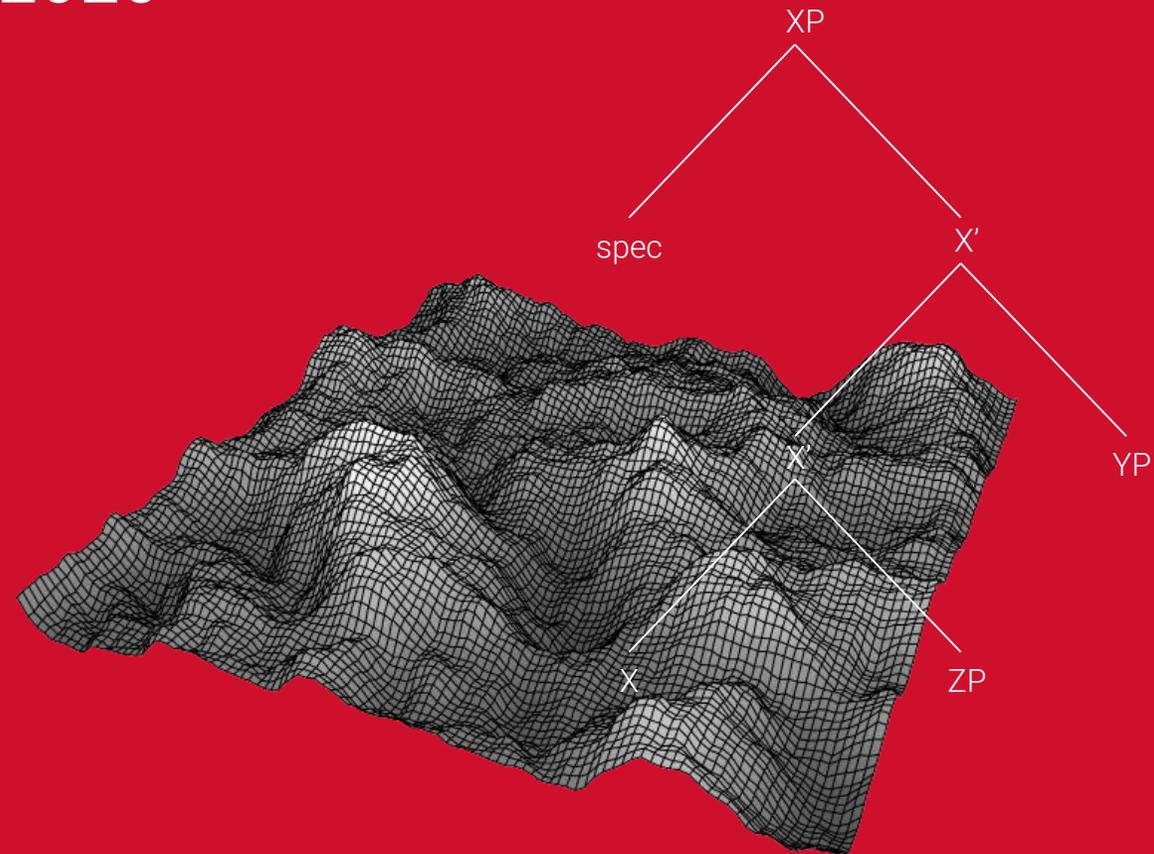


NEURAL STRUCTURE OF LANGUAGE

Spring 2020





**EVIDENCE
FOR
HIERARCHICAL
STRUCTURE**

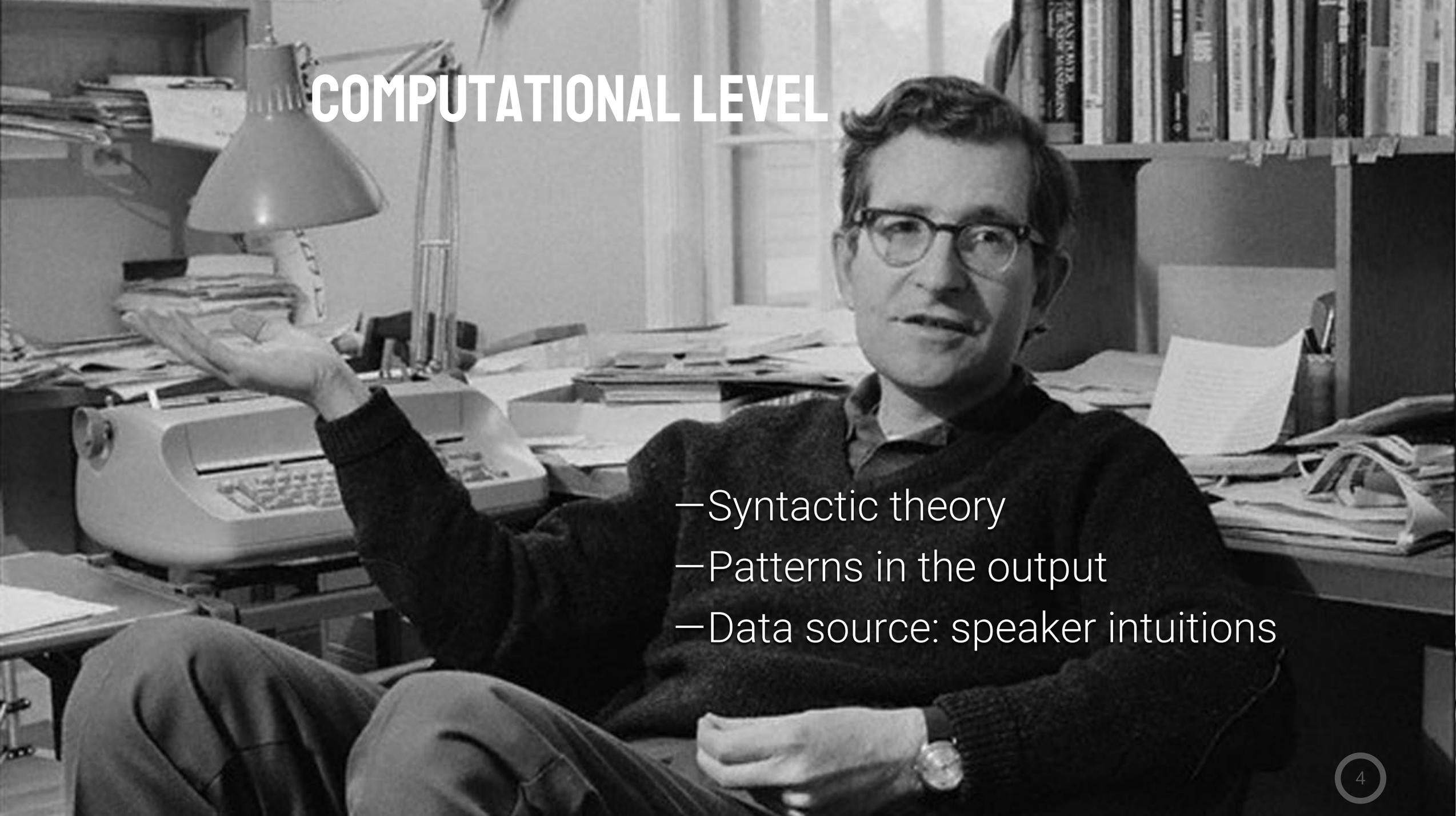
Computational level evidence

- Structural ambiguity
- Negative polarity items

Algorithmic/Implementational level evidence

- Neural oscillations
- Neuronal activity in Broca's area modeled by nodes-closing
- Activation in Broca's area for natural (but not unnatural) lang.

COMPUTATIONAL LEVEL



- Syntactic theory
- Patterns in the output
- Data source: speaker intuitions

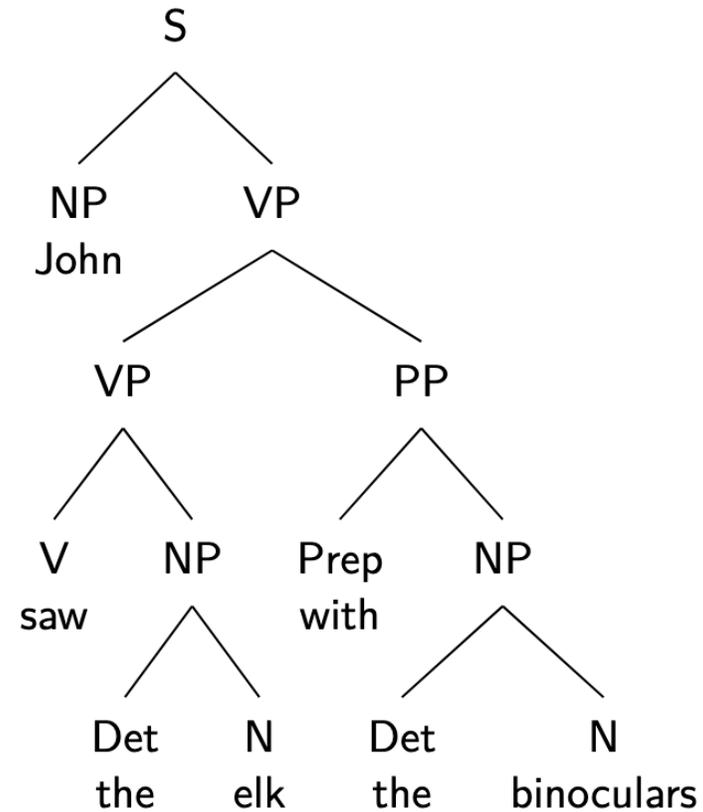
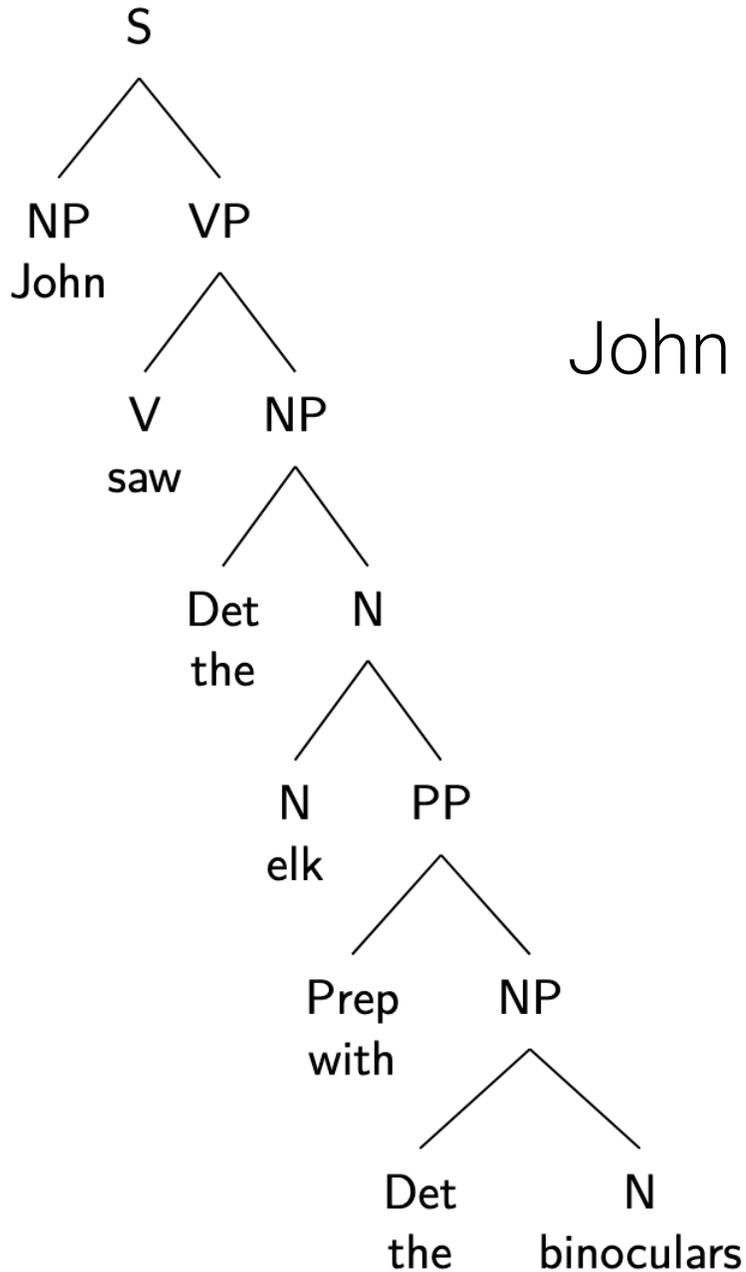
AMBIGUITY

John saw the elk with the binoculars.

Who has the binoculars?

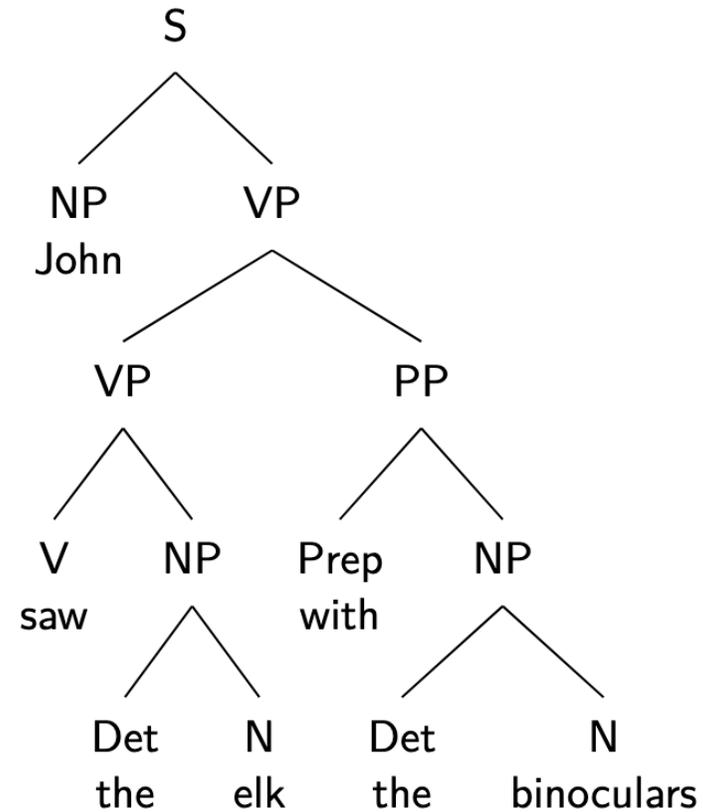
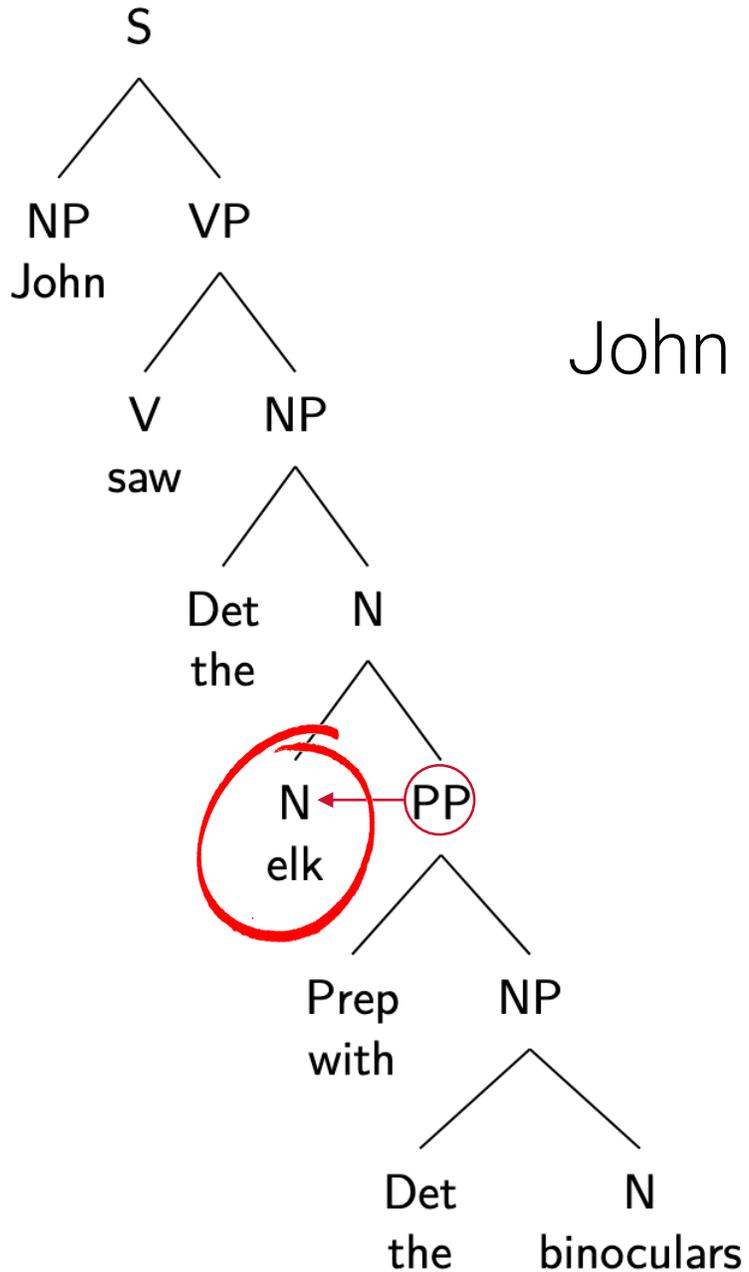
AMBIGUITY

John saw the elk with the binoculars.



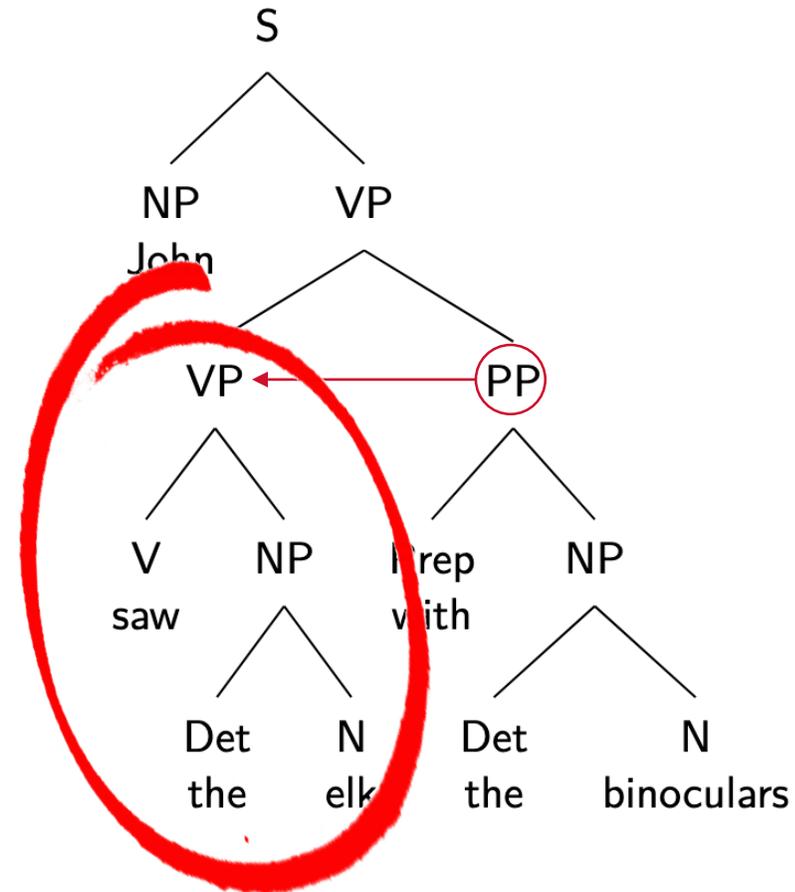
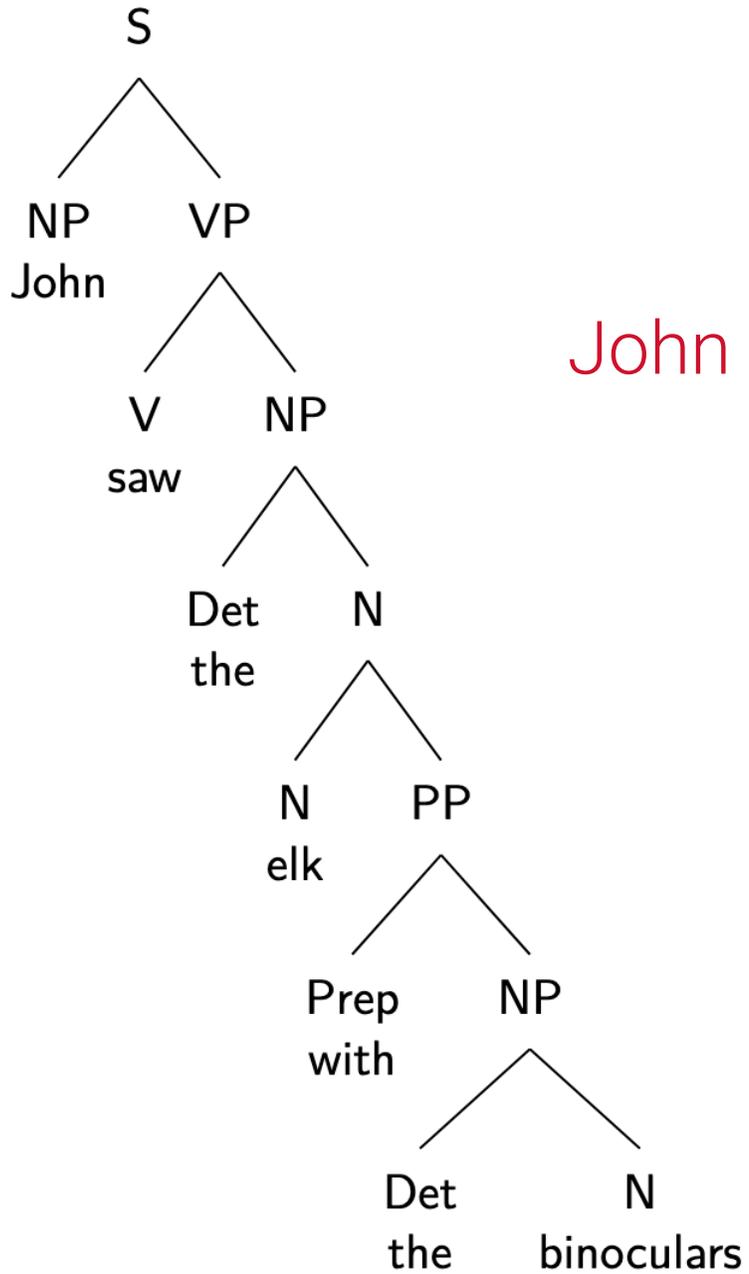
AMBIGUITY

John saw **the elk** with the binoculars.



AMBIGUITY

John saw the elk with the binoculars.



Computational level evidence

- ~~Structural ambiguity~~
- Negative polarity items

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- Neural oscillations
- Neuronal activity in Broca's area modeled by nodes-closing
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NEGATIVE POLARITY ITEMS



The book I bought appealed to anybody.

NEGATIVE POLARITY ITEMS



The book I bought did **not** appeal to **anybody**.

NEGATIVE POLARITY ITEMS



The book I bought did **not** appeal to **anybody**.

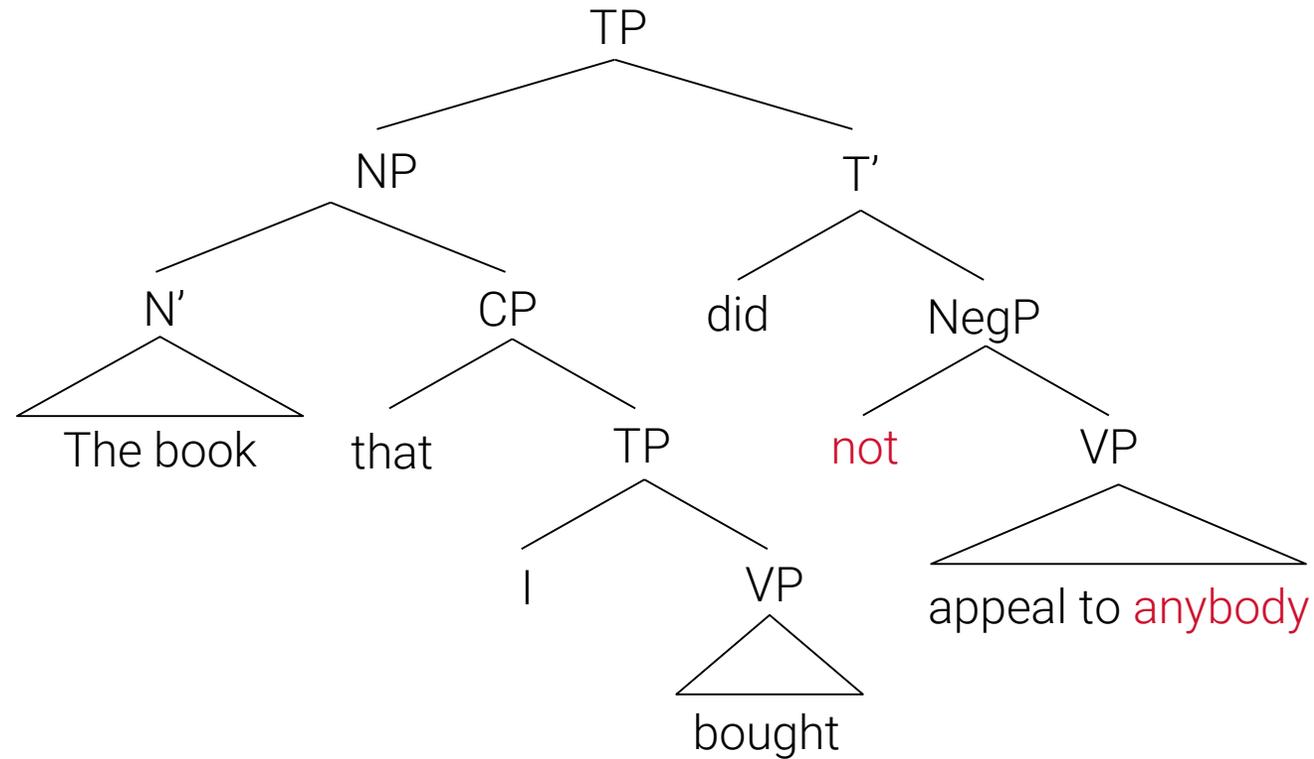
Rule: negation must *precede* the negative polarity item.

NEGATIVE POLARITY ITEMS

 The book I did **not** buy appealed to **anybody**.

~~Rule: negation must precede the negative polarity item.~~

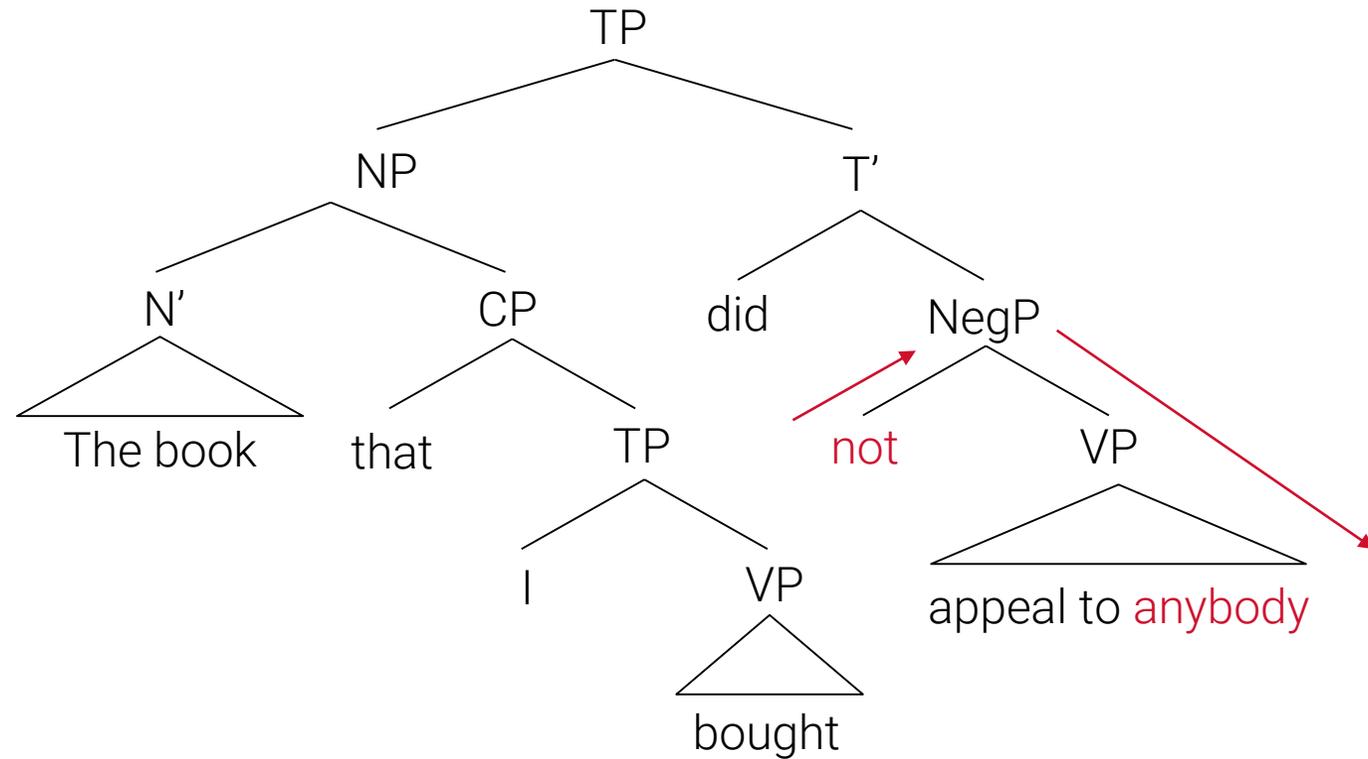
The book I bought did **not** appeal to **anybody**.



C-COMMAND

Up 1 level, then down

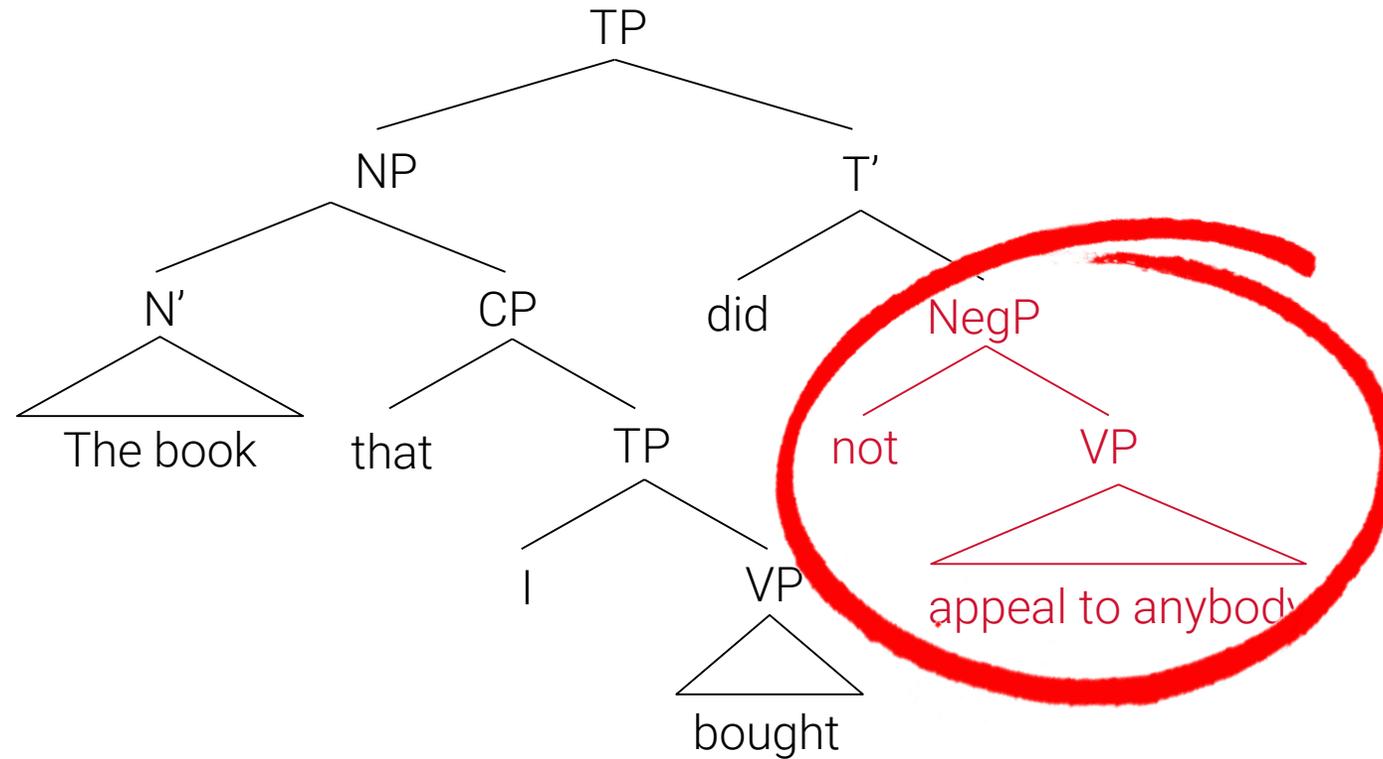
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C-COMMAND

Up 1 level, then down

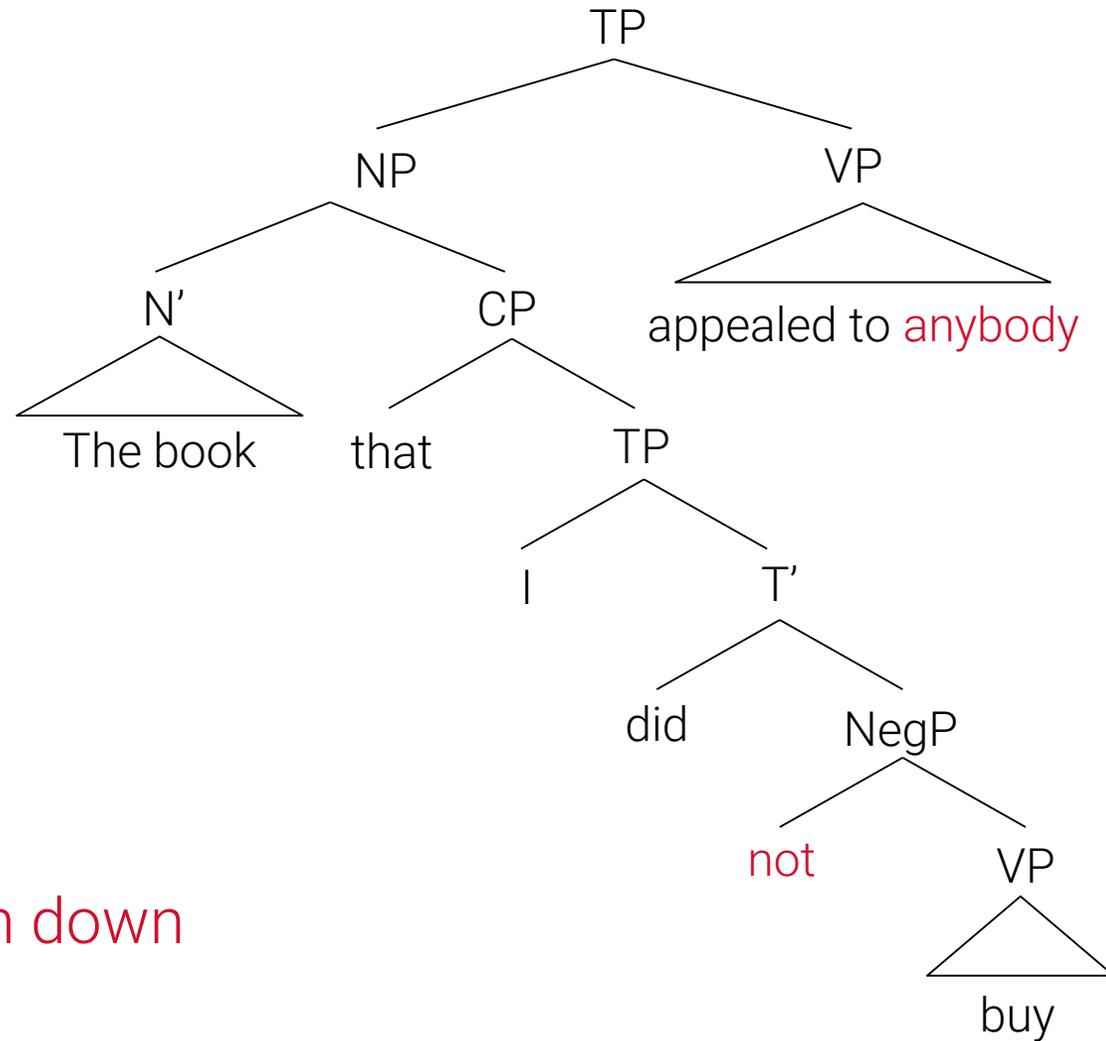
The book I bought did **not** appeal to **anybody**.



C-COMMAND

Up 1 level, then down

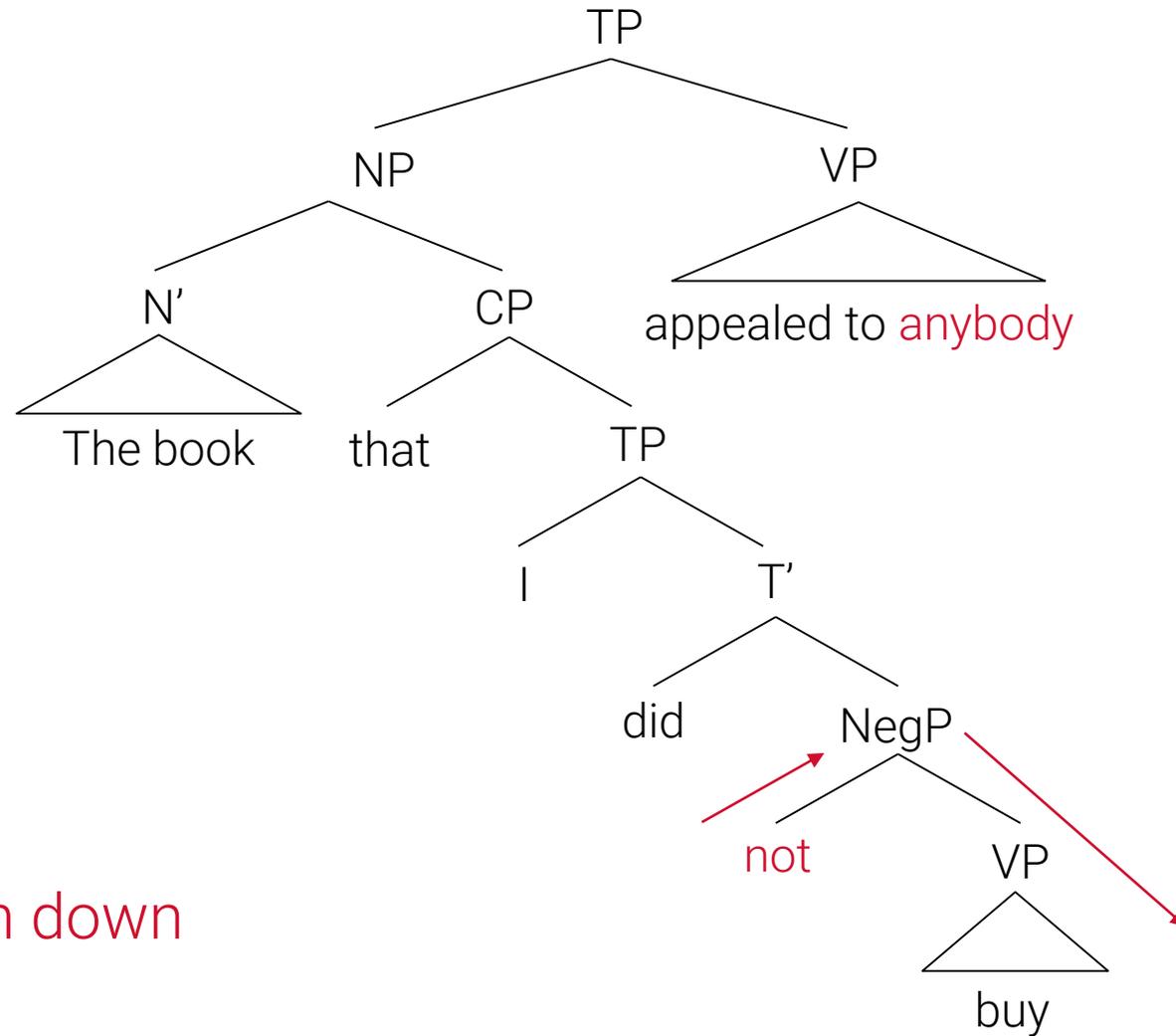
The book I did **not** buy appealed to **anybody**.



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Up 1 level, then down

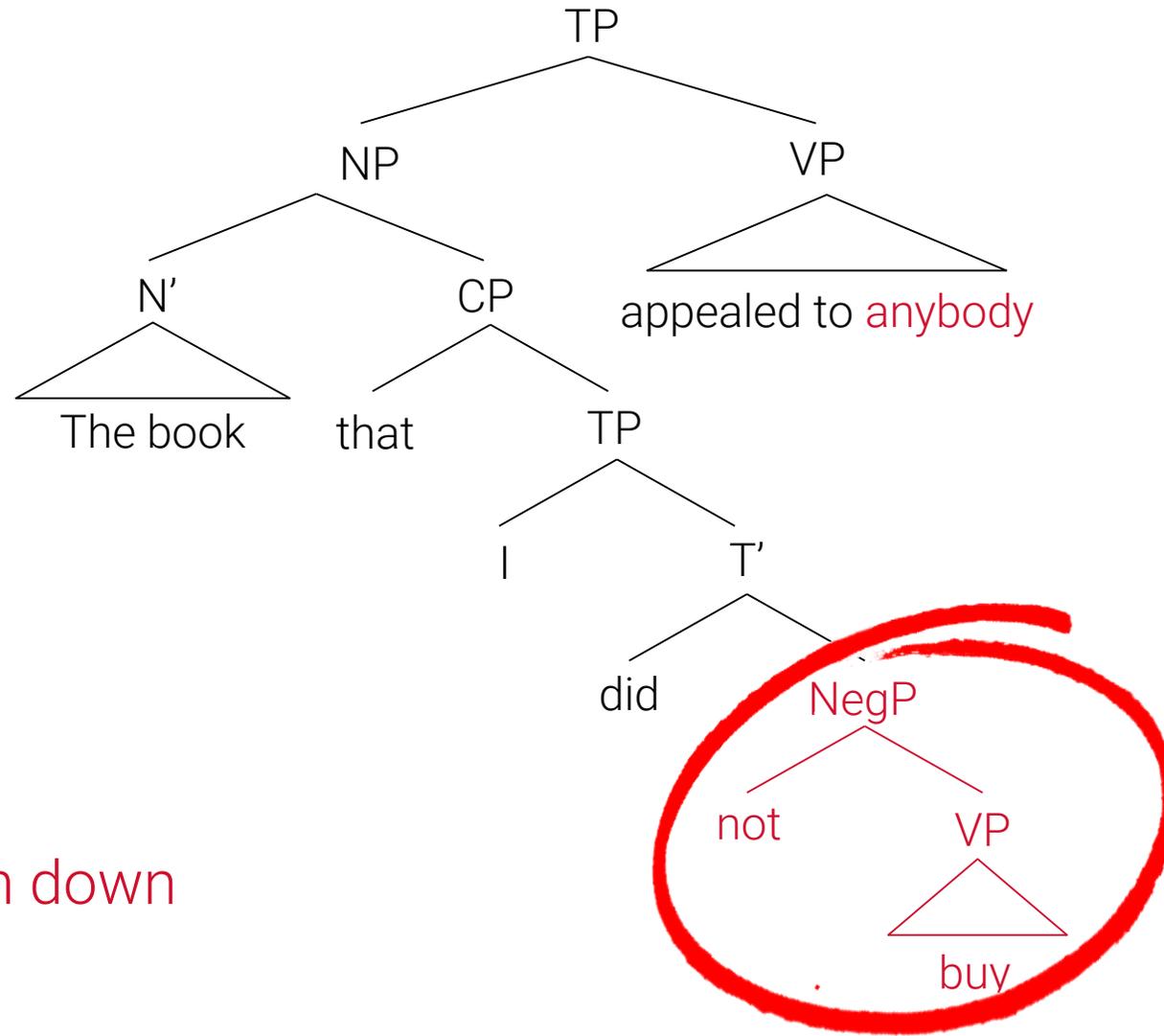
The book I did **not** buy appealed to **anybody**.



C-COMMAND

Up 1 level, then down

The book I did **not** buy appealed to **anybody**.



C-COMMAND

Up 1 level, then down

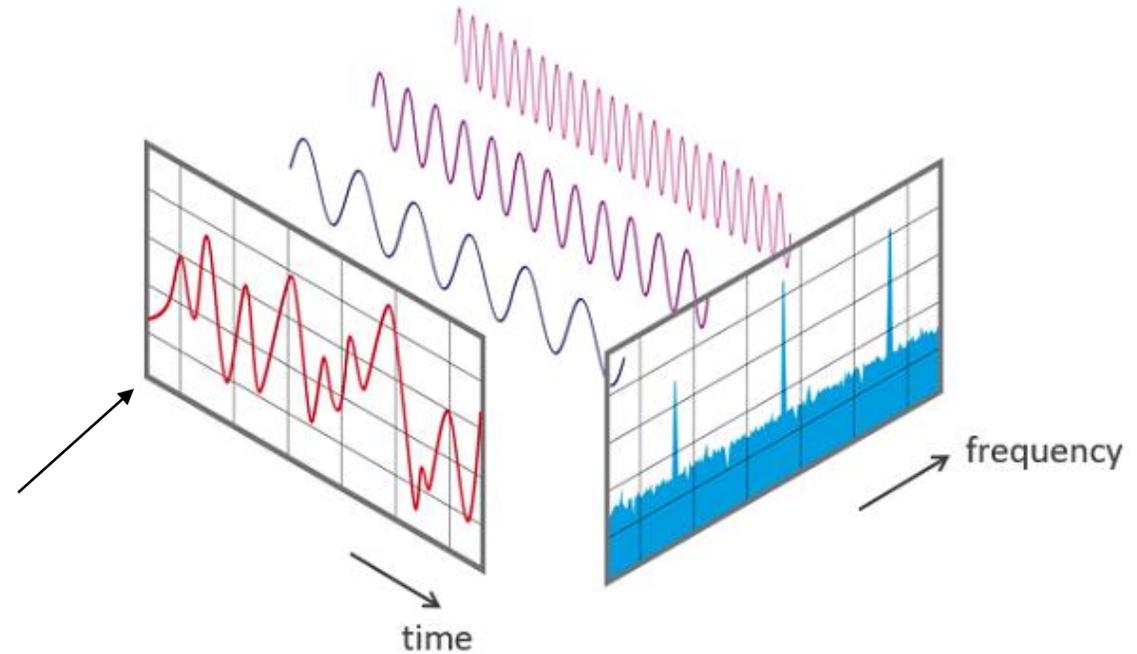
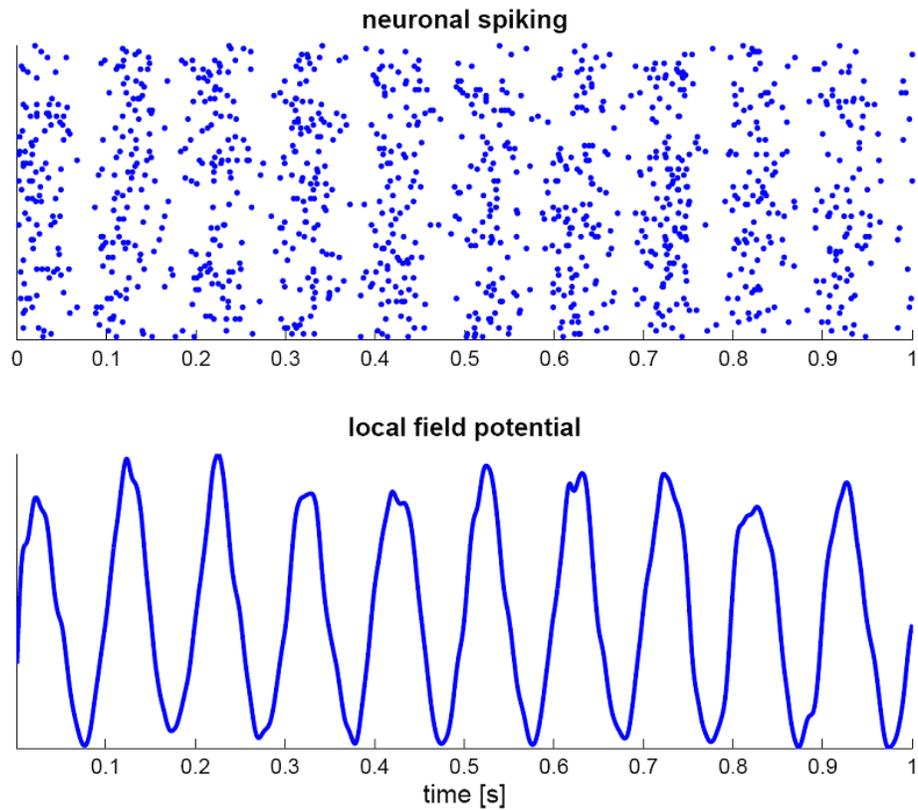
Computational level evidence

- ~~=Structural ambiguity~~
- ~~=Negative polarity items~~

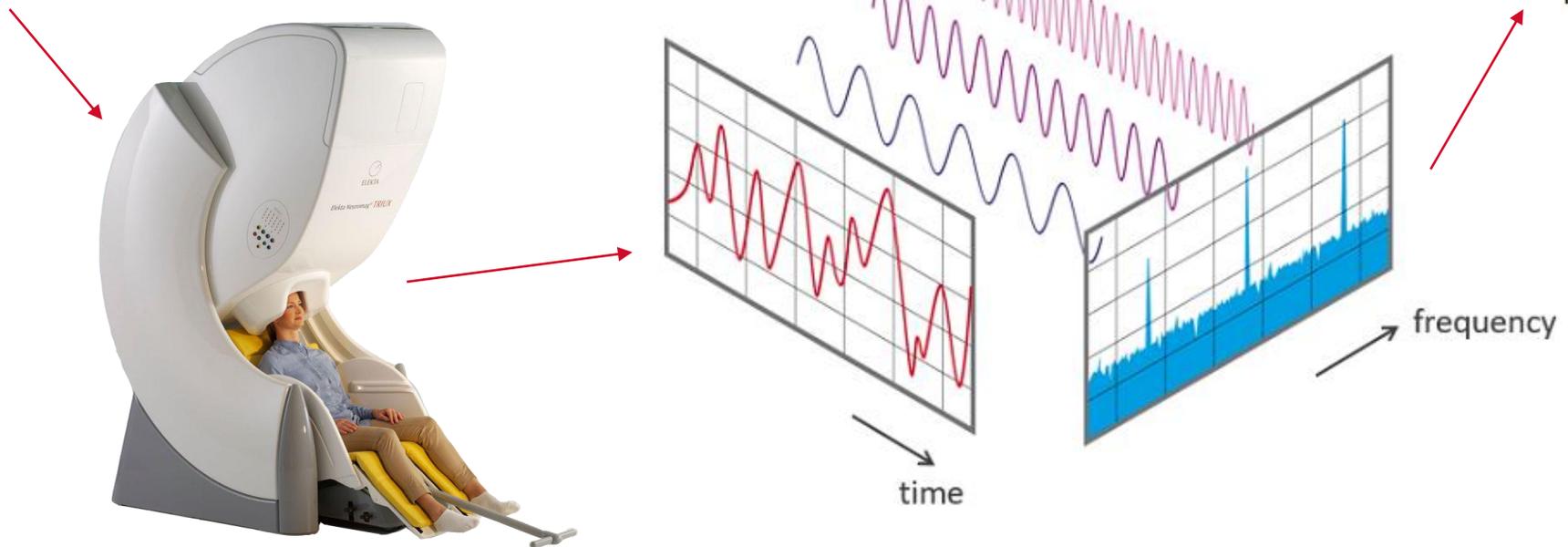
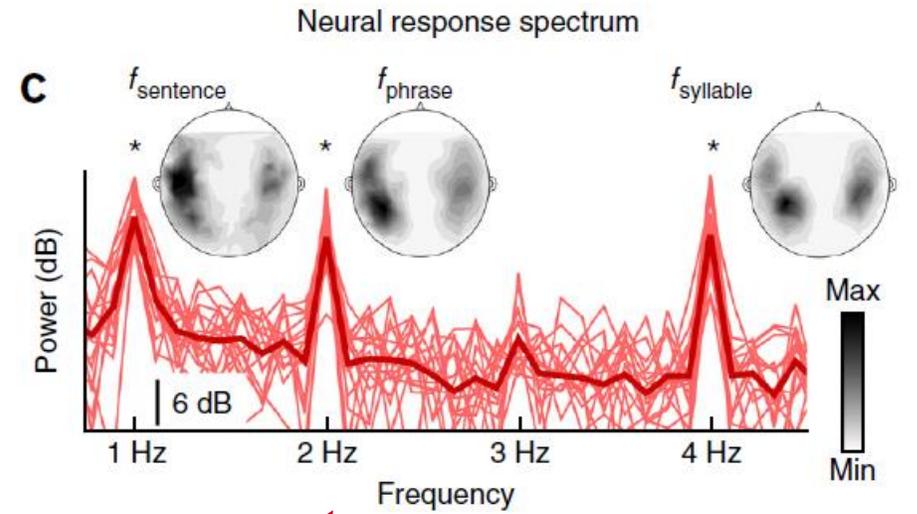
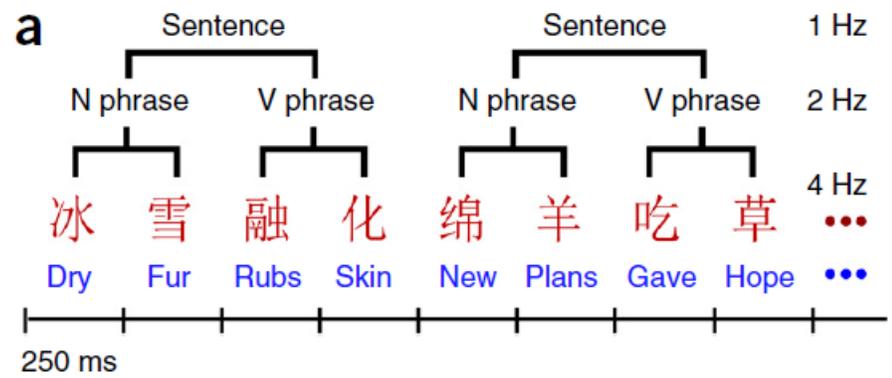
Algorithmic/Implementational level evidence

- Neural oscillations
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NEURAL OSCILLATIONS

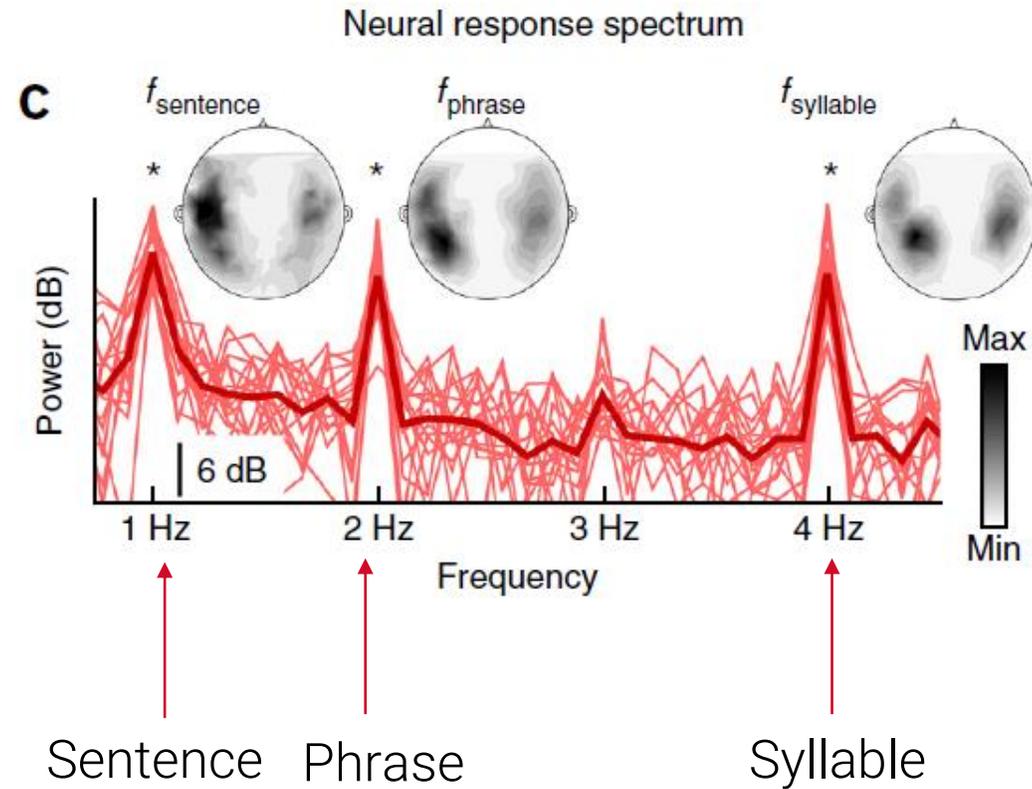


NEURAL OSCILLATIONS

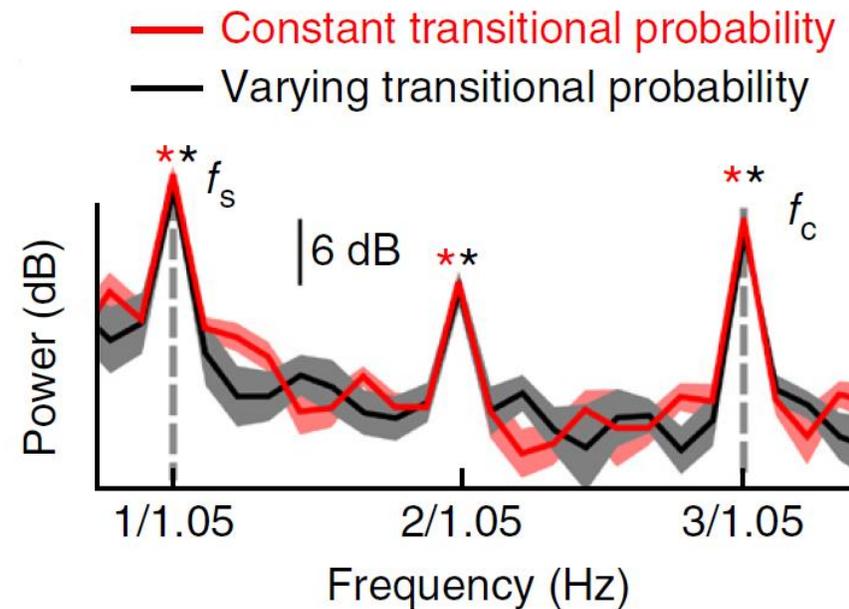


Ding, Melloni, Zhang, Tian & Poeppel (2016)

NEURAL OSCILLATIONS



- Hierarchical structure maps to neural oscillations.
- Transition probability does not.



Same neural oscillations,
regardless of transition probability.

Computational level evidence

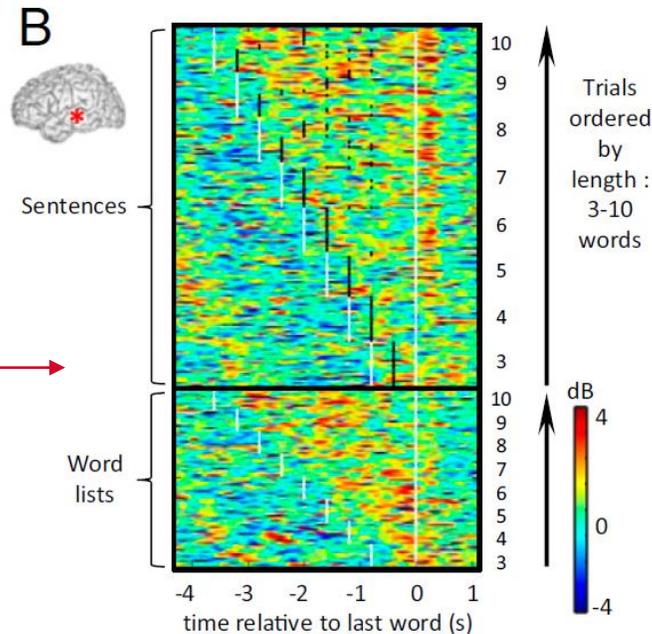
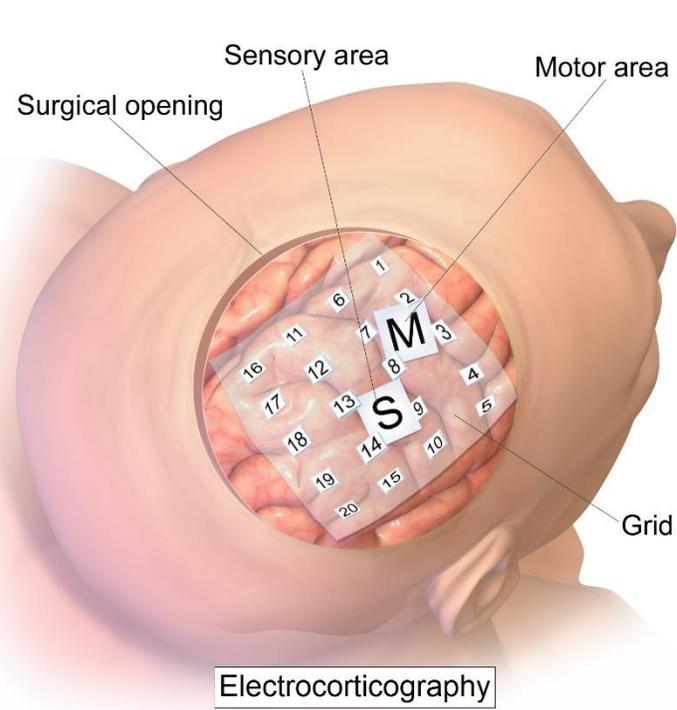
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Algorithmic/Implementational level evidence

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NEURONAL ACTIVITY

Electrocorticography (electrodes on the brain)

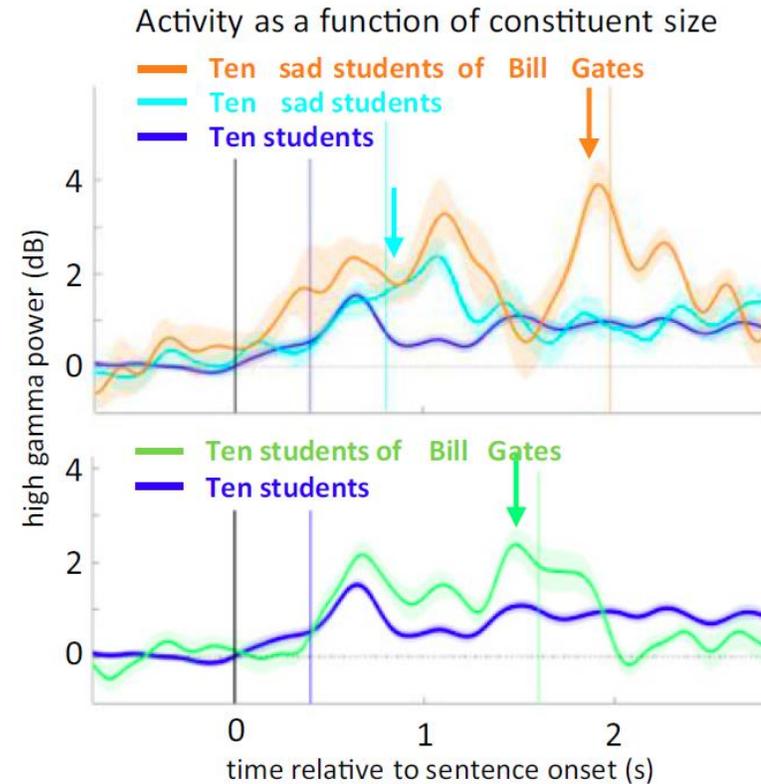


Peak in brain activation following the last word of a sentence.

The peak is larger if there are more phrase nodes to close.

EFFECT OF CONSTITUENT CLOSURE:

Increasing brain activity followed by a drop at the final word or the word that **could have** been the final word of a constituent.



MODELING BRAIN ACTIVITY

Brain activity in Broca's Area best modeled by a bottom-up parsing algorithm.

Nodes-closing model parallels bottom-up parsing.

Bottom-up Parsing:
Build phrase structure after you get all the words in the phrase.

A Bottom-up

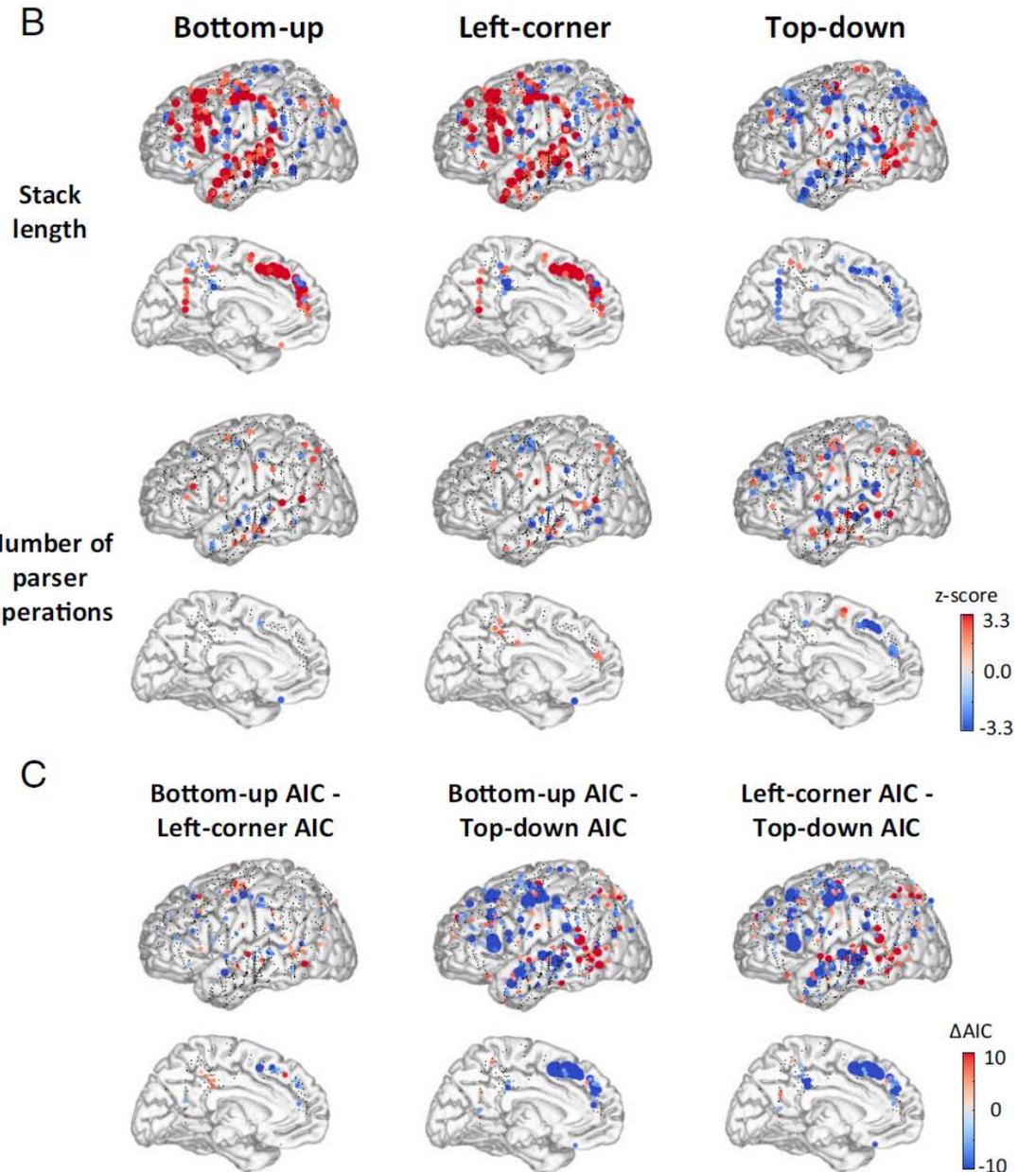
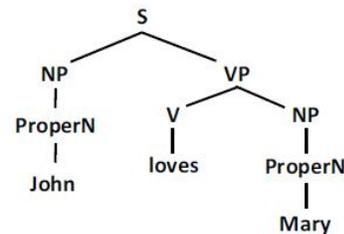
Stack	Operations
[S]	shift John
John [S]	reduce by ProperN→John
ProperN [S]	reduce by NP→ProperN
NP [S]	shift loves
loves NP [S]	reduce by V→loves
V NP [S]	shift Mary
Mary V NP [S]	reduce by ProperN→Mary
ProperN V NP [S]	reduce by NP→ProperN
NP V NP [S]	reduce by VP→V NP
VP NP [S]	reduce by S→NP VP

Left-corner

Stack	Operations
[S]	shift John
John [S]	project ProperN→John
ProperN [S]	project NP→ProperN
NP [S]	project+complete S→NP VP
[VP]	shift loves
loves [VP]	project V→loves
V [VP]	project+complete VP→V NP
[NP]	shift Mary
Mary [NP]	project ProperN→Mary
ProperN [NP]	project+complete NP→ProperN

Top-down

Stack	Operations
[S]	expand by S→NP VP
[NP] [VP]	expand by NP→ProperN
[ProperN] [VP]	expand by ProperN→John
[John] [VP]	scan John
[VP]	expand by VP→V NP
[V] [NP]	expand by V→loves
[loves] [NP]	scan loves
[NP]	expand by NP→ProperN
[ProperN]	expand by ProperN→Mary
[Mary]	scan Mary



Computational level evidence

- ~~=Structural ambiguity~~
- ~~=Negative polarity items~~

Algorithmic/Implementational level evidence

- ~~=Neural oscillations~~
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UNIVERSAL GRAMMAR

PRINCIPLES: universal constraints that govern the shape of languages.

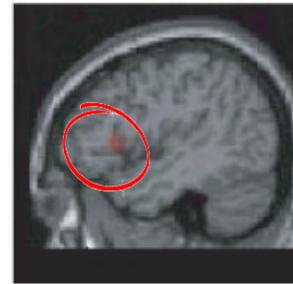


Structure dependence

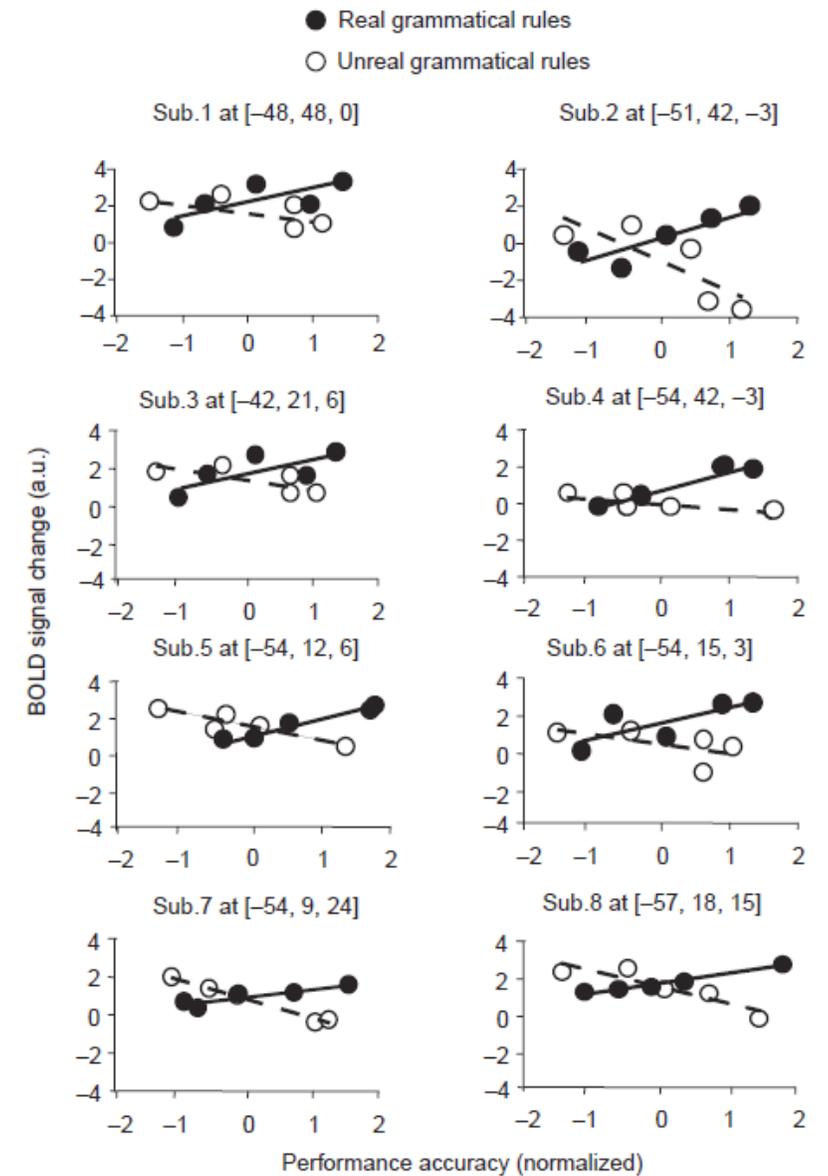
- Rules of syntax reference hierarchical structure, rather than linear word order.

— Neural activity in Broca's Area **increased** as subjects learned **real** rules.

— Neural activity in Broca's Area **decreased** as subjects learned **unreal** rules.



[-45, 21, 6]



- Humans can learn languages that violate **structure dependence**, but Broca's Area cannot process them.
- Hierarchical structure is a built-in component of our linguistic computational machinery.

DISCUSSION QUESTIONS

Broca's Area can only process rules that don't involve *counting*.

How sure are we that this is an innate constraint?

Could this be due to our language exposure?