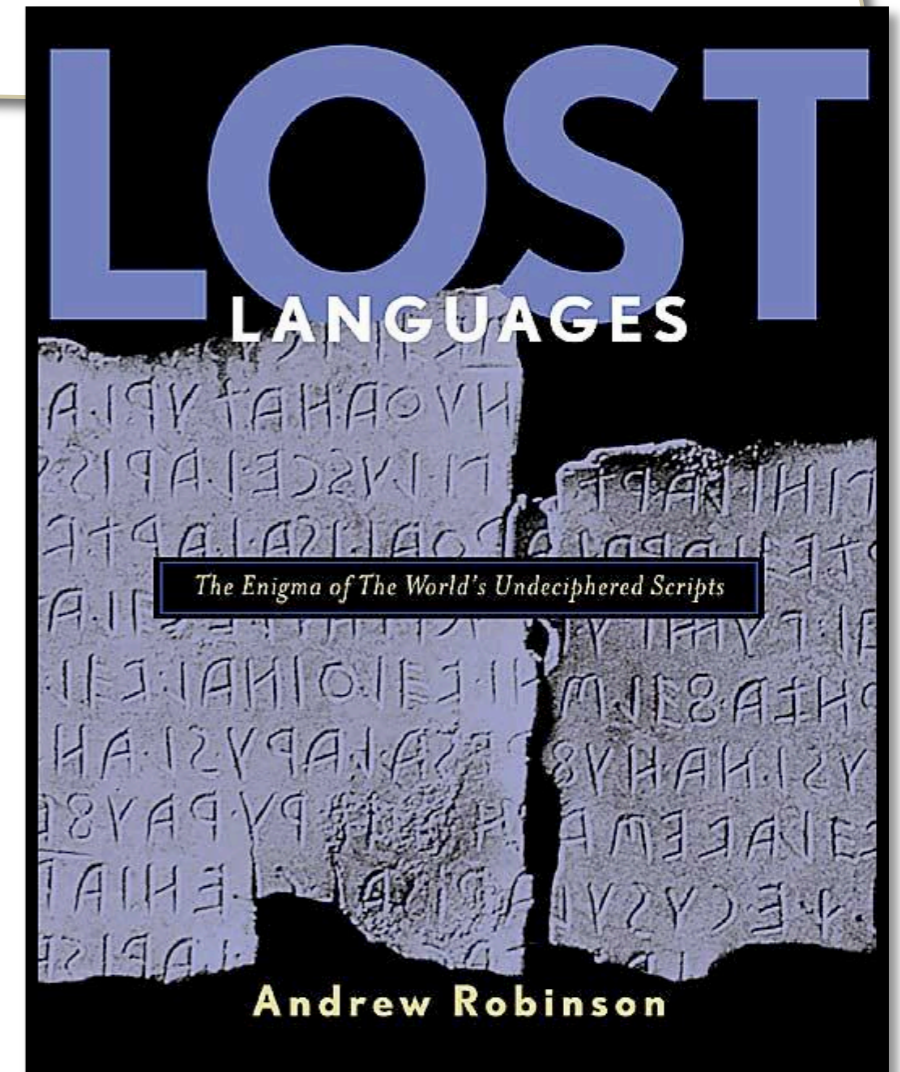
Arabic:	dheker	ذَكَرَ
Syriac:	dukrā	ܕܘܟܪܐ
Hebrew:	zakhar	זָכַר

fr: masculin
it: maschile
sp: macho

- Systematic mapping between alphabets

ذ	↔	ܐ	↔	ז
(dh)		(z)		(d)

successful archaeological decipherment has turned out to require a synthesis of logic and intuition based, as already remarked, on wide linguistic, archaeological, historical and cultural knowledge that computers do not (and presumably cannot) possess.



The Ugaritic Language



Family : Northwest Semitic

Tablets from : 14th – 12th century BCE

Discovered : 1928

Deciphered : 1932 (by WW1 code breakers)

Large portion of vocabulary covered by cognates with Semitic languages

Arabic:	malik	مَلِك
Syriac:	malkā	ܡܠܟܐ
Hebrew:	melek	מֶלֶךְ
Ugaritic:	malku	𐎎 𐎌 𐎍

Corpus: 34,105 tokens, 7,386 unique types

The Epic Of Ba'al

(English translation)

As soon as El sees Her,
He cracks a smile and laughs.
His feet He sets on the footstool,
And twiddles His fingers.
He lifts His voice
And shouts:
"Why has Lady Asherah of the Sea come?
Why came the Creatress of Gods?
Art Thou hungry?
Then have a morsel!
Or art Thou thirsty?
Then have a drink!
Eat!
Or drink!
Eat bread from the tables!
Drink wine from the goblets!
From a cup of gold, the blood of vines!
If the love of El moves Thee,
Yea the affection of The Bull arouses Thee!"

And Lady Asherah of the Sea replied:
"Thou art great, O El,
Thou art verily wise!
The gray of Thy beard hath verily instructed Thee!
Here are pectorals of gold for Thy breast.

Lo, also it is the time of His rain.
Baal sets the season,
And gives forth His voice from the clouds.
He flashes lightning to the earth.
As a house of cedars let Him complete it,
Or a house of bricks let Him erect it!
Let it be told to Aliyan Baal:
'The mountains will bring Thee much silver.
The hills, the choicest of gold;
The mines will bring Thee precious stones,
And build a house of silver and gold.
A house of lapis gems!'"

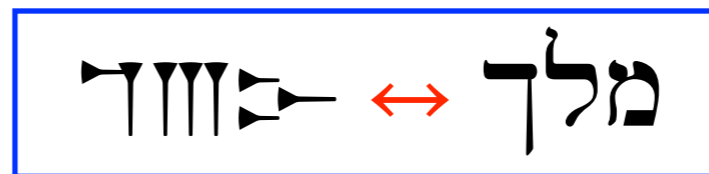
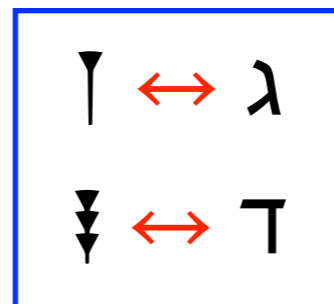
The Decipherment Task

- Given:

- ▶ Corpus of undeciphered language
- ▶ Lexicon of related language (non-parallel)

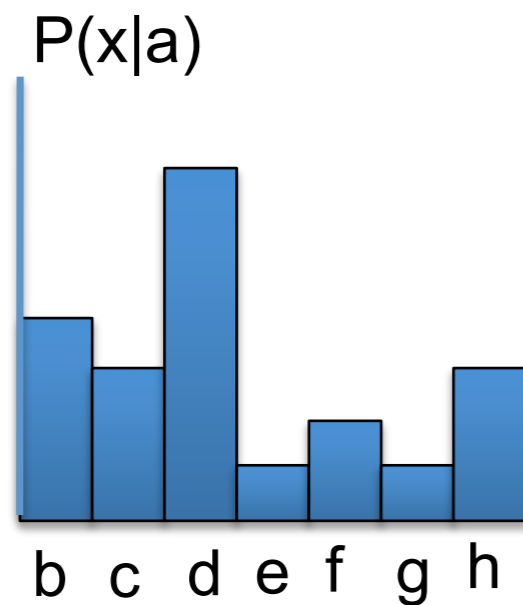
- Learn:

- ▶ Alphabetic mapping
- ▶ Word mappings



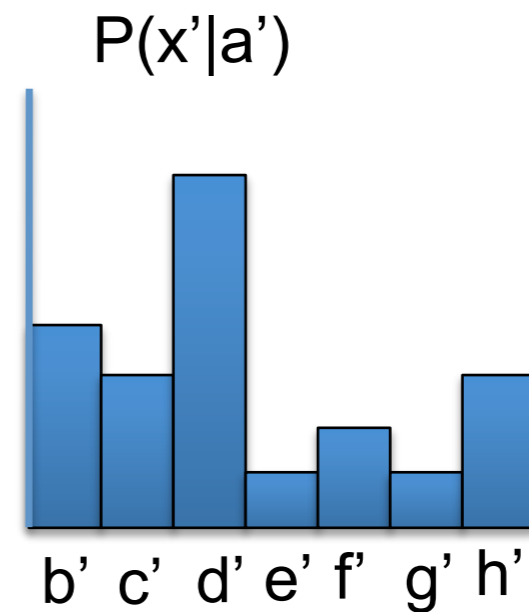
Decipherment Intuition I

- True alphabetic mapping
⇒ similar character-level distributions



Ugaritic letters

≈

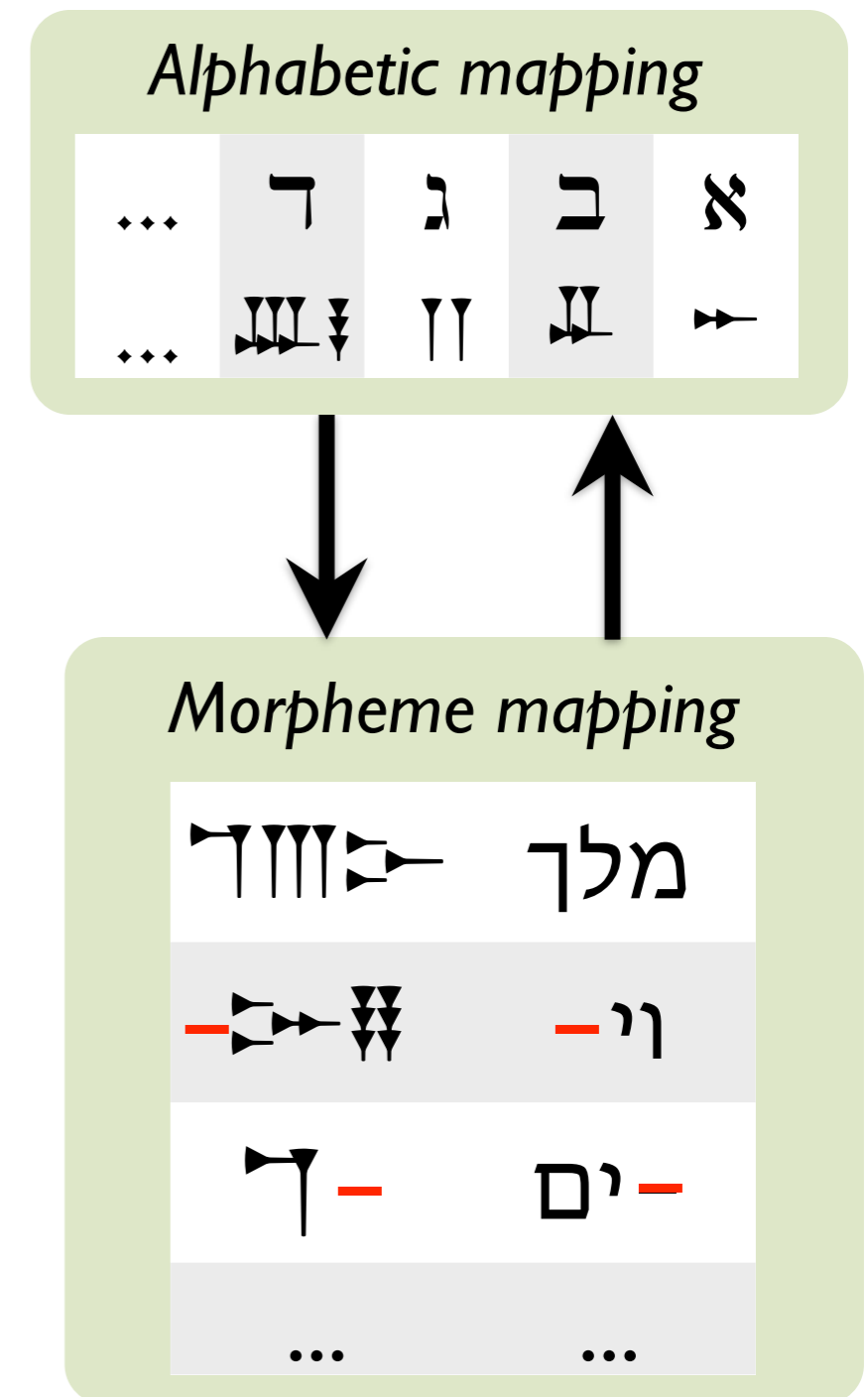


Hebrew letters

Decipherment Intuition II

Interplay between learning:

- Alphabetic mapping
- Higher level morpheme & word correspondences



Deciphering Wingdings



Deciphering Wingdings

☺ ♡ ❄️ ⚡ ☺

☺ ♡ ❄️ ⚡ ☺ d

♡ ☺ ⚡ ☺

♡ ☺ ⚡ ☺ d

d ☺ ☺ ⚡

☺ = d

Deciphering Wingdings

☺ 🍎 ❄️ ⚡ ☺

☺ 🍎 ❄️ ⚡ | ☺ d

🍎 ☺ ⚡ ☺

🍎 ☺ ⚡ | ☺ d

d ☺ ☺ ⚡

☺ = d

Deciphering Wingdings

✌️ 🍎 ❄️ ⚡️ ✌️

✌️ 🍎 ❄️ ⚡️ | e d

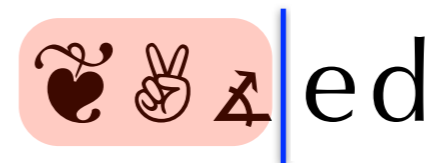
🍎 ✌️ ⚡️ ✌️

🍎 ✌️ ⚡️ | e d



d e ✌️ ⚡️

⚡️ = d
✌️ = e

Deciphering Wingdings



de  

 = d
 = e

Deciphering Wingdings

☺ ♡ ❄️ ↗️ | ☺

☺ ♡ ❄️ ↗️ | ed

♡ ☺ ↗️ | ☺

♡ ☺ ↗️ | ed

de ☺ ↗️

⋈ == d
⌘ == e

Deciphering Wingdings

s 🍷 ❄️ 🏠 | s

s 🍷 ❄️ 🏠 | ed

🍷 s 🏠 | s

🍷 s 🏠 | ed

de s 🏠

🌀 = d
🍷 = e
🏠 = s

Deciphering Wingdings

s 🍷 ❄️ k | s

s 🍷 ❄️ k | e d

🍷 s k | s

🍷 s k | e d

d e s k

🌀 = d
⌘ = e
✌️ = s
🔼 = k

Deciphering Wingdings

s a ❄ k | s

a s k | s

de s k

s a ❄ k | e d

a s k | e d

⚡ = d 🍷 = a
⌘ = e
✌ = s
↗ = k

Deciphering Wingdings

s a c k | s

a s k | s

de s k

s a c k | e d

a s k | e d

⌘ = d

⌘ = e

⌘ = s

⌘ = k

⌘ = a

⌘ = c

Deciphering Wingdings

s a c k | s

a s k | s

d e s k

s a c k | e d

a s k | e d

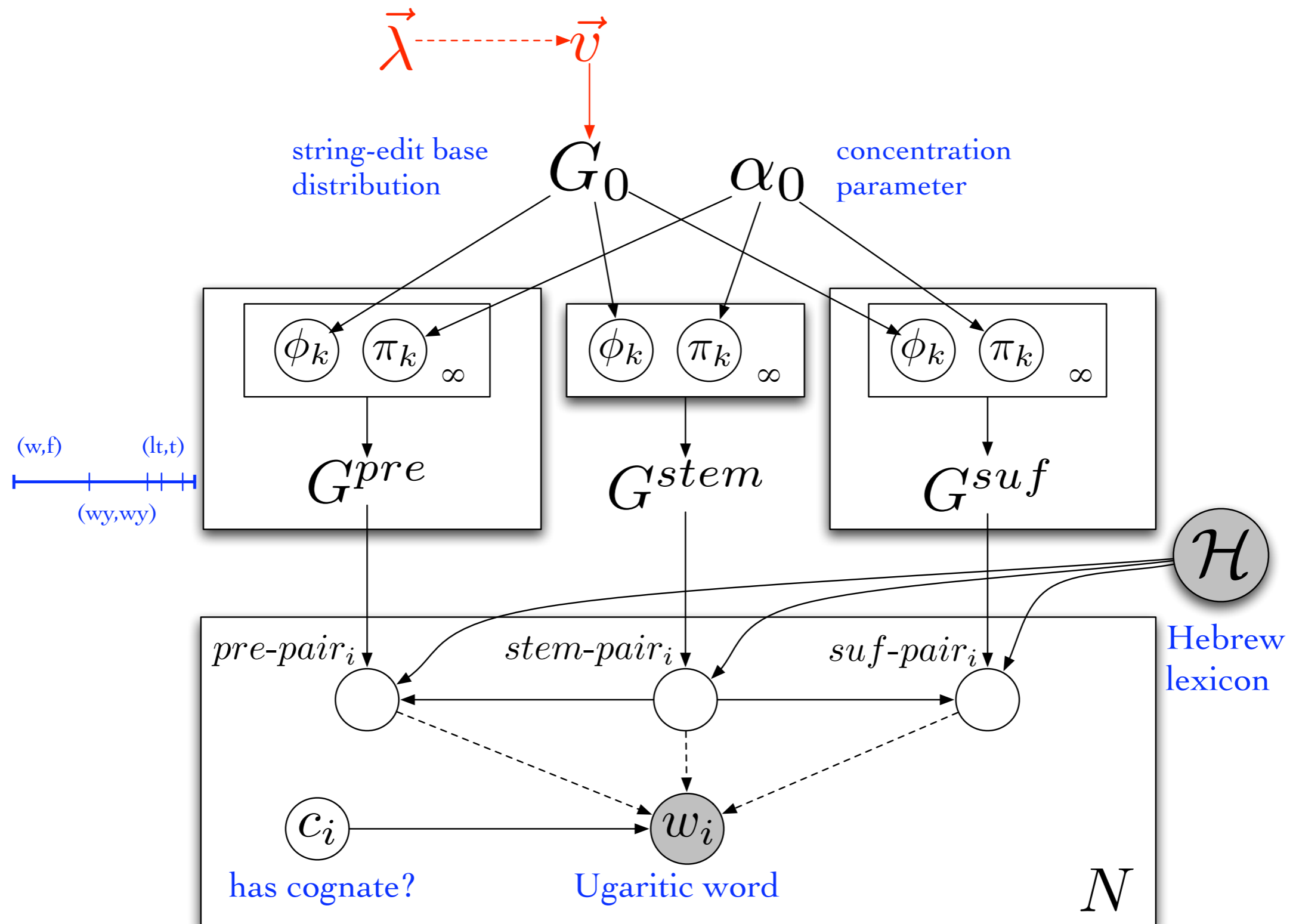
- Used knowledge of English lexicon & morphology (*ask, -ed*)

- Discovery of morpheme correspondences



- Discovery of character correspondences

A Probabilistic Decipherment Model



Results

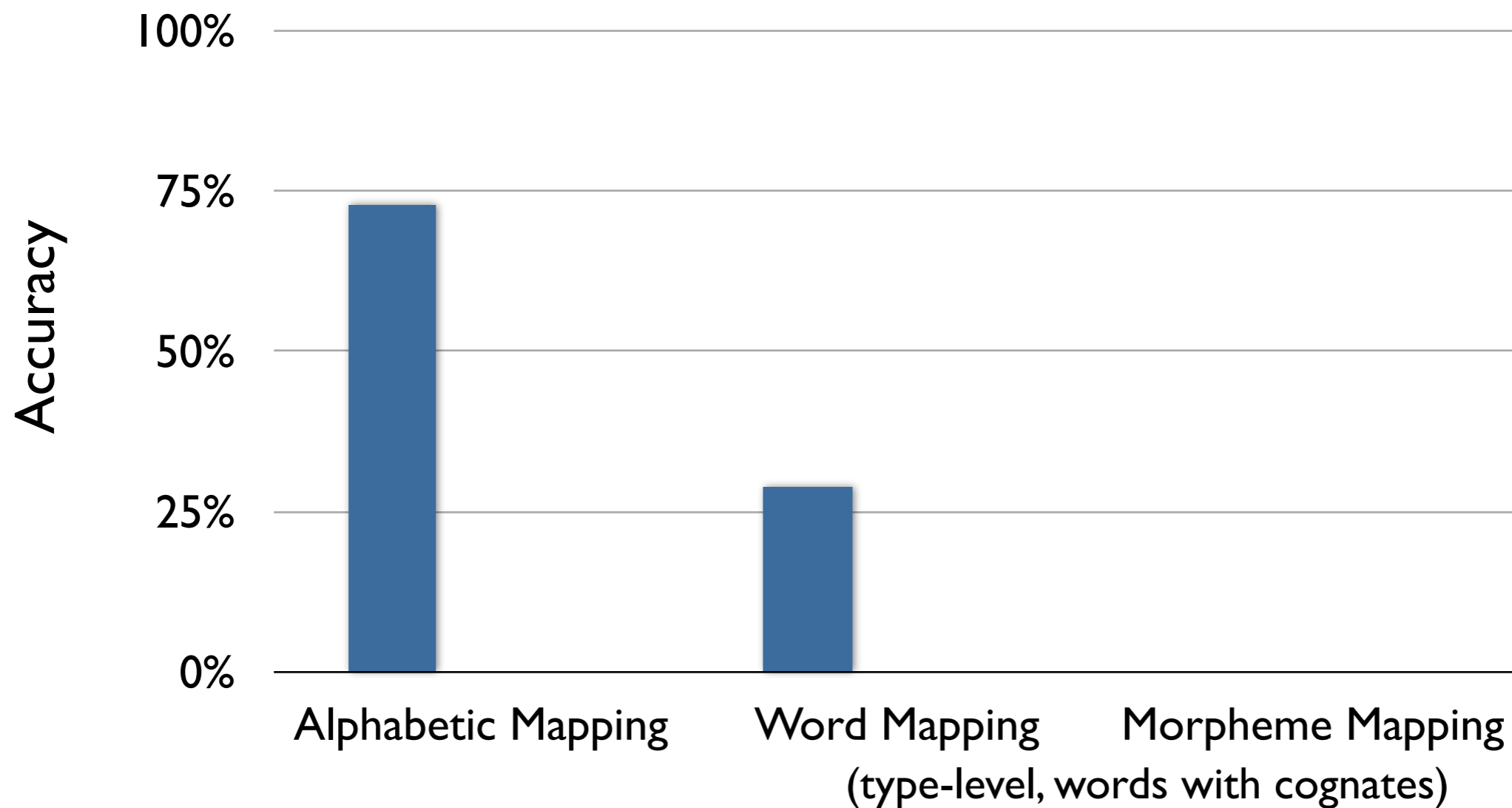
- HMM Baseline
- Model: no structural sparsity
- Complete Model

Accuracy

(type-level, words with cognates)

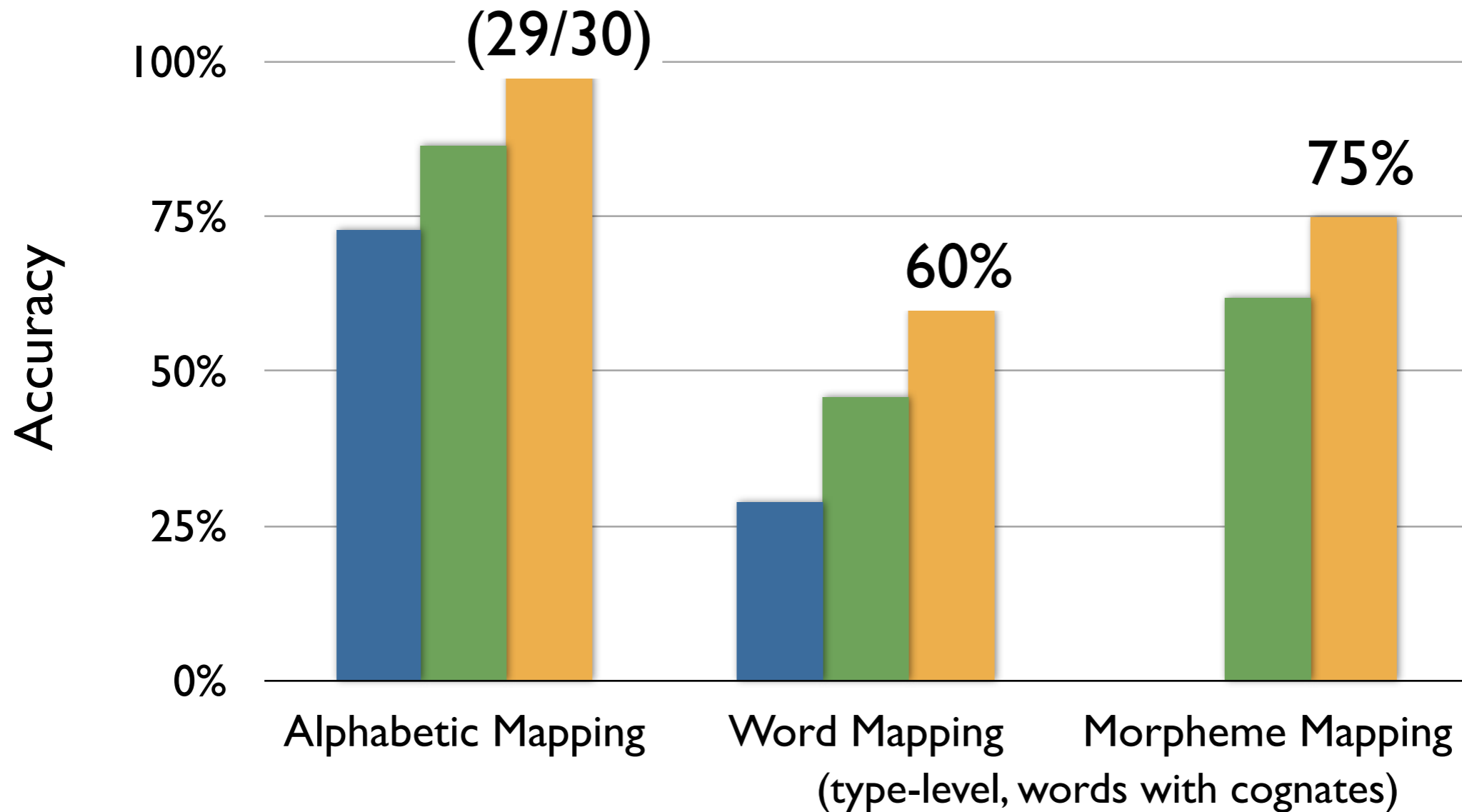
Results

- HMM Baseline
- Model: no structural sparsity
- Complete Model



Results

- HMM Baseline
- Model: no structural sparsity
- Complete Model



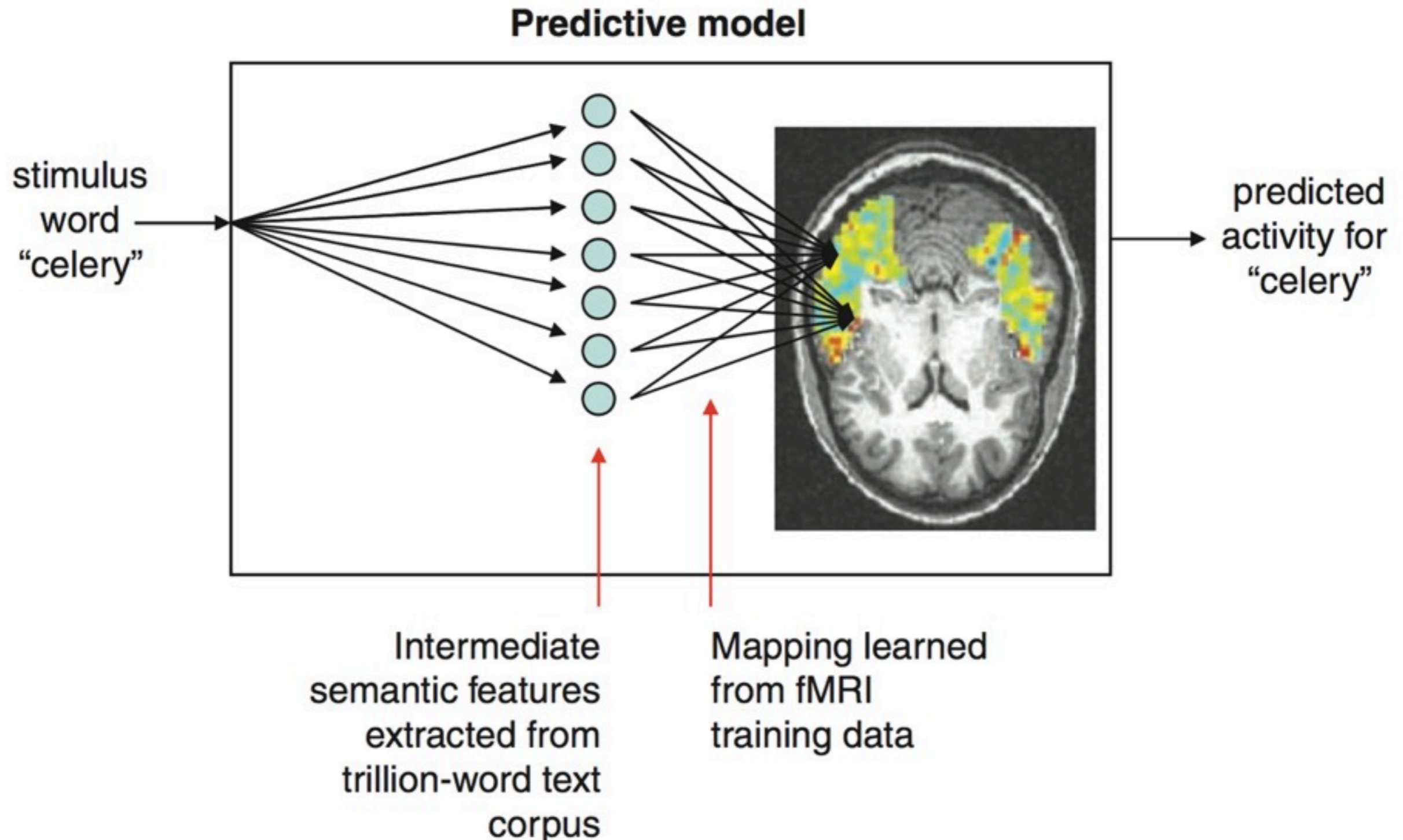
Play Jeopardy

(IBM)

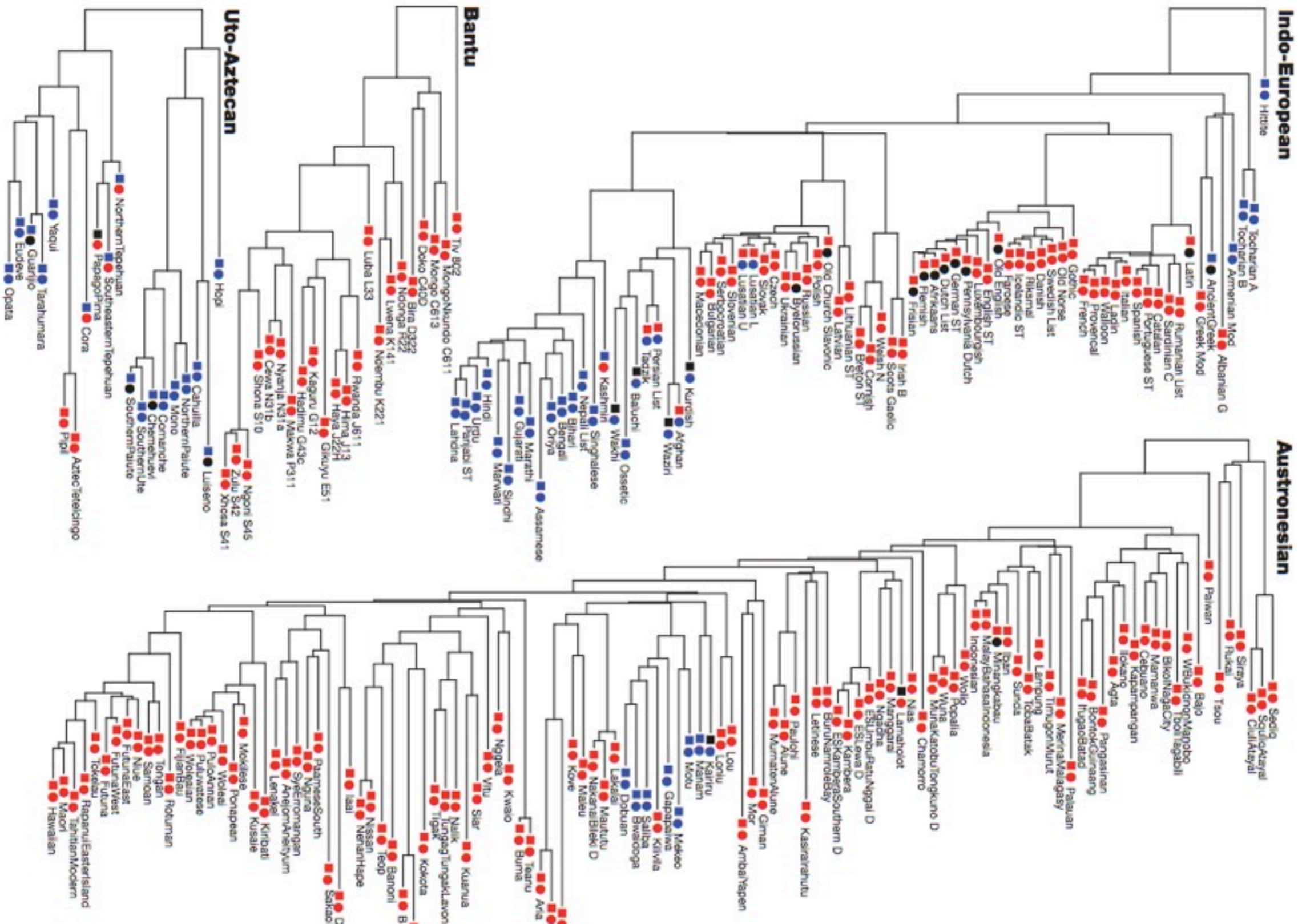


Read your Mind

(T. Mitchell)



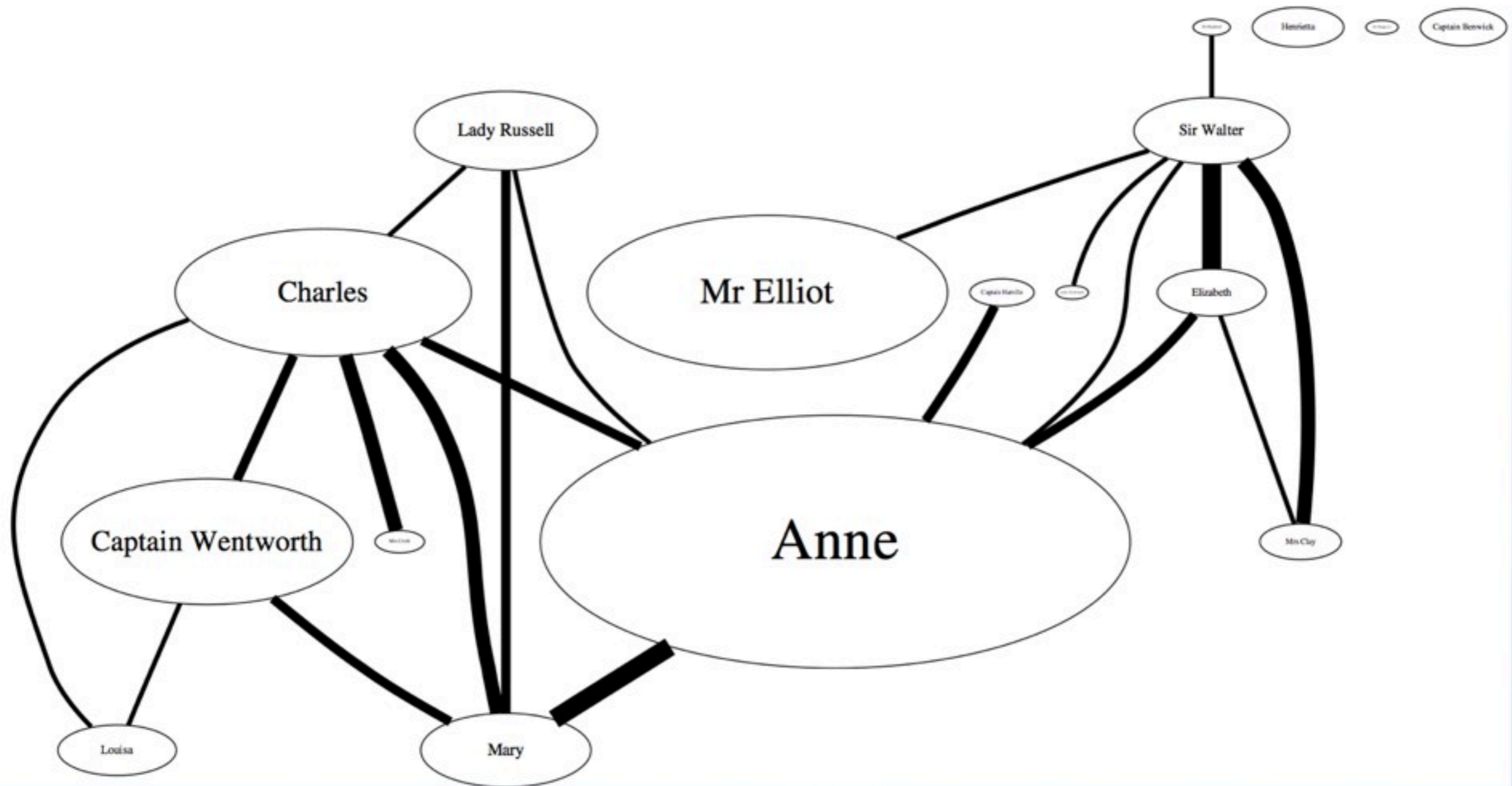
Trace Language History



Locate Origin of Human Language

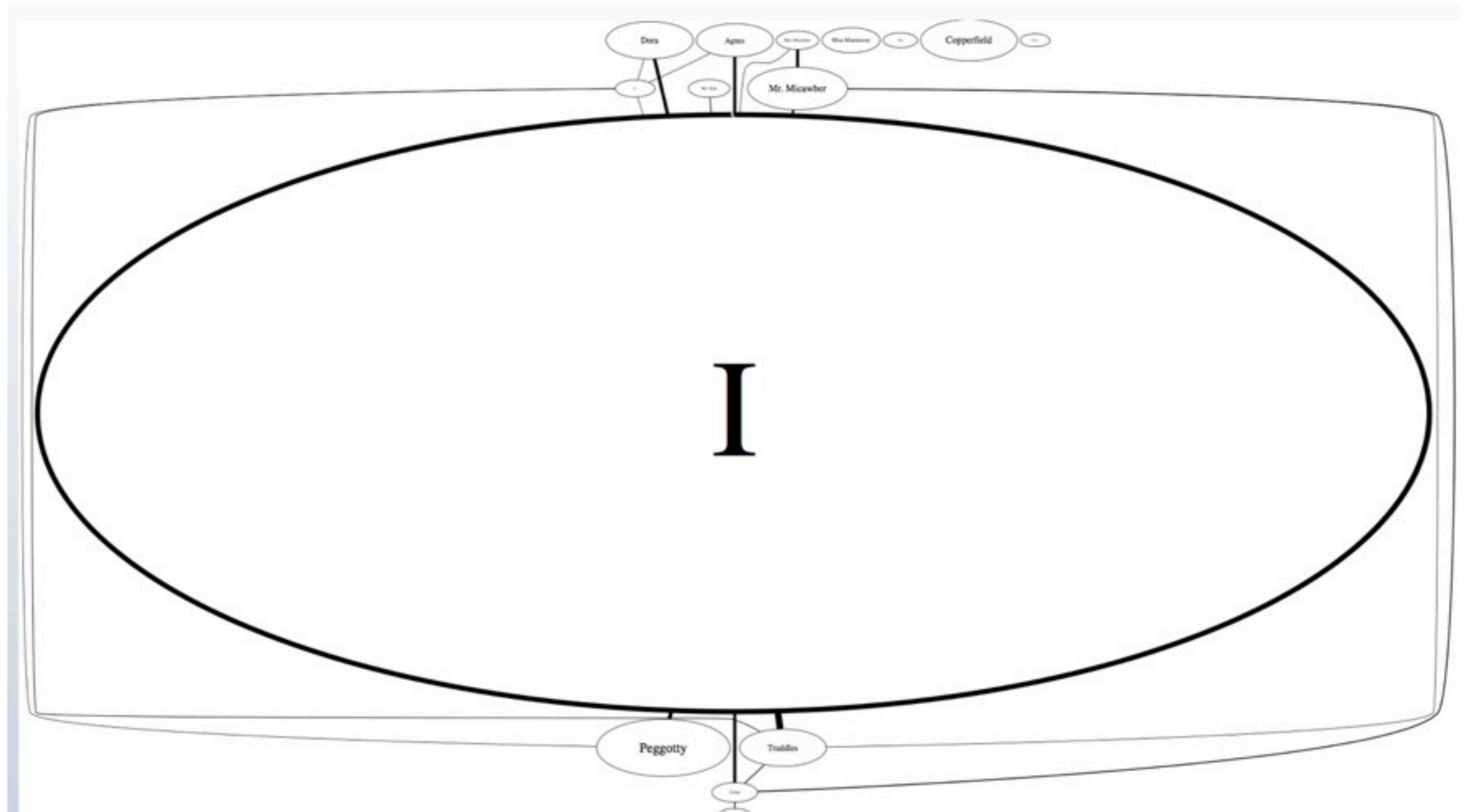


Analyze Fiction



Persuasion by Jane Austen

Analyze Fiction



David Copperfield by Charles Dickens

Decipher Messages from Serial Killers

Zodiac 408 (solved, 1969, by couple at breakfast)

Δ □ P / Z / U B □ X O R X 9 X X B
W V + ε G Y F O Δ H P □ K ε ρ Y ε
M J Y Λ U I X Δ ρ T ⊥ N G Y D ● ⊕
S φ / Δ □ B P O R A U □ F R J ρ E
X Λ L M Z J O R \ 9 F H V W ε Δ Y
□ + ρ G D Δ K I ⊕ ⊕ ρ X Δ ● ⊕ S φ
R N ⊥ I Y E J O Δ ρ G B T G S □ B
L O / P □ B □ X ρ E H M U Λ R R X

Ϸ Z K ρ 9 I ⊕ W ρ I Δ ● L M R Δ □
B P D R + τ κ ⊕ \ N φ ε E U H X F
Z Ϸ 9 O V W I ● + ⊥ L ⊕ L Λ R O H
I Δ D R □ T Y R \ O ε / □ X J G A
P ● M Δ R U ⊥ □ L ⊕ N V E K H X G
R I I J K ● Δ Δ L M J N A ⊕ Z φ P
⊕ U ρ K A Δ □ B V W \ + V T ⊥ O P
Λ π S ρ R J F U ε ⊕ Δ D ⊕ G □ □ I M

N K ⊕ S Ϸ E / Δ □ □ Z F A P □ B V
9 ε X ρ W ρ □ F □ Δ Ϸ + □ Δ A Δ B
□ O T ⊕ R U Ϸ + □ D Y ρ □ Λ S ρ W
V Z ε G Y K E □ T Y A Δ □ □ L ⊥ □
H I F B X Δ ⊕ X A D Ϸ \ Δ L I π ρ
□ E F □ □ ⊕ ⊕ ⊕ P O R X ρ F □ G Ϸ
Z □ J T ⊥ ρ □ Δ J I + R B P Q W O
V E X R Δ W I ⊕ ρ E H M ⊕ X U I X



Zodiac 340 (still unsolved)

H E R > 9 J Λ V P X I ⊕ L T G ● O
N 9 + B φ □ O □ D W Y · < □ K ε ⊕
B X ε Ϸ M + u z G W φ ⊕ L □ ⊕ H J
S 9 9 Δ Λ J Δ □ V ρ 9 O + + R K ●
□ Δ M + ⊕ ⊥ τ O I ● F P + P ● X /
9 Δ R Λ F J O - □ O C □ F > ● D φ
□ ● + K ρ □ ε ⊕ u Ϸ X G V · ⊕ L I
φ G ● J ρ τ □ O + □ N Y ⊕ + □ L Δ
O < M + 8 + Z R ρ F B Ϸ X A O ● K
- ⊕ J U V + Λ J + O 9 Δ < F B Y -
U + R / ● ⊥ E I D Y B 9 8 T M K O
● < Ϸ J R J I □ ● T ● M · + P B F
⊕ ⊕ Δ S X □ + N I ● F B Ϸ φ I Δ R
J G F N Λ F ● ● B · Ϸ V ● ⊥ + +
Y B X ● □ I ● Δ C E > V U Z ● - +
I Ϸ · ⊕ ⊕ B K φ O 9 Λ · 7 M ρ G ●
R Ϸ T + L ● O C < + F J W B I ⊕ L
+ + ⊕ W C ⊕ W Ϸ P O S H T / φ ⊕ 9
I F X Ϸ W < Δ ⊥ B ρ Y O B □ - Ϸ Ϸ
> M D H N 9 X S ⊕ Z O Δ A I K I +

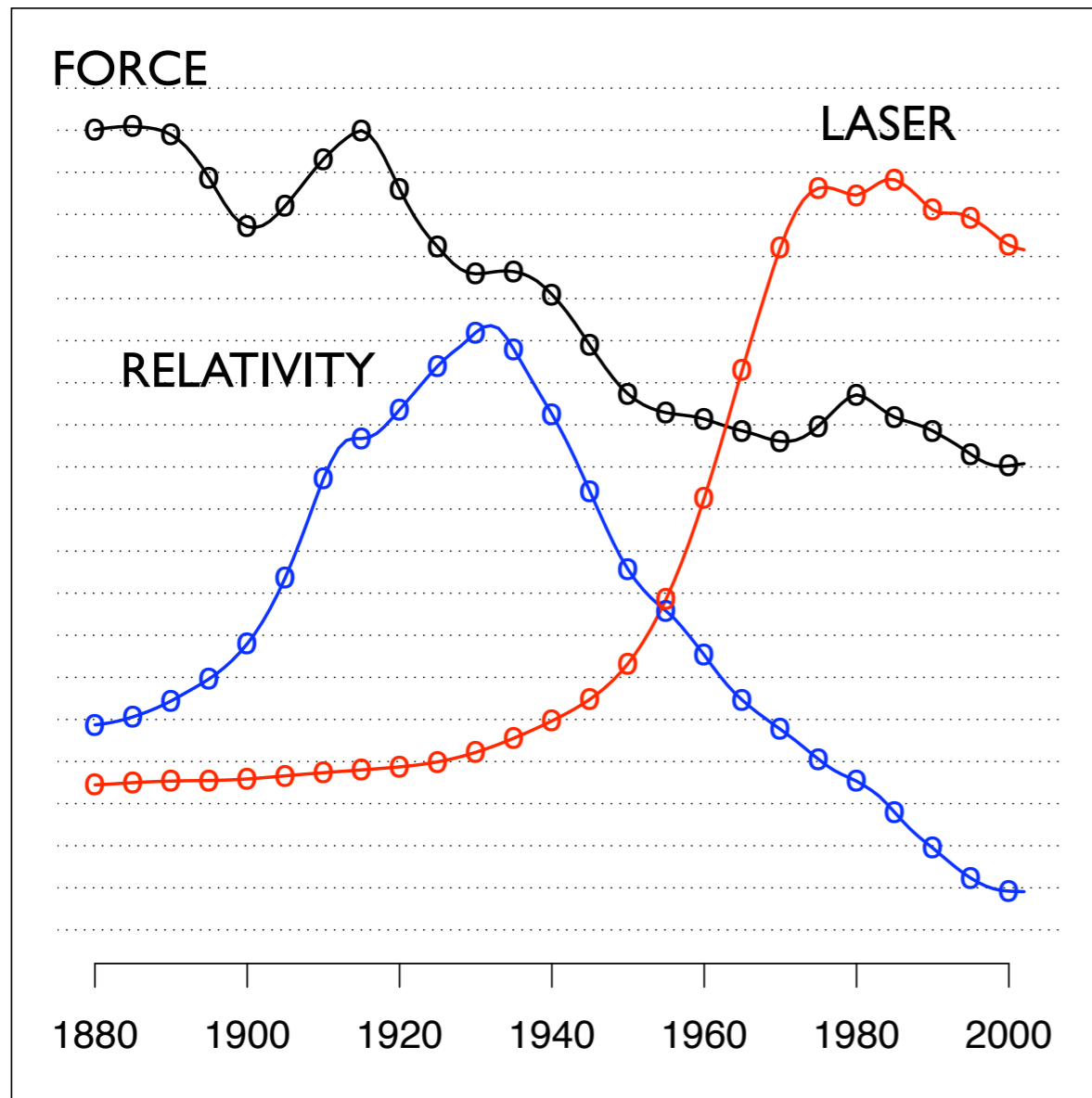
⊕

COOP-5 PPO
1596-78
2-14-78 GWA
7-3-78

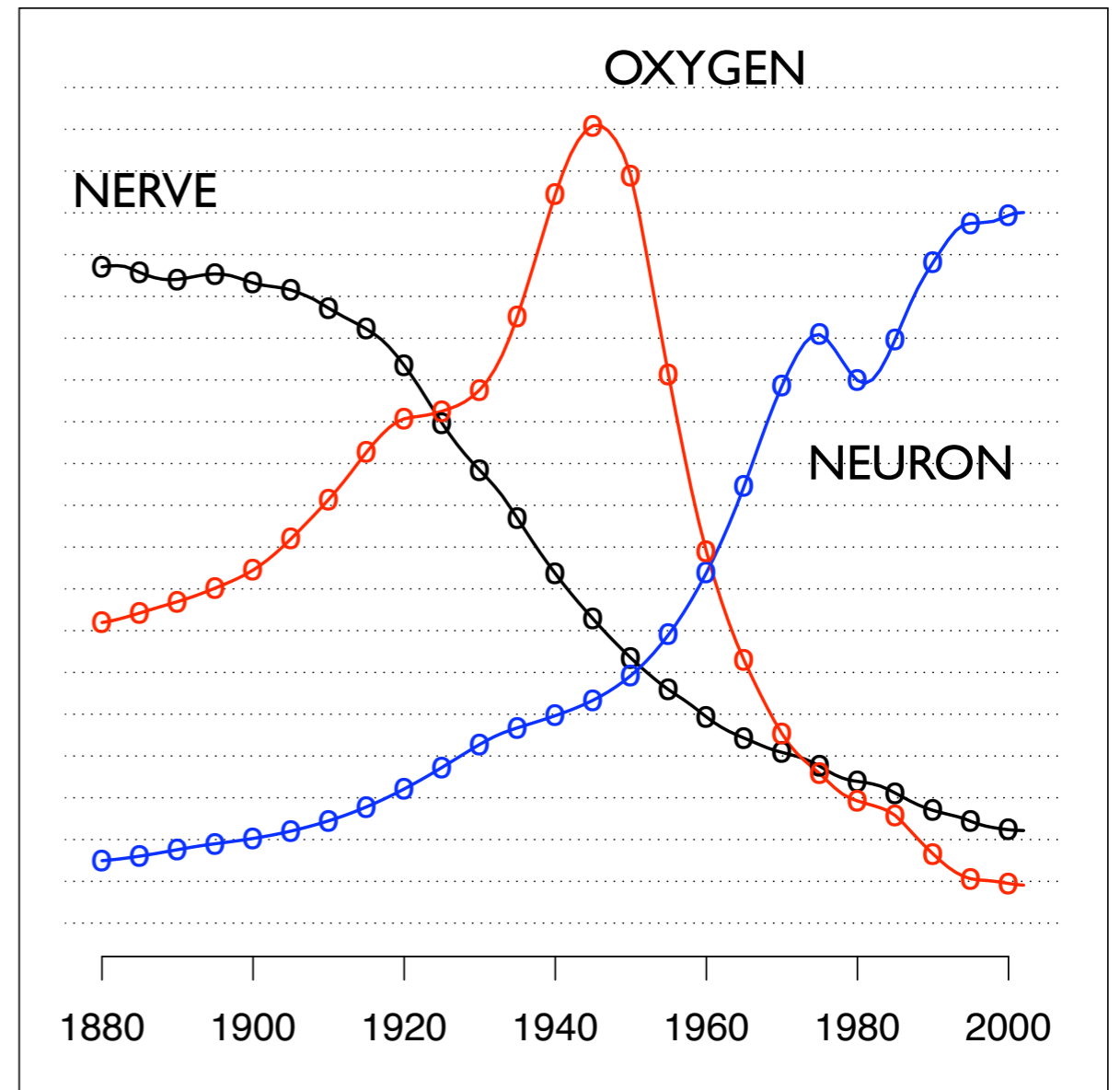
#2 8967

Model the evolution of topics over time

"Theoretical Physics"



"Neuroscience"



Translate (?)

We do not see ourselves as others see us.

let's go!

他の人が私たちを見るように私たちは自分が表示されません。

into Japanese

We see us as others do not see myself.

back into English

他の人は自分が表示されないように我々は我々を参照してください。

back into Japanese

Others do not see us as one, please refer to us.

back into English

.....

我々は、すべての人々が幸せではないです。

back into Japanese

We are not all happy people.

back into English

Want to Learn More?

- CS 545 (“Natural Language and the Computer”)
 - Prereq: CS 367 or programming experience
 - Spring 2012
- If you have any questions: bsnyder@cs.wisc.edu