Computational cognitive modeling: How to investigate child language acquisition using math

Lisa Pearl
University of California, Irvine

Computation of Language Laboratory
UC Irvine

Lisa S. Pearl
Professor
Department of Language Science
SSPB 2219
University of California, Irvine
lpearl@uci.edu

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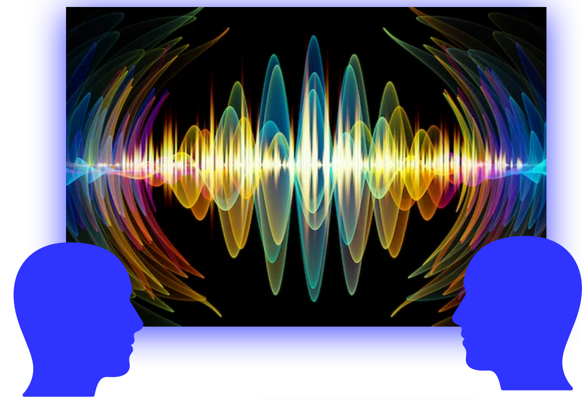
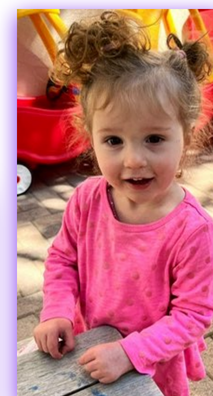
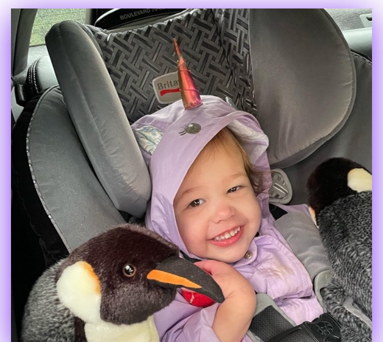
Linguistics Student Association
CSU Fullerton

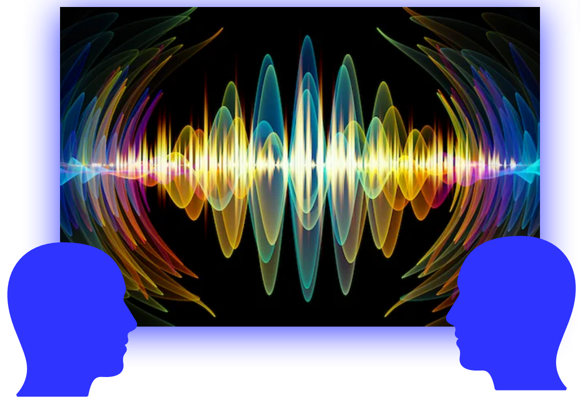
About child language acquisition





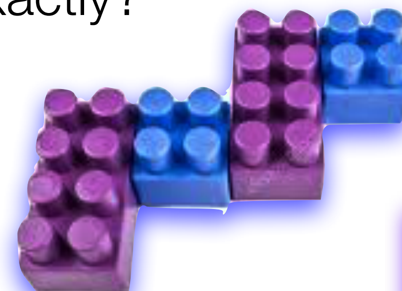
child language acquisition:
extraction of language information
by young children

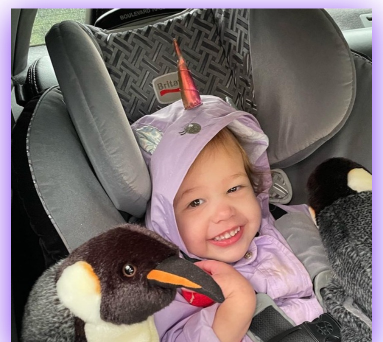


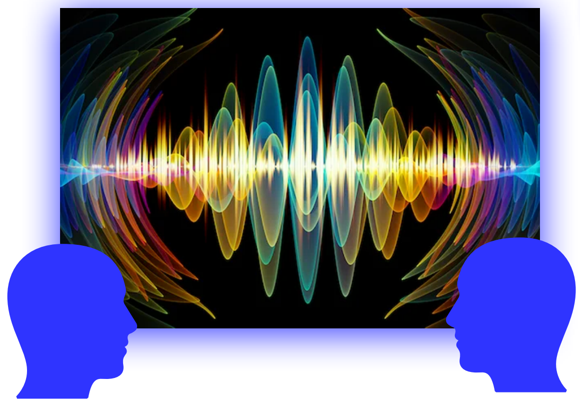


child language acquisition

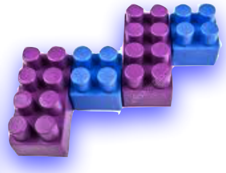
One question:
What kind of language information exactly?

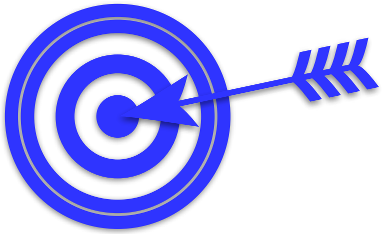






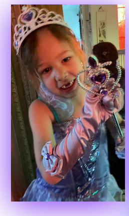
child language acquisition

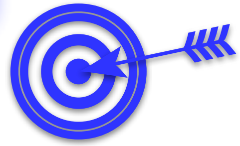




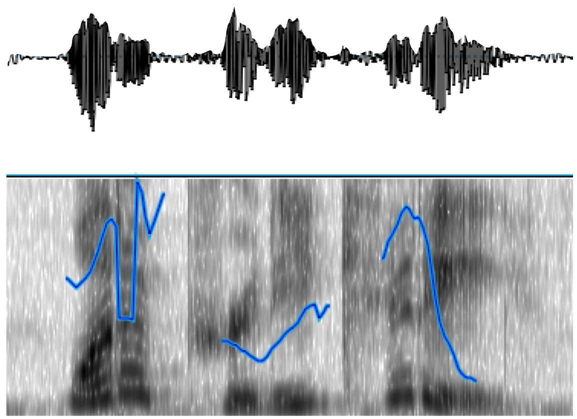
Some examples of target language information

child language acquisition





how to identify words in fluent speech (speech segmentation)

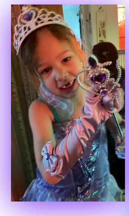


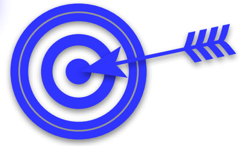
wʌɾəpɹɪɾikɪɾi

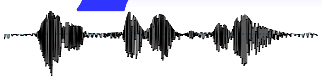
wʌɾ ə pɹɪɾi kɪɾi

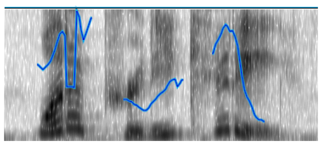
what a pretty kitty!

child language acquisition







what a pretty kitty!

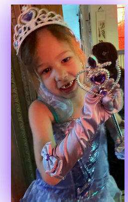
speech segmentation

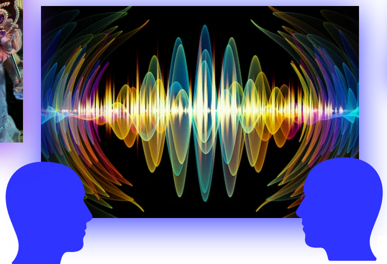
how to pronounce words (phonology)

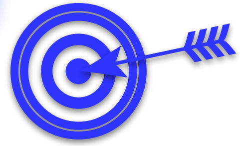
✓ KI tty

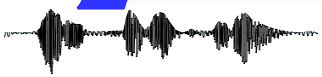
✗ ki TTY

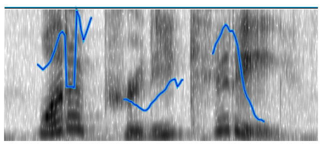
child language acquisition











what a pretty kitty!

speech segmentation

KI tty

ki TTY

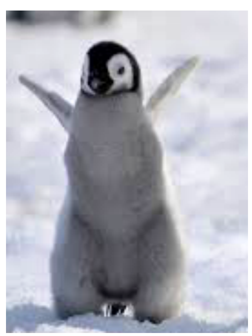
phonology

certain words behave like other words
(syntactic categorization)

Countable
Noun

what a pretty ___!

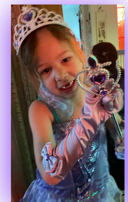
penguin

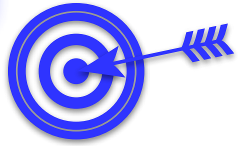


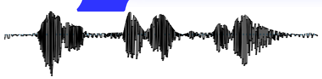
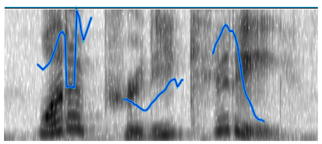
kitty

owl

child language acquisition



what a pretty kitty!

speech segmentation

✓ KI tty

✗ ki TTY

phonology

penguin **Noun** owl

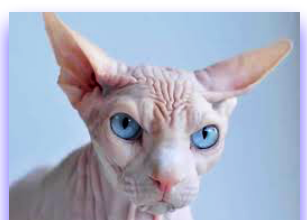
kitty

syntactic categorization

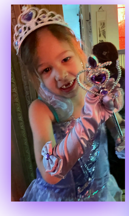
how to interpret words in context
(syntax, semantics)

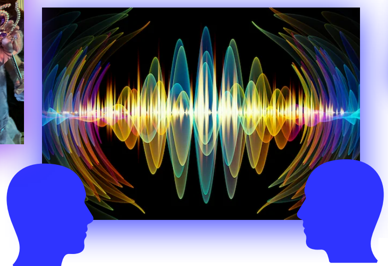
"Oh look — a kitty!"
"He's such a pretty kitty!"

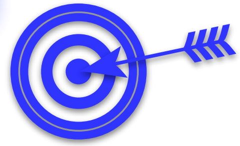
"Look — there's another one!"


child language acquisition







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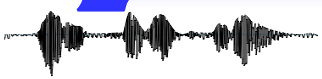
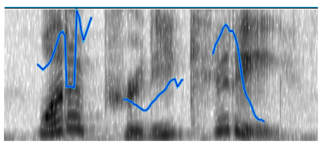




what a pretty kitty!

speech segmentation

✓KI tty

✗ ki TTY

phonology

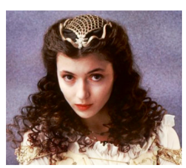
penguin **Noun** owl
kitty

syntactic categorization

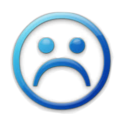
syntax, semantics

how to put words together to ask questions (syntax)

This kitty was bought as a present for someone.

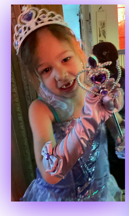
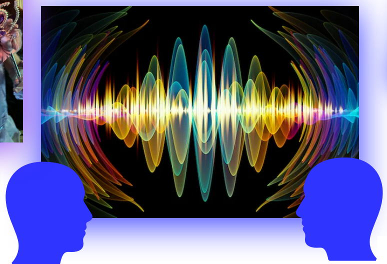


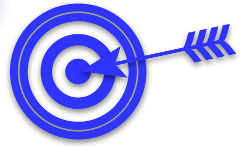
Lily thinks this kitty is pretty.



"Who does Lily think the kitty for is pretty?"

child language acquisition



“Oh look — a pretty kitty!”
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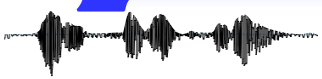
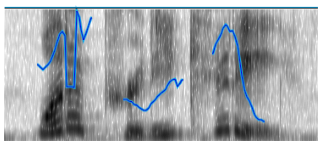
“Look — there’s another one!”

what a pretty kitty!

speech segmentation

✓ KI tty
✗ ki TTY

phonology

penguin **Noun** owl
kitty

syntactic categorization

syntax, semantics

“Who does Lily think the kitty for is pretty?”

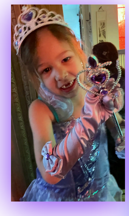
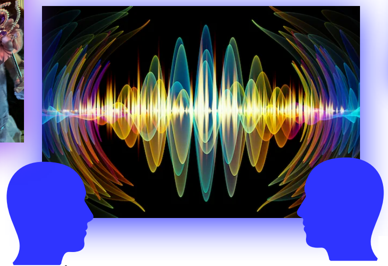
syntax

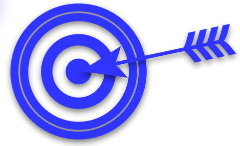
how to identify the right interpretation in context (pragmatics)

“I think I saw all the kitties on the stairs.”

“No - every kitty didn’t sit on the stairs”

child language acquisition



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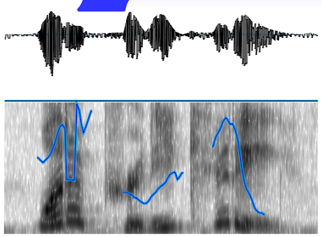

what a pretty kitty!

speech segmentation

KI tty

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phonology

penguin **Noun** owl
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syntactic categorization

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“Who does Lily think the kitty for is pretty?”

syntax

how to identify the right interpretation in context (pragmatics)

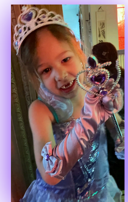
“I think I saw all the kitties on the stairs.”

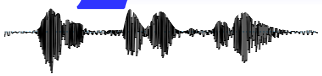
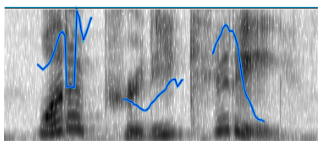
“No - every kitty didn’t sit on the stairs”

No kitties sat on the stairs.

Not all kitties sat on the stairs.

child language acquisition



what a pretty kitty!

speech segmentation

KI tty

ki TTY

phonology

penguin Noun owl

kitty

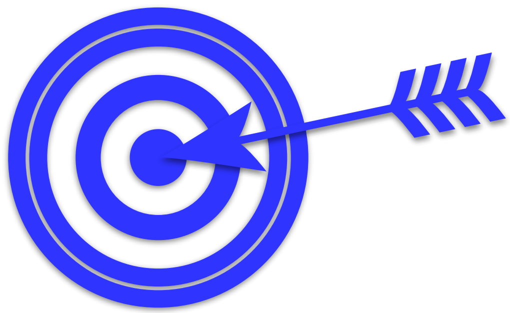
syntactic categorization

“Oh look — a pretty kitty!”
“He’s such a pretty kitty!”
“Look — there’s another one!”

syntax, semantics

“Who does Lily think the kitty for is pretty?”

syntax



This is just some of the target knowledge for children’s acquisition. (There’s much more.)

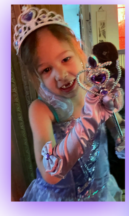


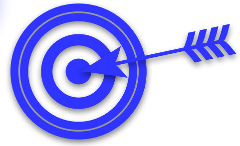
“Every kitty didn’t sit on the stairs”

Not all kitties sat on the stairs.

pragmatics

child language acquisition



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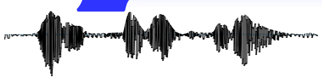
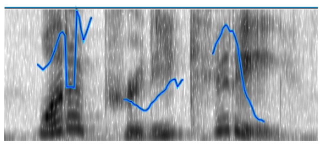



what a pretty kitty!

speech segmentation

✓ KI tty

✗ ki TTY

phonology

penguin **Noun** owl
kitty

syntactic categorization

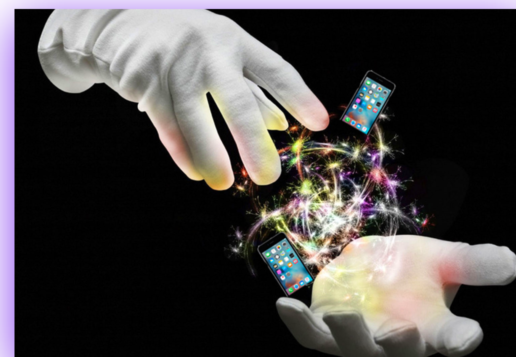
syntax, semantics

☹

"Who does Lily think the kitty for is pretty?"

syntax

Another important question:
How does this magical
acquisition process occur?





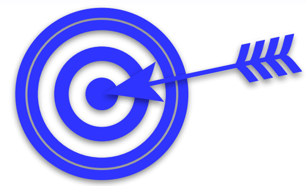
"Every kitty didn't sit on the stairs"

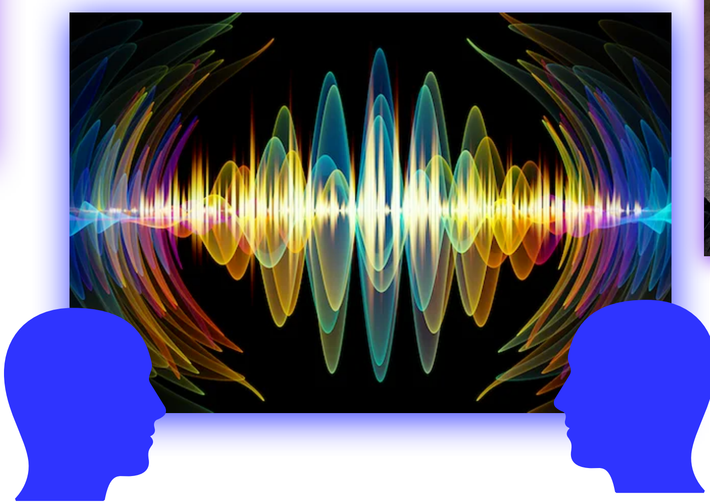
✓ Not all kitties sat on the stairs.

pragmatics

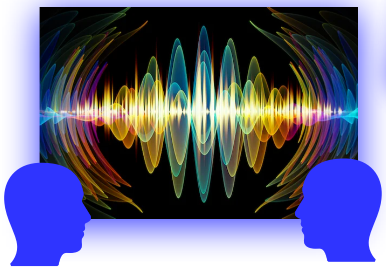
child language acquisition

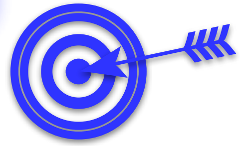
Children are amazing at learning language

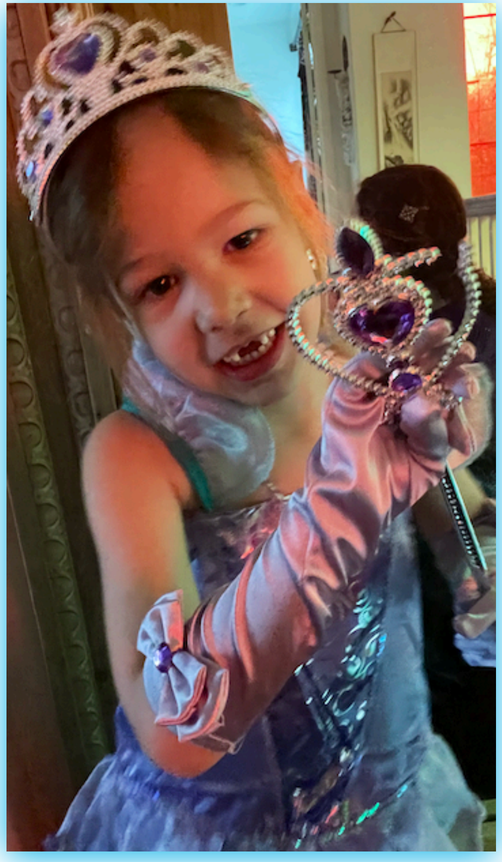




child language acquisition







Much of the linguistic system is already known by age 4.

syntactic categorization

phonology

syntax, semantics

speech segmentation

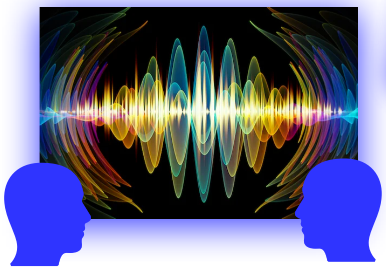
syntax

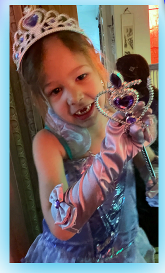
pragmatics

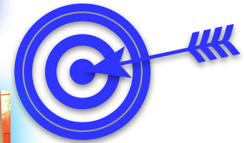
child language acquisition

Also, children figure language out
mostly without explicit instruction.

child language acquisition

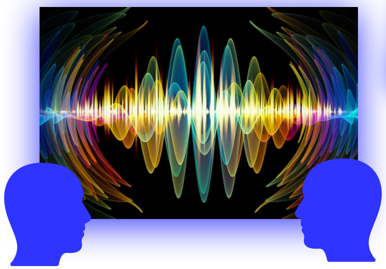


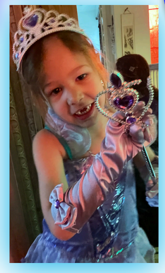
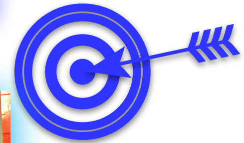




What they're doing: Extracting patterns and making generalizations from the surrounding data mostly just by hearing examples of what's allowed in the language.

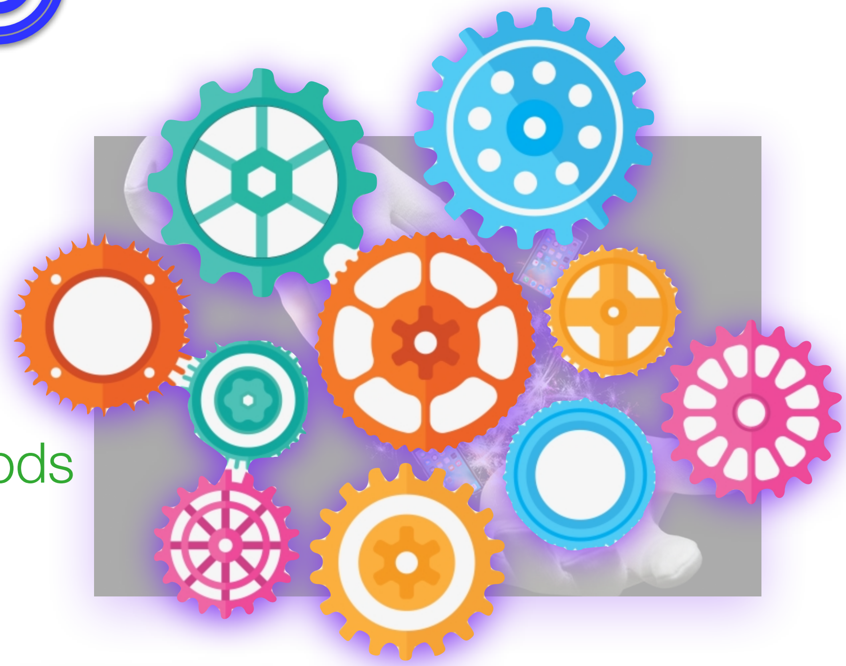
child language acquisition



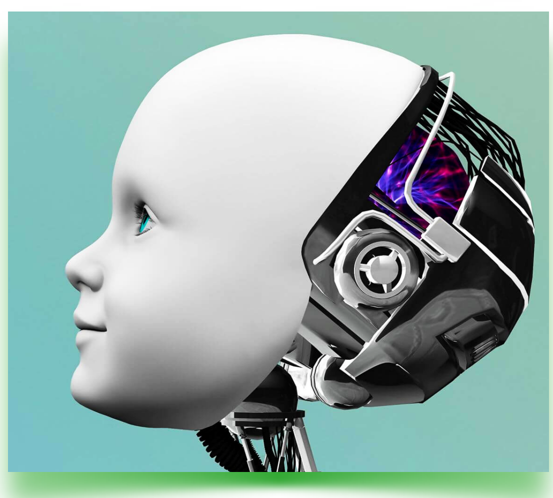




This is pretty magical. But how does it work?

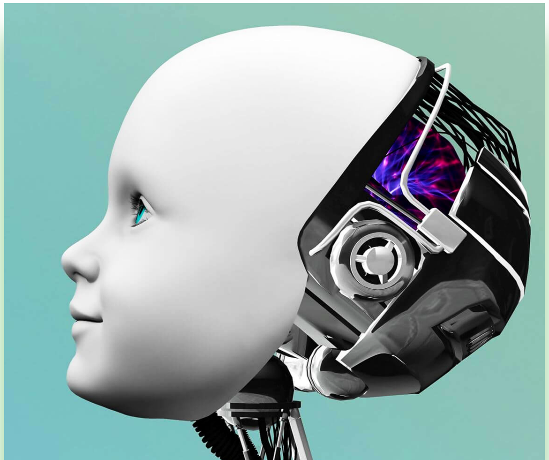
child language acquisition



I primarily use quantitative methods like computational cognitive modeling to try to figure this out.



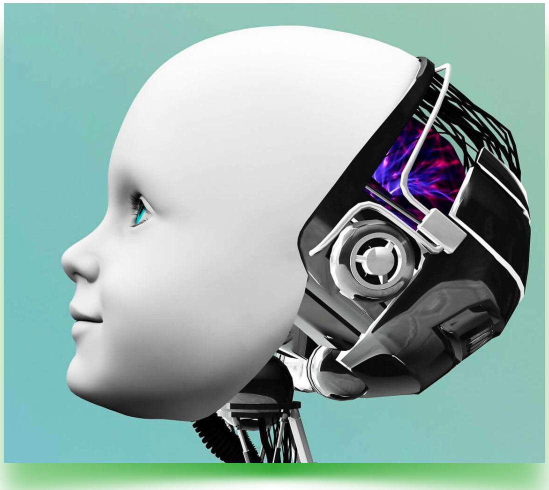
computational cognitive modeling

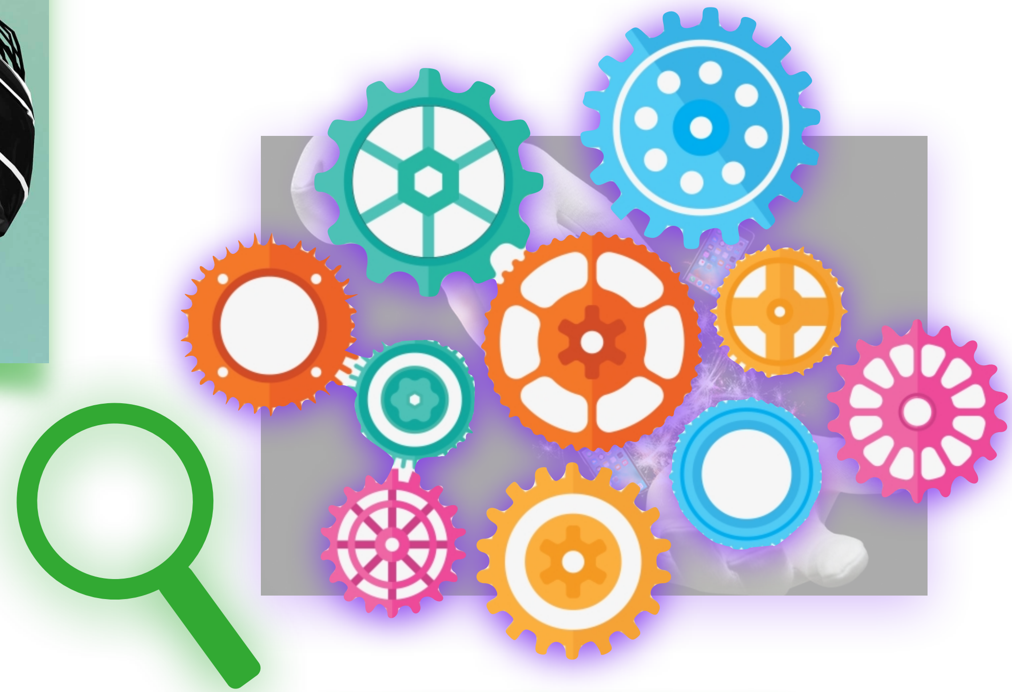


Computational cognitive modeling lets us explore theoretical ideas precisely, and evaluate how well any particular theory can explain empirical data on children's language acquisition.

Pearl, 2010, 2014, Pearl and Goldwater, 2016, Pearl, 2017, 2019, 2020, 2021,a,b, 2023a,b, under review

computational cognitive modeling

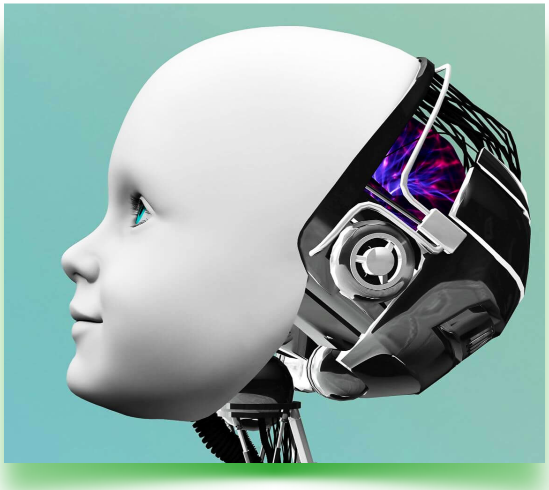


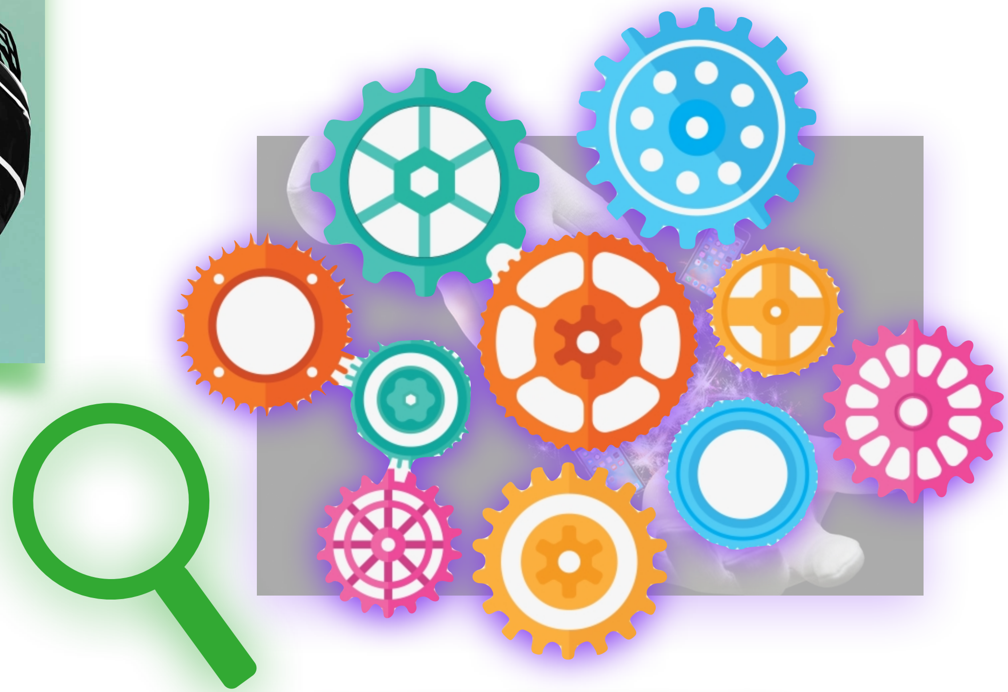


Math is at the heart of this tool.

Pearl, 2010, 2014, Pearl and Goldwater, 2016, Pearl, 2017, 2019, 2020, 2021,a,b, 2023a,b, under review

computational cognitive modeling

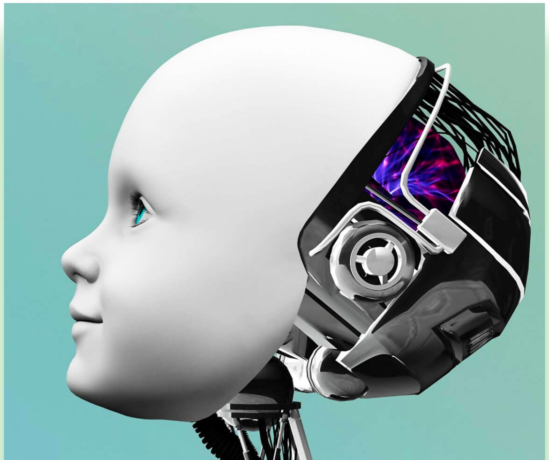




One main part: Counting things

Pearl, 2010, 2014, Pearl and Goldwater, 2016, Pearl, 2017, 2019, 2020, 2021,a,b, 2023a,b, under review

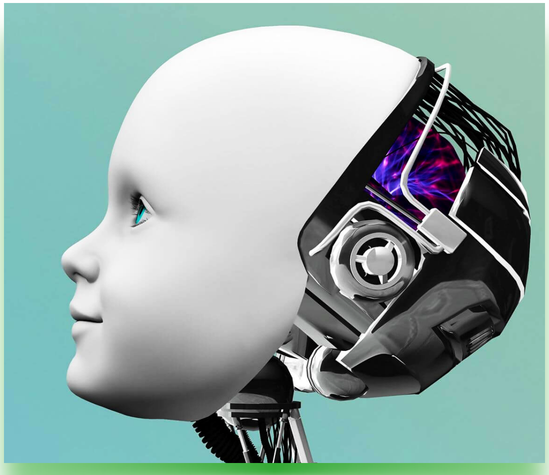
computational cognitive modeling



One main part: Counting things
(sometimes we count a lot of things)

Pearl, 2010, 2014, Pearl and Goldwater, 2016, Pearl, 2017, 2019, 2020, 2021,a,b, 2023a,b, under review

computational cognitive modeling

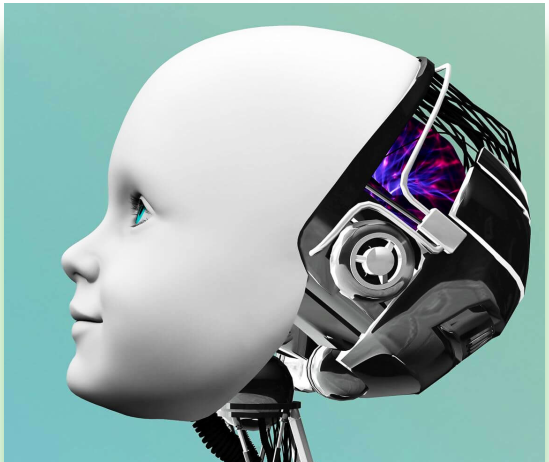


counting

Another part: principled reasoning
based on those counts

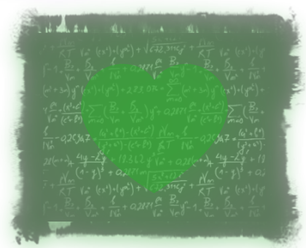
Pearl, 2010, 2014, Pearl and Goldwater, 2016, Pearl, 2017, 2019, 2020, 2021,a,b, 2023a,b, under review

computational cognitive modeling



counting

Another part: principled reasoning
based on those counts

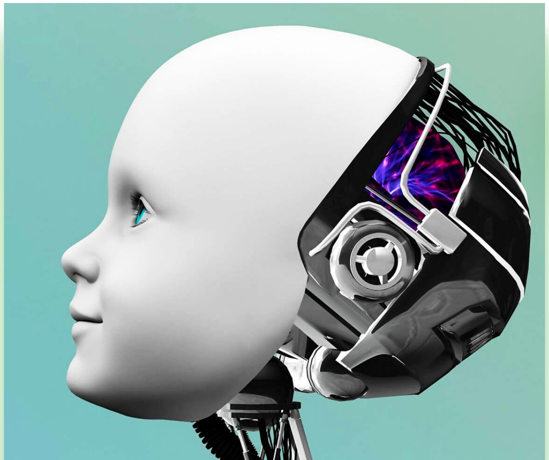


Bayesian inference

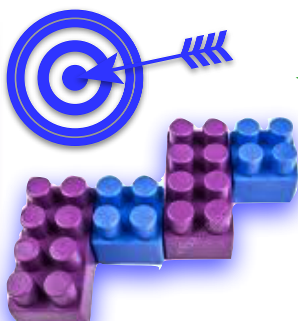
$p(Generalization \mid Data) \propto p(Generalization) \cdot p(Data \mid Generalization)$

Pearl, 2010, 2014, Pearl and Goldwater, 2016, Pearl, 2017, 2019, 2020, 2021,a,b, 2023a,b, under review

computational cognitive modeling



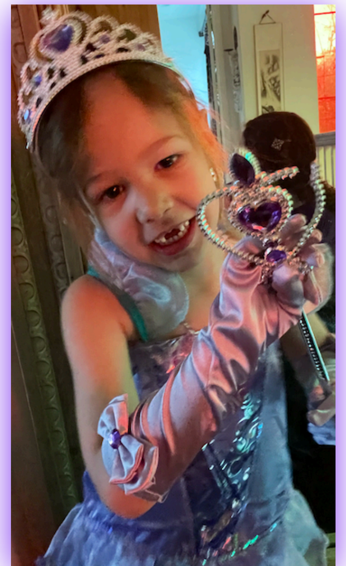
But what do we count and reason over? How do we connect that information to language acquisition?

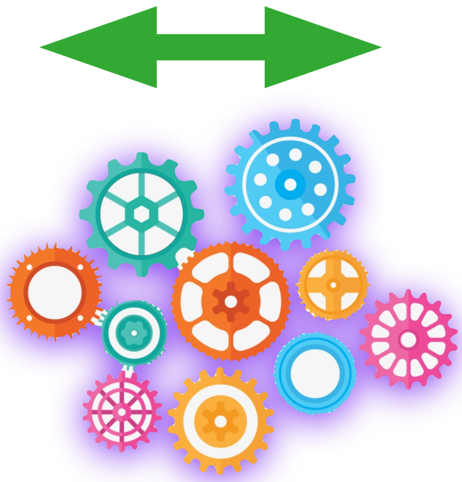


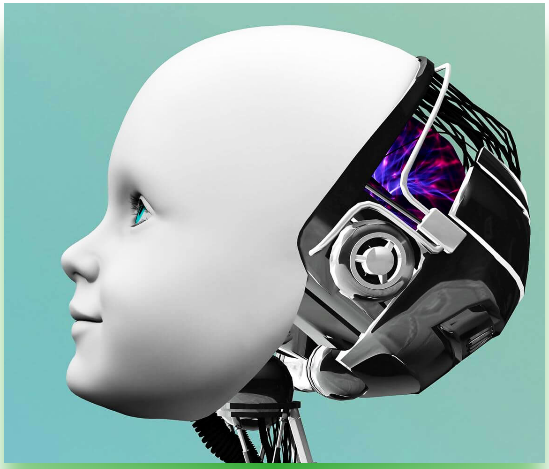
Pearl, 2010, 2014, Pearl and Goldwater, 2016, Pearl, 2017, 2019, 2020, 2021,a,b, 2023a,b, under review

child language acquisition

computational cognitive modeling





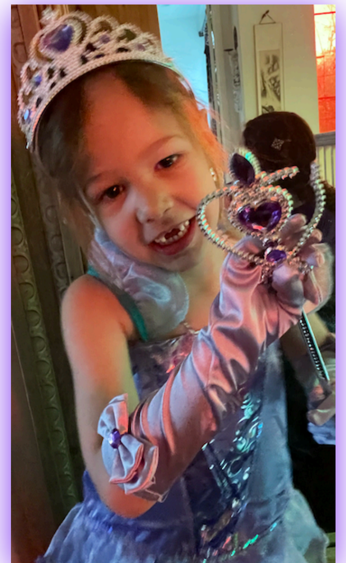


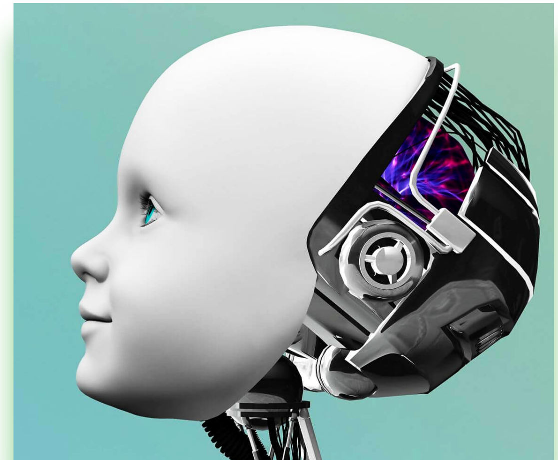
We typically using computational cognitive modeling to encode a child's acquisition process very precisely.

Pearl, 2010, 2014, Pearl and Goldwater, 2016, Pearl, 2017, 2019, 2020, 2021,a,b, 2023a,b, under review

child language acquisition

computational cognitive modeling





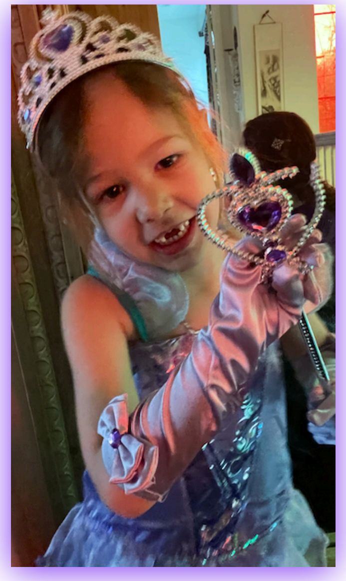
We think the child is learning by counting different parts of her input and reasoning over those counts in a sensible way.

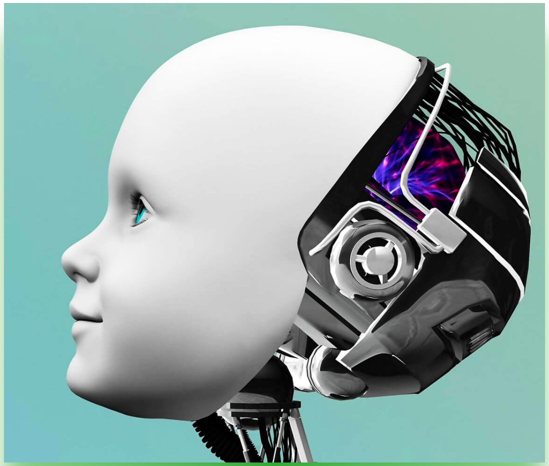
So, the modeled learner will count those same things and learn about language by doing principled reasoning over those counts.

Pearl, 2010, 2014, Pearl and Goldwater, 2016, Pearl, 2017, 2019, 2020, 2021,a,b, 2023a,b, under review

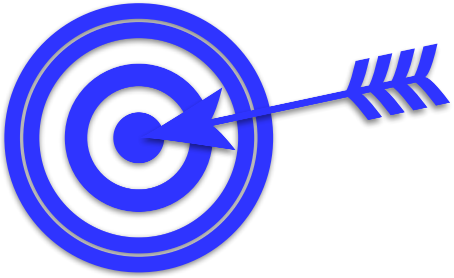
child language acquisition

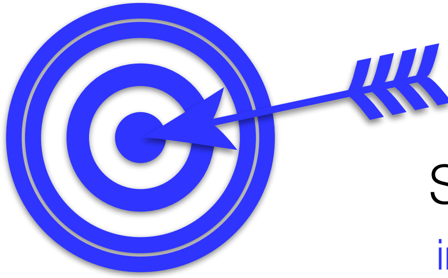
computational cognitive modeling





Let's see how this works for a type of syntactic knowledge known as "syntactic islands".



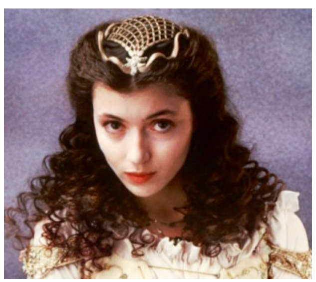


Syntactic islands

involve *wh*-dependencies.

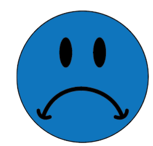
This kitty was bought as a present for someone.

Lily thinks this kitty is pretty.

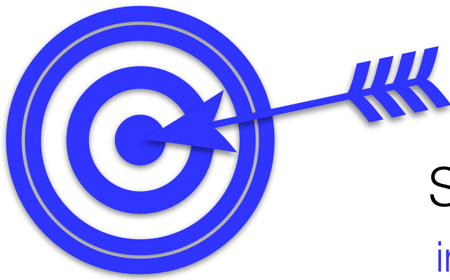


What’s going on here?

Who does Lily think the kitty for is pretty?



What does Lily think is pretty, and who does she think it’s for?



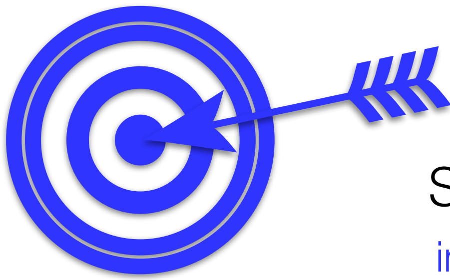
Syntactic islands

involve *wh*-dependencies.

What's going on here?

There's a dependency between the *wh*-word *who* and where it's understood (the gap)

*Who does Lily think the kitty for*__$_{who}$ *is pretty?*



Syntactic islands

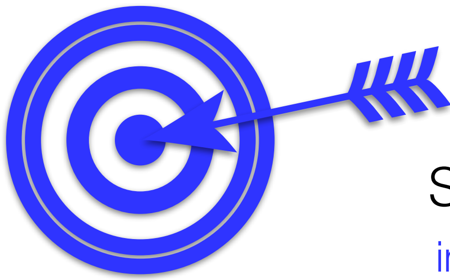
involve *wh*-dependencies.

What's going on here?

There's a dependency between the *wh*-word *who* and where it's understood (the gap)

Who does Lily think the kitty for__$_{who}$ is pretty?

This dependency is strongly dispreferred in English.



Syntactic islands

involve *wh*-dependencies.

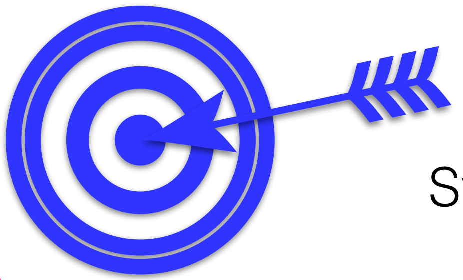
What's going on here?

There's a dependency between the *wh*-word *who* and where it's understood (the gap)

Who does Lily think the kitty for $\_\__{who}$ is pretty?

This dependency is strongly dispreferred in English.

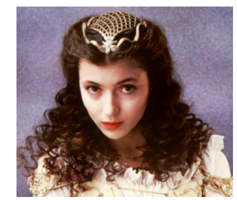
One explanation: The dependency crosses a "syntactic island" (Ross 1967)

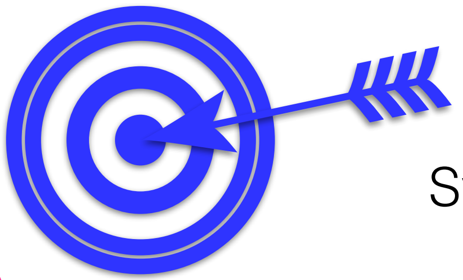


Syntactic islands

Ross 1967

Who does Lily think the kitty for__$_{who}$ is pretty? Subject island





Syntactic islands

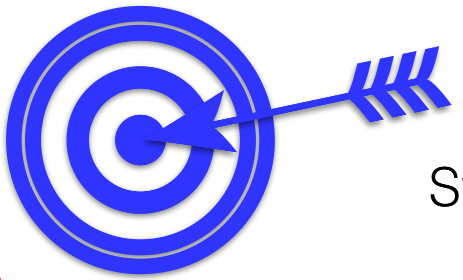
Ross 1967

Who does Lily think the kitty for __$_{who}$ is pretty? Subject island

Jack is somewhat tricksy.

He claimed he bought something.

What did Jack make the claim that he bought __$_{what}$?



Syntactic islands

Ross 1967

Who does Lily think the kitty for $\_\_{who}$ is pretty? Subject island

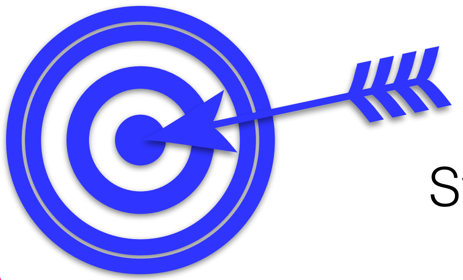
What did Jack make the claim that he bought $\_\_{what}$? Complex NP island

Jack is somewhat tricksy.

He claimed he bought something.

Elizabeth wondered if he actually did and what it was.

What did Elizabeth wonder whether Jack bought $\_\_{what}$?



Syntactic islands

Ross 1967

Who does Lily think the kitty for __who is pretty? Subject island

What did Jack make the claim that he bought __what? Complex NP island

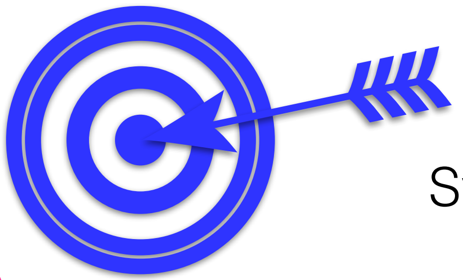
What did Elizabeth wonder whether Jack bought __what? Whether island

Jack is somewhat tricksy.

He claimed he bought something.

Elizabeth worried it was something dangerous.

What did Elizabeth worry if Jack bought __what?



Syntactic islands

Who does Lily think the kitty for__who is pretty? Subject island

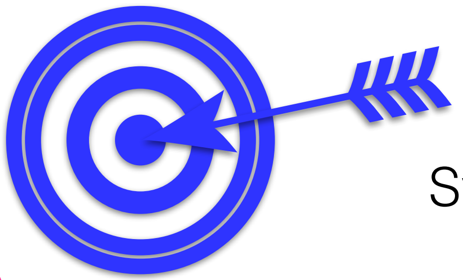
What did Jack make the claim that he bought __what? Complex NP island

What did Elizabeth wonder whether Jack bought __what? Whether island

What did Elizabeth worry if Jack bought __what? Adjunct island

Important: It’s not about the length of the dependency.

(Chomsky 1965, Ross 1967)



Syntactic islands

Who does Lily think the kitty for __who is pretty? Subject island

What did Jack make the claim that he bought __what? Complex NP island

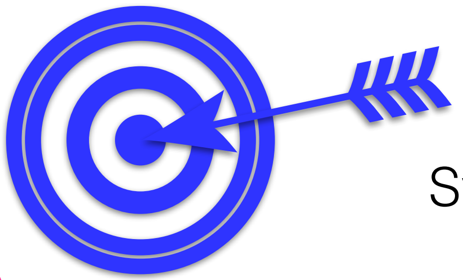
What did Elizabeth wonder whether Jack bought __what? Whether island

What did Elizabeth worry if Jack bought __what? Adjunct island

Important: It's not about the length of the dependency.
(Chomsky 1965, Ross 1967)

What did Elizabeth think __what? ✔

Elizabeth



Syntactic islands

Who does Lily think the kitty for __who is pretty? Subject island

What did Jack make the claim that he bought __what? Complex NP island

What did Elizabeth wonder whether Jack bought __what? Whether island

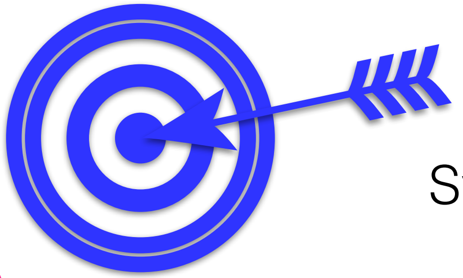
What did Elizabeth worry if Jack bought __what? Adjunct island

Important: It's not about the length of the dependency.
(Chomsky 1965, Ross 1967)

What did Elizabeth think Jack said __what?

Elizabeth

Jack



Syntactic islands

Elizabeth

Who does Lily think the kitty for __who is pretty? Subject island

What did Jack make the claim that he bought __what? Complex NP island

Jack

What did Elizabeth wonder whether Jack bought __what? Whether island

What did Elizabeth worry if Jack bought __what? Adjunct island

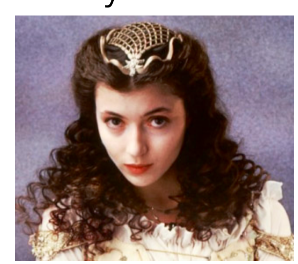
Important: It's not about the length of the dependency.

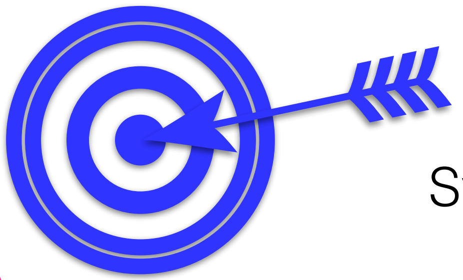
(Chomsky 1965, Ross 1967)

What did Elizabeth think Jack said Lily saw __what?

✔

Lily





Syntactic islands

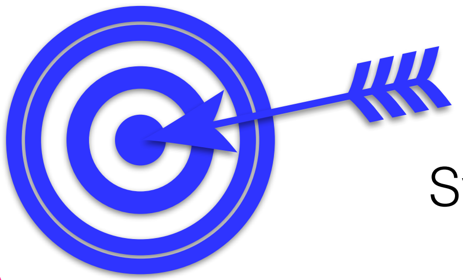
Who does Lily think the kitty for __$_{who}$ is pretty? Subject island

What did Jack make the claim that he bought __$_{what}$? Complex NP island

What did Elizabeth wonder whether Jack bought __$_{what}$? Whether island

What did Elizabeth worry if Jack bought __$_{what}$? Adjunct island

English adults judge these island-crossing dependencies to be far less acceptable than many others, including others that are very similar except that they don't cross syntactic islands (Sprouse et al. 2012).



Syntactic islands

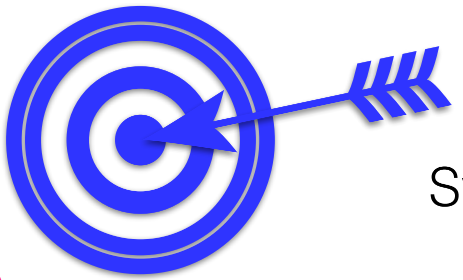
Who does Lily think the kitty for __who is pretty? Subject island

What did Jack make the claim that he bought __what? Complex NP island

What did Elizabeth wonder whether Jack bought __what? Whether island

What did Elizabeth worry if Jack bought __what? Adjunct island

English-learning children strongly disprefer one of these island-crossing dependencies compared to others (de Villiers et al. 2008).



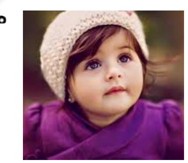
Syntactic islands

Who does Lily think the kitty for __who is pretty? Subject island

What did Jack make the claim that he bought __what? Complex NP island

What did Elizabeth wonder whether Jack bought __what? Whether island

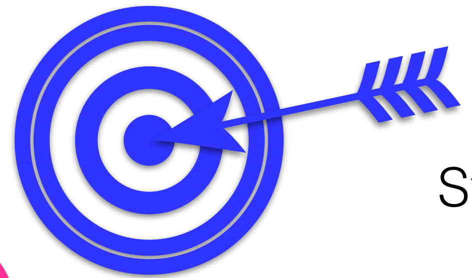
What did Elizabeth worry if Jack bought __what? Adjunct island



Additional *wh*-dependency knowledge:
The frequency of a lexical item can also affect adult acceptability judgments of potential syntactic islands.

What did Elizabeth say that Jack saw __what?

What did Elizabeth whine that Jack saw __what?



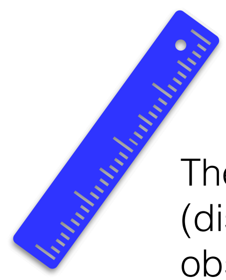
Syntactic islands

Who does Lily think the kitty for __$_{who}$ is pretty? Subject island

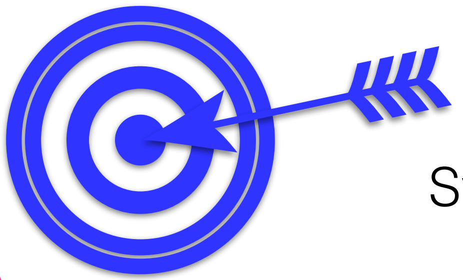
What did Jack make the claim that he bought __$_{what}$? Complex NP island

What did Elizabeth wonder whether Jack bought __$_{what}$? Whether island

What did Elizabeth worry if Jack bought __$_{what}$? Adjunct island



These judgments and (dis)preferences are a measurable observable behavior that can signal the successful acquisition of syntactic island knowledge.



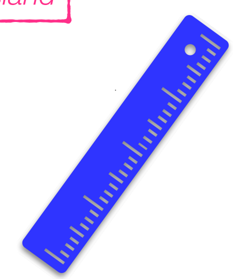
Syntactic islands

Who does Lily think the kitty for __who is pretty? Subject island

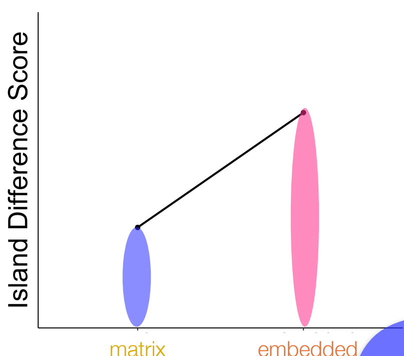
What did Jack make the claim that he bought __what? Complex NP island

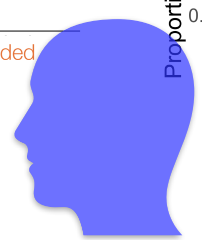
What did Elizabeth wonder whether Jack bought __what? Whether island

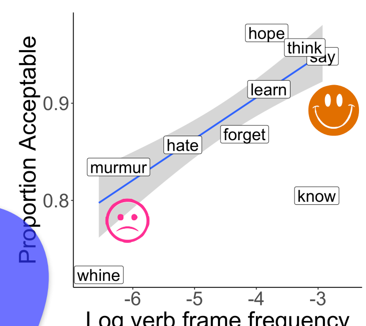
What did Elizabeth worry if Jack bought __what? Adjunct island

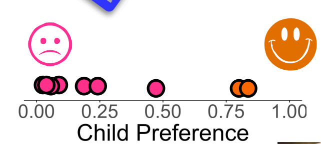


measurable observable behavior

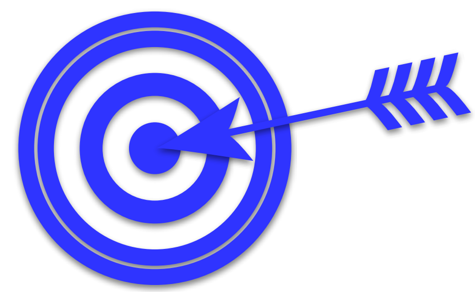








Syntactic islands



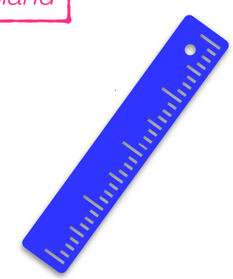
Who does Lily think the kitty for __who is pretty? Subject island

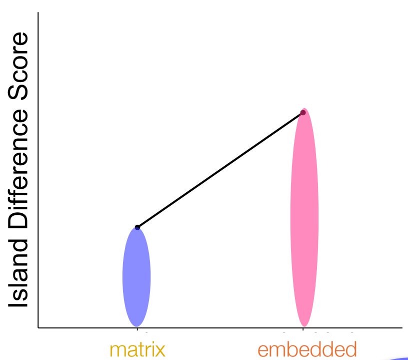
What did Jack make the claim that he bought __what? Complex NP island

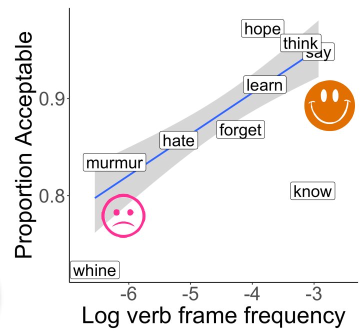
What did Elizabeth wonder whether Jack bought __what? Whether island

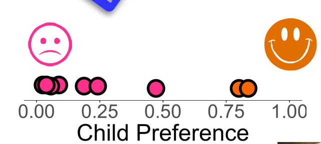
What did Elizabeth worry if Jack bought __what? Adjunct island

So, these judgments and (dis)preferences can serve as a target for successful acquisition — an outcome we can measure.

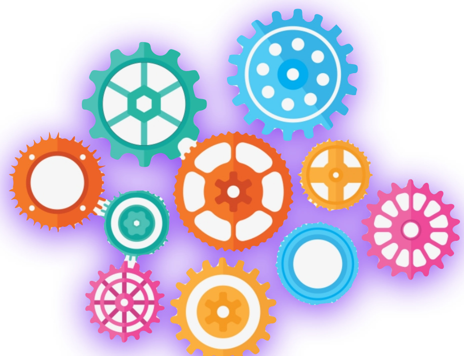


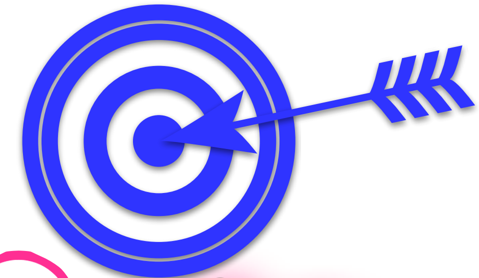


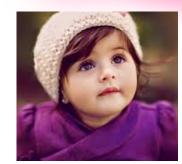


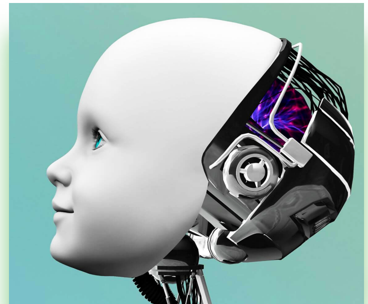


This is the target of acquisition.
But how could a child learn this?



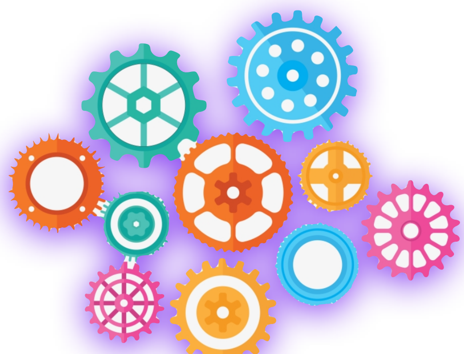
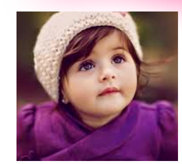


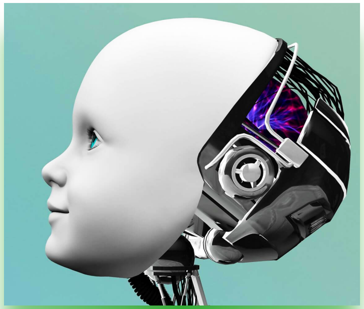


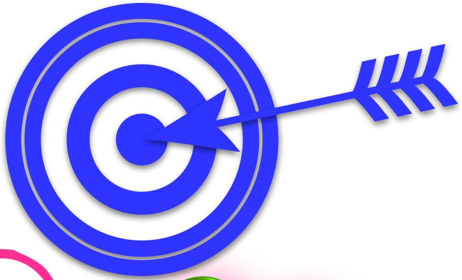



Let’s use a computational cognitive model to help figure this out.

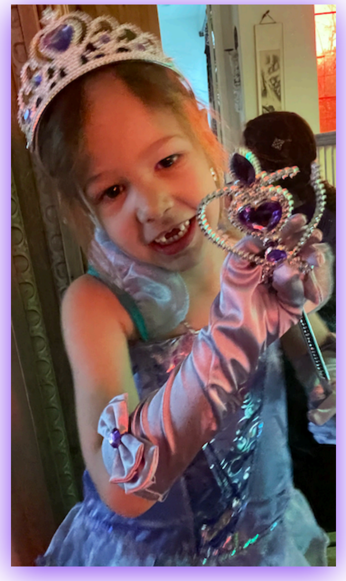




What’s a learning theory the modeled learner could encode?



one learning theory

Pearl & Sprouse 2013
Dickson, Pearl, & Futrell 2022, 2024, in prep.

Learn the right building blocks

Learn the right building blocks

Pearl & Sprouse 2013
Dickson, Pearl, & Futrell 2022, 2024, in prep.

View *wh*-dependencies in terms of their building blocks and track (count) those building blocks in the input.

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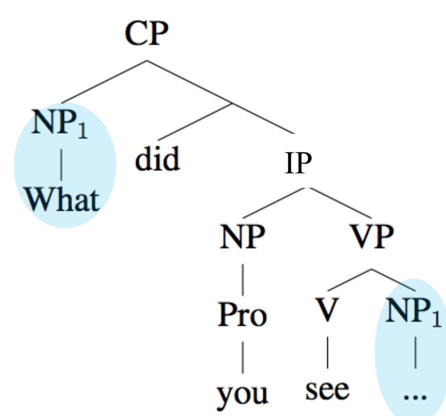
building blocks of *wh*-dependencies

Dependencies represented as a sequence of container nodes

What phrases contain the gap
(but not the *wh*-word)?



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building blocks of *wh*-dependencies

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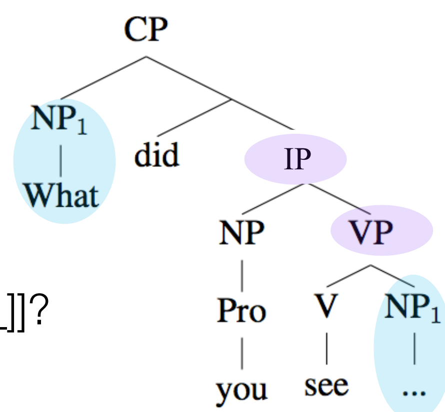

What did you see __?
= What did [$_{IP}$ you [$_{VP}$ see __]]?
= *start*-IP-VP-*end*

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building blocks of *wh*-dependencies

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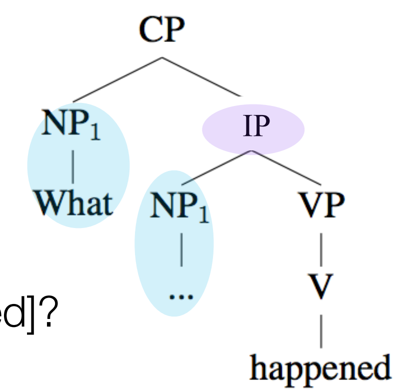

What __ happened?
= What [$_{IP}$ __ happened]?
= *start*-IP-*end*

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building blocks of *wh*-dependencies

Dependencies represented as a sequence of container nodes

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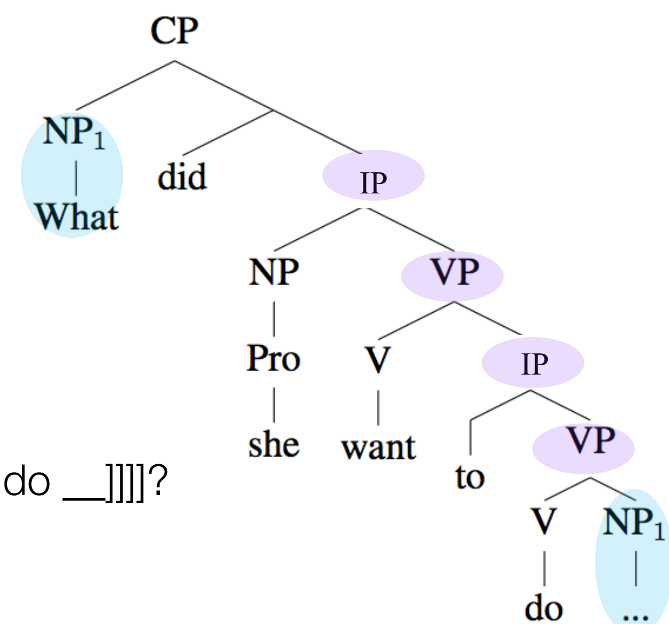

What did you see __?
= What did $[_{IP}$ you $[_{VP}$ see __]]?
= *start*-IP-VP-*end*

What __ happened?
= What $[_{IP}$ __ happened]?
= *start*-IP-*end*

What did she want to do __ ?
= What did $[_{IP}$ she $[_{VP}$ want $[_{IP}$ to $[_{VP}$ do __]]]]?
= *start*-IP-VP-IP-VP-*end*

Learn the right building blocks

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building blocks of *wh*-dependencies

What __ happened?
= What [$_{\text{IP}}$ __ happened]?
= *start*-IP-*end*

What did you see __?
= What did [$_{\text{IP}}$ you [$_{\text{VP}}$ see __]]?
= *start*-IP-VP-*end*

What did she want to do __ ?
= What did [$_{\text{IP}}$ she [$_{\text{VP}}$ want [$_{\text{IP}}$ to [$_{\text{VP}}$ do __]]]]?
= *start*-IP-VP-IP-VP-*end*

(Much) less acceptable dependencies have low probability segments

[$_{\text{CP}}$ *Who* *did* [$_{\text{IP}}$ *Lily* [$_{\text{VP}}$ *think* [$_{\text{CP-that}}$ [$_{\text{IP}}$ [$_{\text{NP}}$ *the kitty* [$_{\text{PP}}$ *for* __]] *was pretty* ?]]]]

start-IP-VP-CP$_{\text{that}}$-IP-NP-PP-*end*

Learn the right building blocks

Pearl & Sprouse 2013
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building blocks of *wh*-dependencies

What __ happened?
= What [$_{\text{IP}}$ __ happened]?
= *start*-IP-*end*

What did you see __?
= What did [$_{\text{IP}}$ you [$_{\text{VP}}$ see __]]?
= *start*-IP-VP-*end*

What did she want to do __ ?
= What did [$_{\text{IP}}$ she [$_{\text{VP}}$ want [$_{\text{IP}}$ to [$_{\text{VP}}$ do __]]]]?
= *start*-IP-VP-IP-VP-*end*

(Much) less acceptable dependencies have low probability segments

[$_{\text{CP}}$ *Who* *did* [$_{\text{IP}}$ *Lily* [$_{\text{VP}}$ *think* [$_{\text{CP-that}}$ [$_{\text{IP}}$ [$_{\text{NP}}$ *the kitty* [$_{\text{PP}}$ *for* __]] *was pretty* ?]]]]

start-IP-VP-CP$_{\text{that}}$-IP-NP-PP-*end*

So if children break these dependencies into smaller building blocks, they can identify if a dependency has bad segments (made up of one or more low probability building blocks).

Learn the right building blocks

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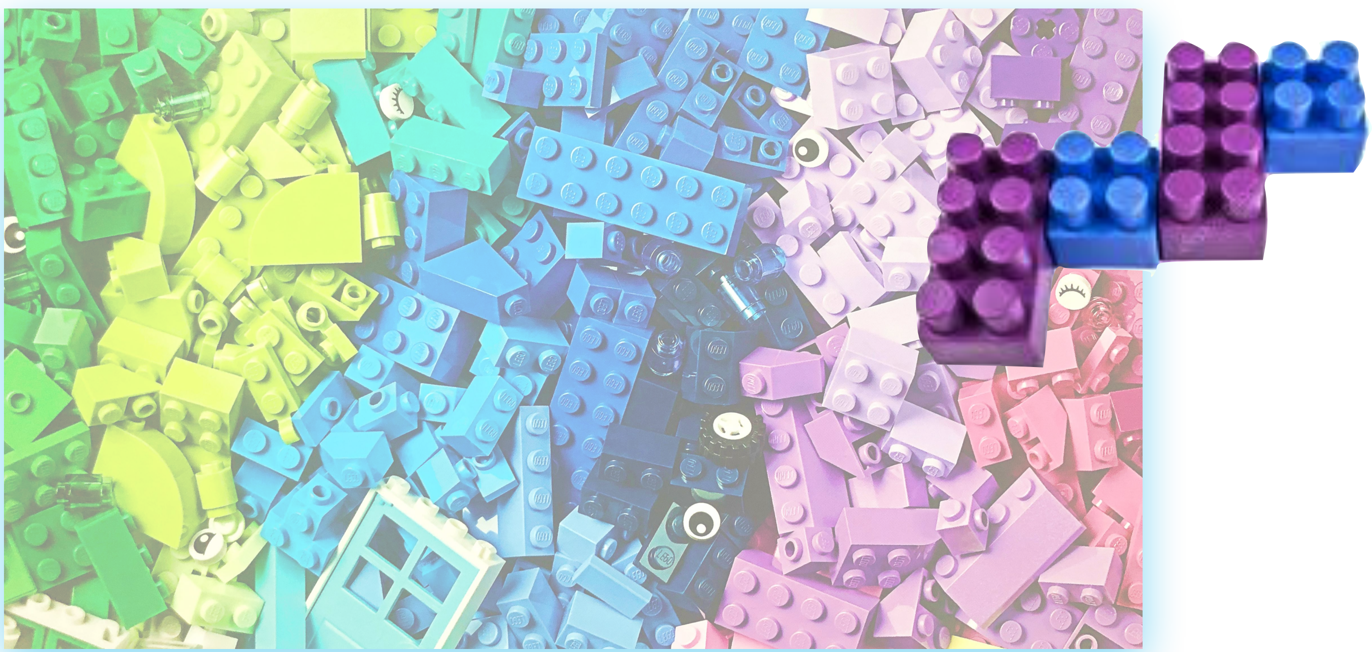
Theory: The child tries to learn
what the "best" building blocks are



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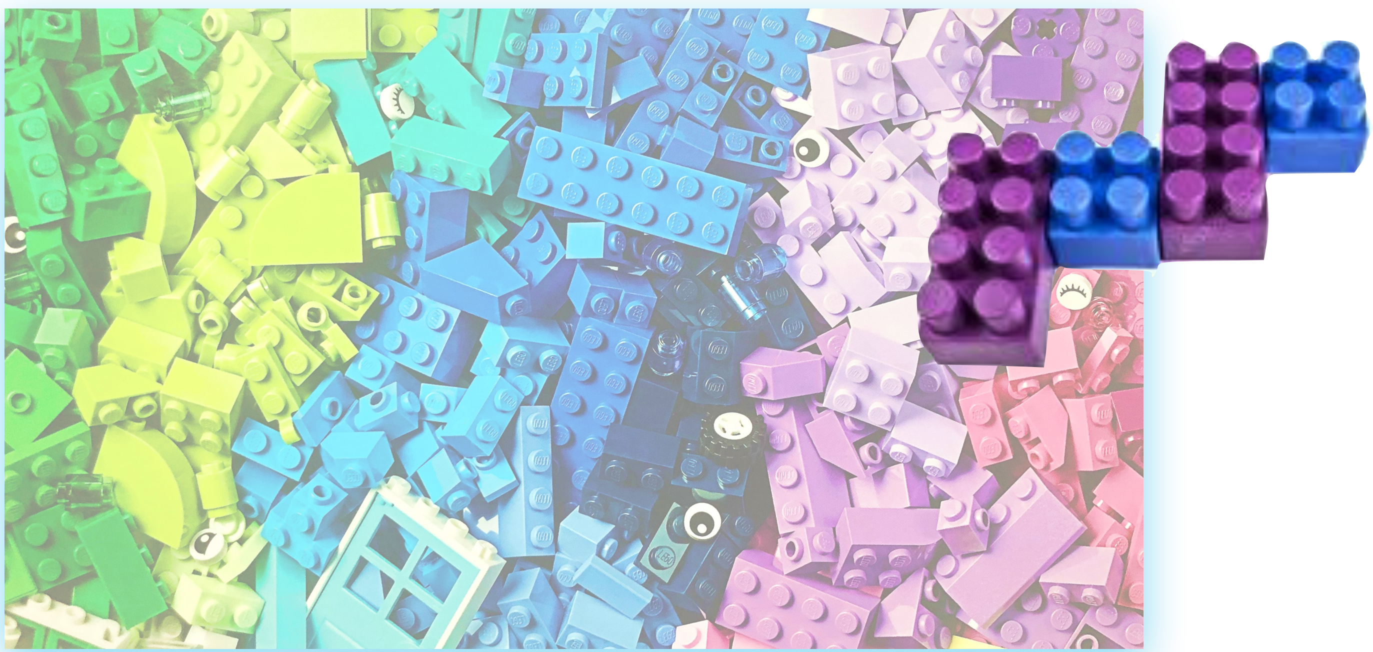
Guiding intuition:
the "best" building blocks are the most "efficient" ones.



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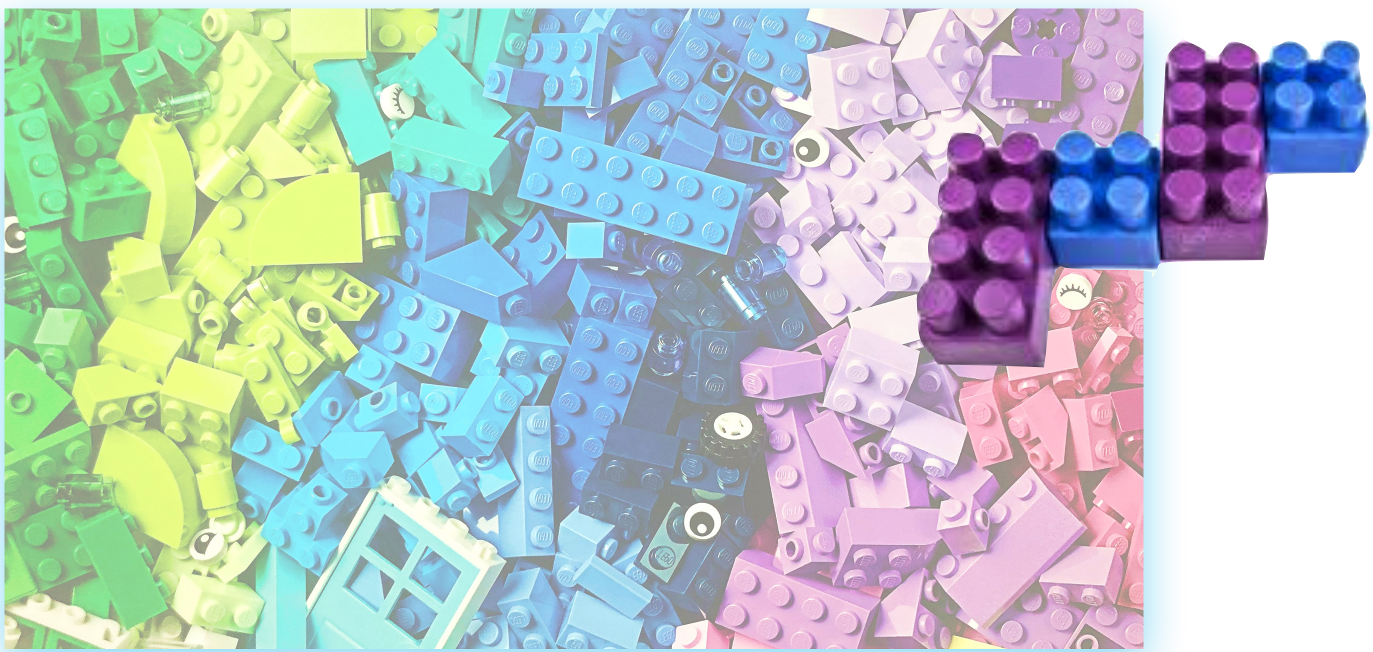
Efficient building blocks allow the representation of current and future *wh*-dependencies to be more probable.



Learn the right building blocks

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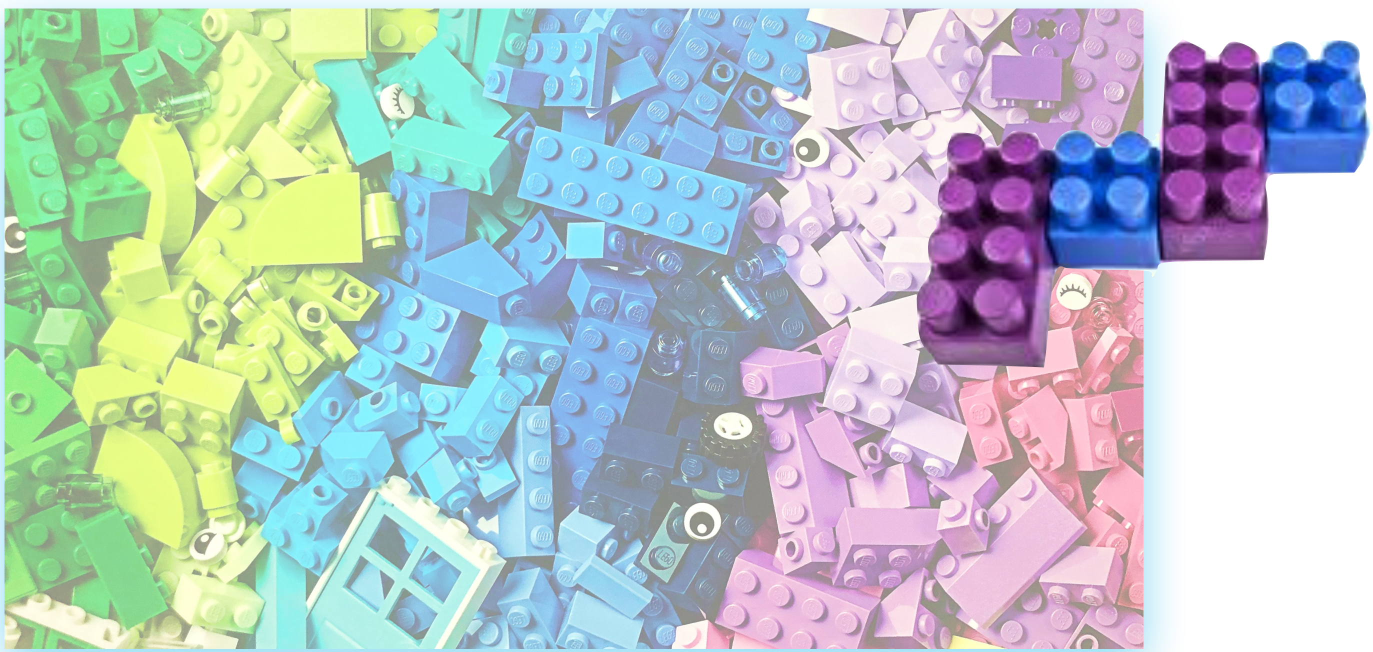
Efficient building blocks allow the representation of current and future *wh*-dependencies to be more probable.

Why? One idea: Higher probability *wh*-dependencies are faster to process (comprehending or producing).



Learn the right building blocks

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learning efficient building blocks

How? Look for building blocks that are a balance between
(1) how big they are
(2) how fast they are to put together to make a *wh*-dependency

Learn the right building blocks

Dickson, Pearl, & Futrell 2022, 2024, in prep.

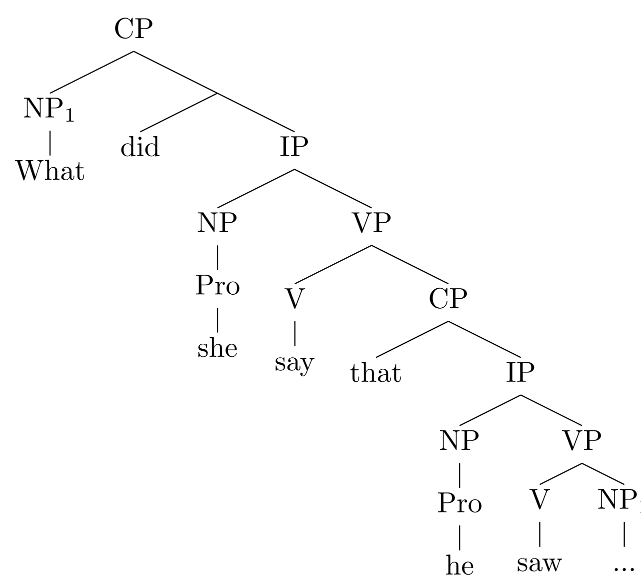
learning efficient building blocks

a balance between

(1) how big they are

(2) how fast they are to put together to make a *wh*-dependency

What did she say that he saw __ ?



Learn the right building blocks

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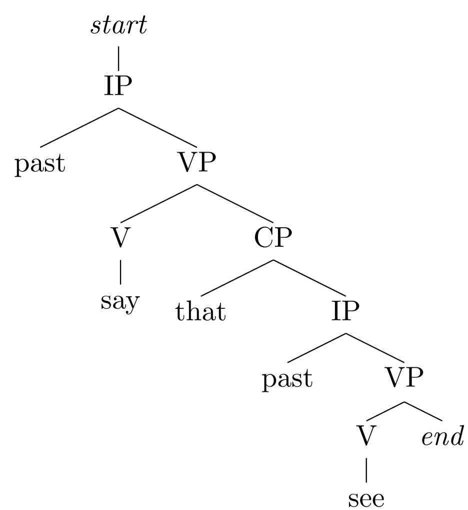
learning efficient building blocks

a balance between

(1) how big they are

(2) how fast they are to put together to make a *wh*-dependency

start-IP$_{\text{past}}$-VP$_{\text{say}}$-CP$_{\text{that}}$-IP$_{\text{past}}$-VP$_{\text{see}}$-*end*



Learn the right building blocks

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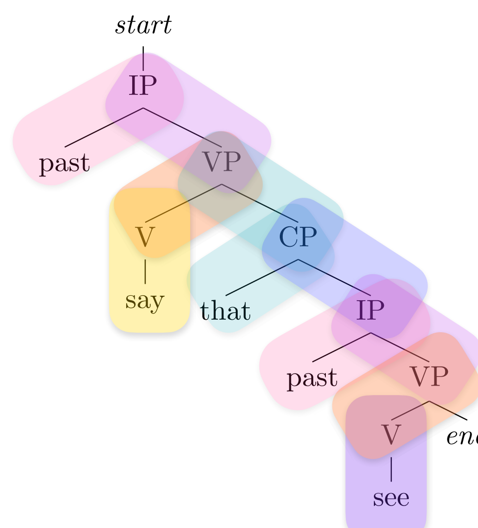
learning efficient building blocks

a balance between
(1) how big they are
(2) how fast they are to put together to make a *wh*-dependency

start-IP_{past}-VP_{say}-CP_{that}-IP_{past}-VP_{see}-*end*

Pieces can be small, so that many of them make up a *wh*-dependency



Learn the right building blocks

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learning efficient building blocks

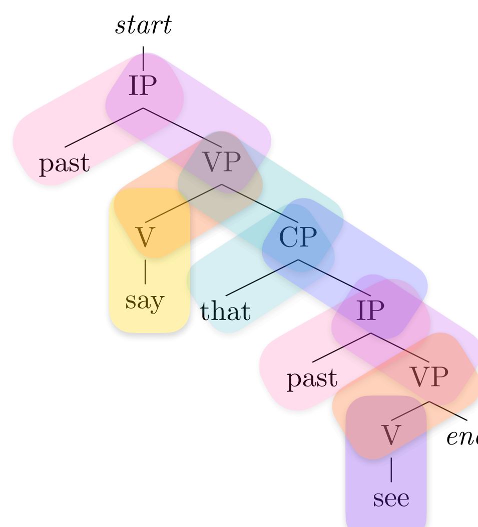
a balance between

(1) how big they are

(2) how fast they are to put together to make a *wh*-dependency

$\textit{start}\text{-IP}_{\text{past}}\text{-VP}_{\text{say}}\text{-CP}_{\text{that}}\text{-IP}_{\text{past}}\text{-VP}_{\text{see}}\text{-}\textit{end}$

It may be slower to put together many small pieces.



Learn the right building blocks

Dickson, Pearl, & Futrell 2022, 2024, in prep.

learning efficient building blocks

a balance between

(1) how big they are

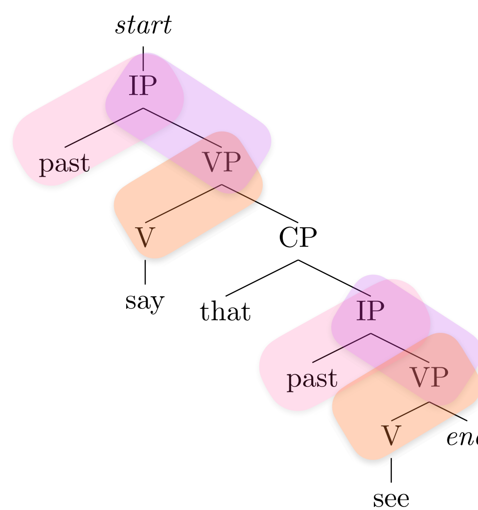
(2) how fast they are to put together to make a *wh*-dependency

$\textit{start}\text{-IP}_{\text{past}}\text{-VP}_{\text{say}}\text{-CP}_{\text{that}}\text{-IP}_{\text{past}}\text{-VP}_{\text{see}}\text{-}\textit{end}$

many smaller

slower because many

But these pieces may get reused, so that makes them faster to access.



Learn the right building blocks

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learning efficient building blocks

a balance between
(1) how big they are
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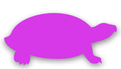
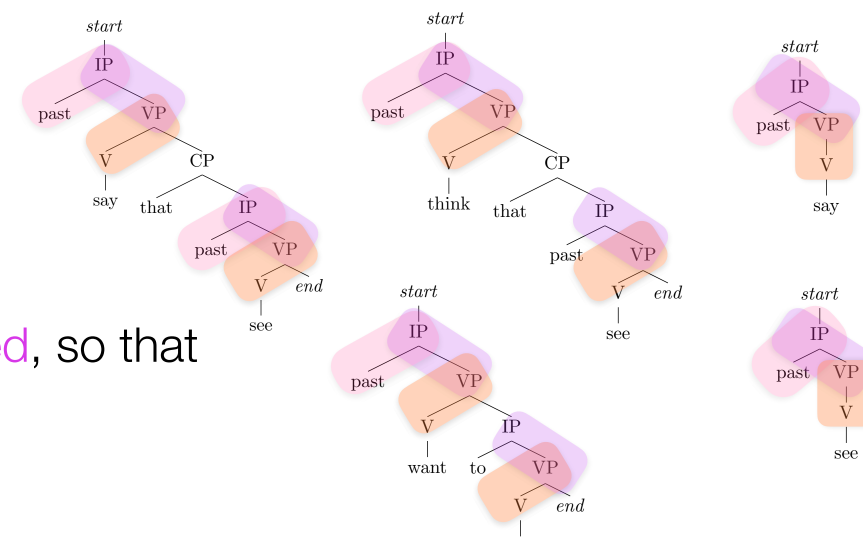
$\textit{start}\text{-IP}_{\text{past}}\text{-VP}_{\text{say}}\text{-CP}_{\text{that}}\text{-IP}_{\text{past}}\text{-VP}_{\text{see}}\text{-}\textit{end}$

many smaller



slower because many



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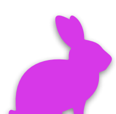

Learn the right building blocks

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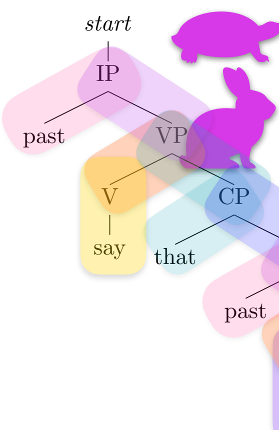
learning efficient building blocks

a balance between
(1) how big they are
(2) how fast they are to put together to make a *wh*-dependency

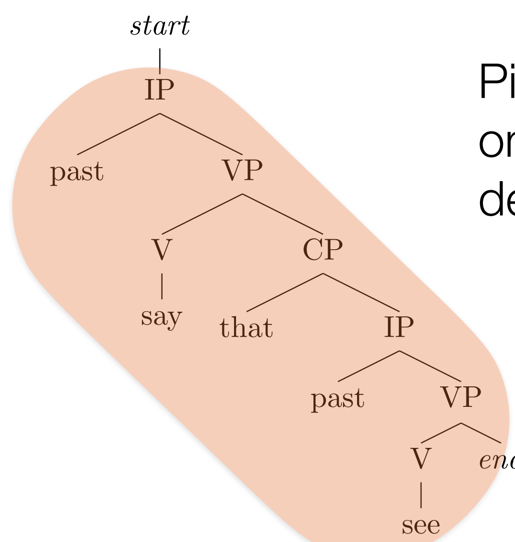
start-IP$_{\text{past}}$-VP$_{\text{say}}$-CP$_{\text{that}}$-IP$_{\text{past}}$-VP$_{\text{see}}$-*end*

many smaller



many

reused



Pieces can be big, so that only one makes up a *wh*-dependency

Learn the right building blocks

Dickson, Pearl, & Futrell 2022, 2024, in prep.

learning efficient building blocks

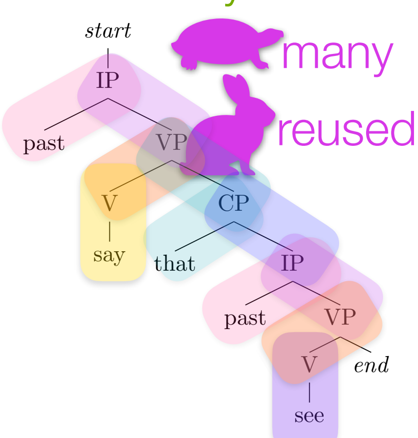
a balance between

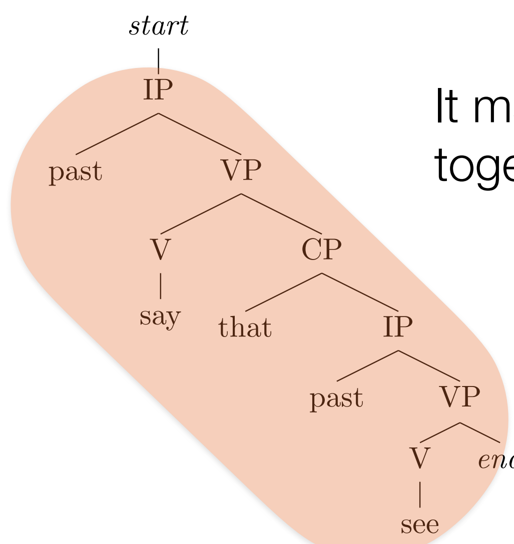
(1) how big they are

(2) how fast they are to put together to make a *wh*-dependency

start-IP_{past}-VP_{say}-CP_{that}-IP_{past}-VP_{see}-*end*

many smaller





It may be faster to put together one big piece.

Learn the right building blocks

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learning efficient building blocks

a balance between
(1) how big they are
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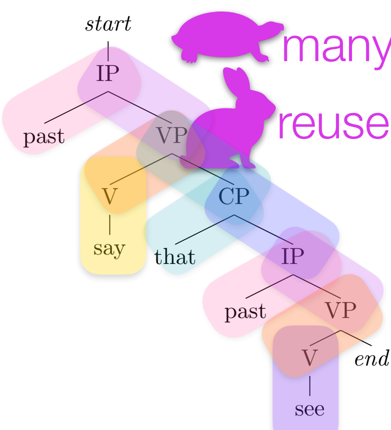
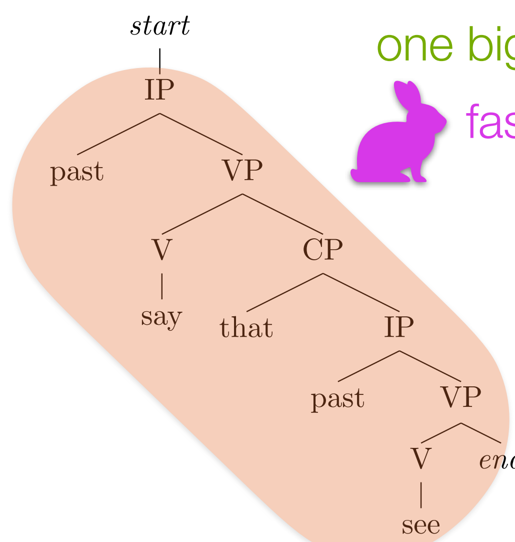
$\textit{start}\text{-IP}_{\text{past}}\text{-VP}_{\text{say}}\text{-CP}_{\text{that}}\text{-IP}_{\text{past}}\text{-VP}_{\text{see}}\text{-}\textit{end}$

many smaller



many
reused



one big

faster because one

It may be slower if the piece is used rarely.

Learn the right building blocks

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learning efficient building blocks

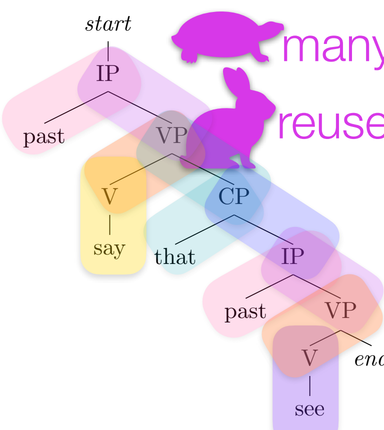
a balance between
(1) how big they are
(2) how fast they are to put together to make a *wh*-dependency

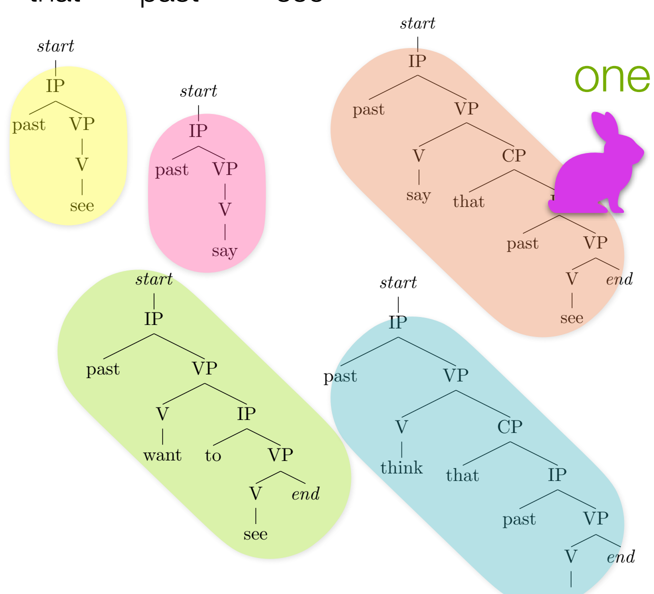
$\textit{start}\text{-IP}_{\text{past}}\text{-VP}_{\text{say}}\text{-CP}_{\text{that}}\text{-IP}_{\text{past}}\text{-VP}_{\text{see}}\text{-}\textit{end}$

many smaller

many

reused





one big

faster because one

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Learn the right building blocks

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learning efficient building blocks

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(1) how big they are
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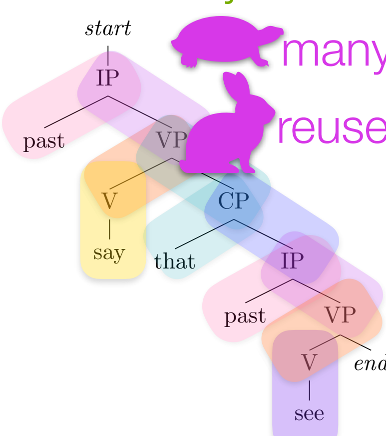
$\textit{start}\text{-IP}_{\text{past}}\text{-VP}_{\text{say}}\text{-CP}_{\text{that}}\text{-IP}_{\text{past}}\text{-VP}_{\text{see}}\text{-}\textit{end}$

many smaller

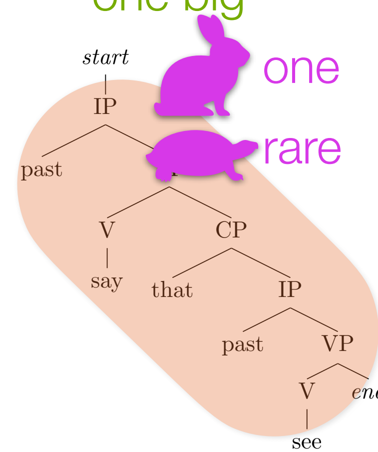


many

reused

The most efficient option is probably a balance of bigger and smaller blocks that collectively are faster to access and put together.

one big



one

rare

Learn the right building blocks

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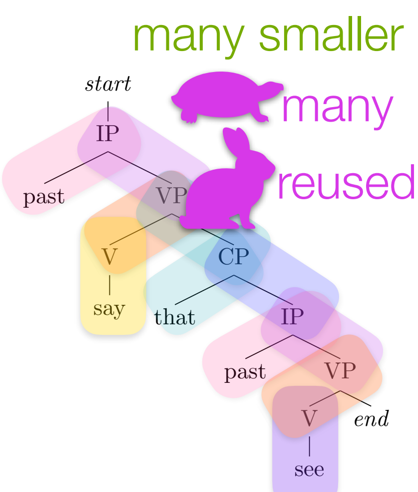
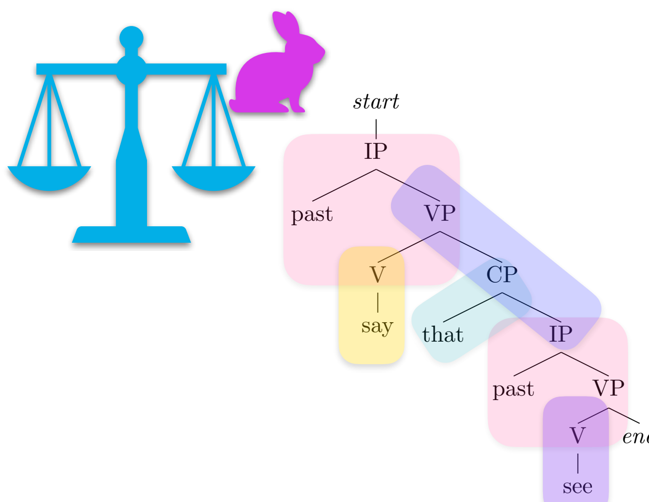
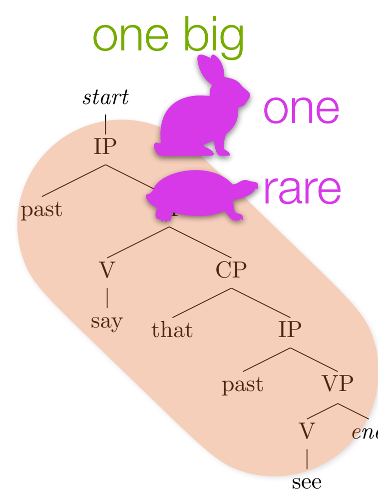
learning efficient building blocks

a balance between
(1) how big they are
(2) how fast they are to put together to make a *wh*-dependency

start-IP_{past}-VP_{say}-CP_{that}-IP_{past}-VP_{see}-*end*







Learn the right building blocks

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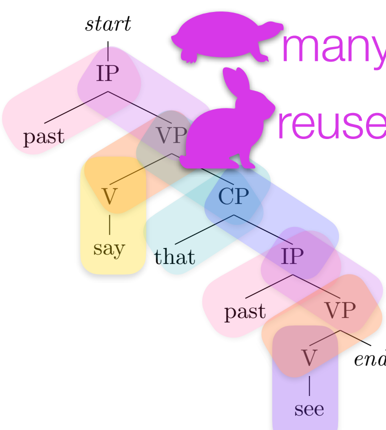
learning efficient building blocks

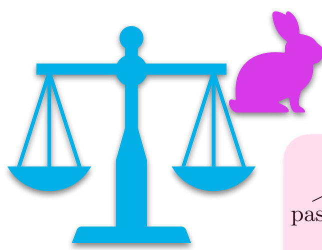
How can children find the best balance?

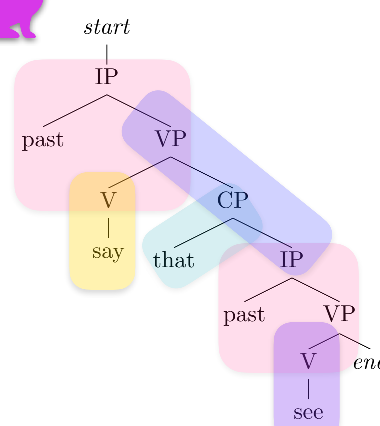
many smaller

many

reused



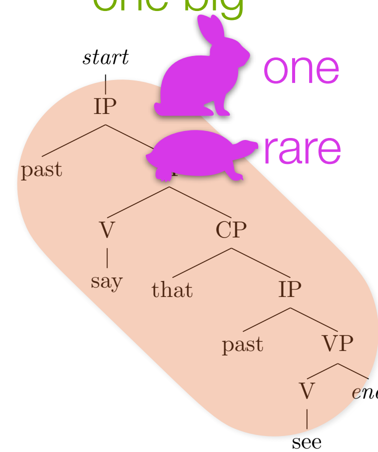




one big

one

rare



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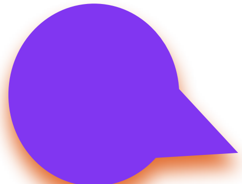

Use Bayesian inference to search through the hypothesis space of all possible building blocks (O’Donnell 2015) and find an efficient set for children’s input.

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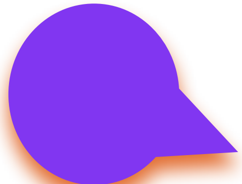
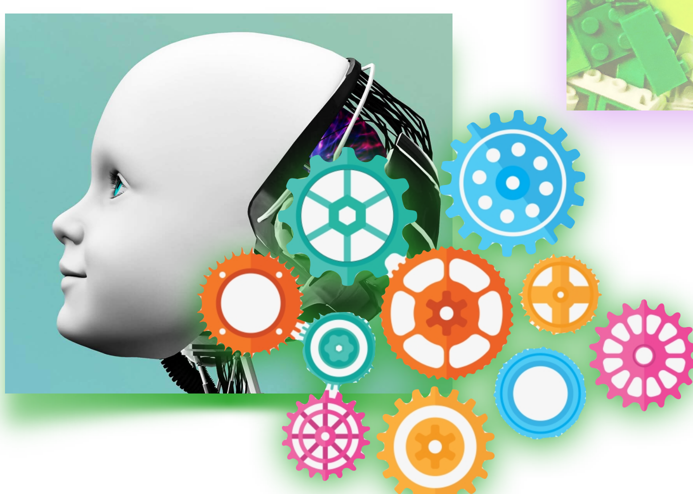


So that's what the modeled child will do



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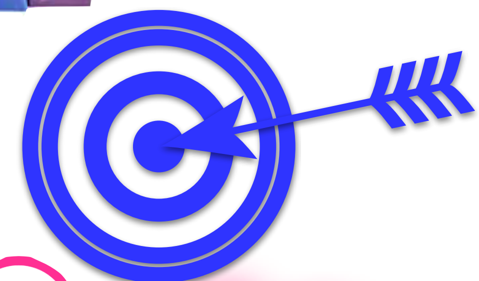
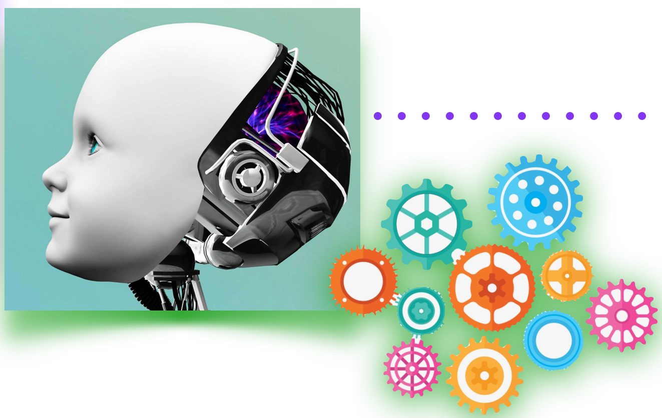
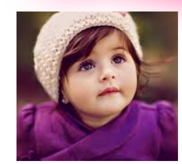


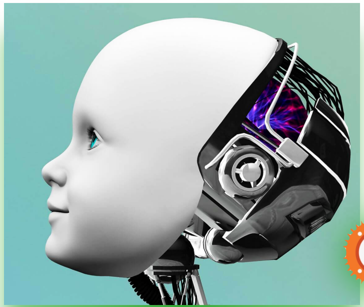
We'll see if this modeled child can learn the target knowledge that real children learn.





Dickson, Pearl, & Futrell 2022, 2024, in prep.

We'll have the modeled child learn from the same kind of input children encounter, for the same amount of time.



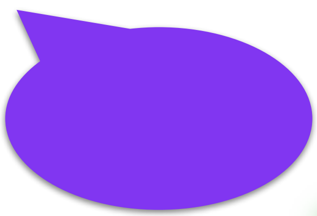
Dickson, Pearl, & Futrell 2022, 2024, in prep.

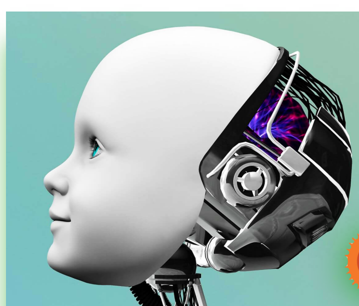
We'll have the modeled child learn from the same kind of input children encounter, for the same amount of time.

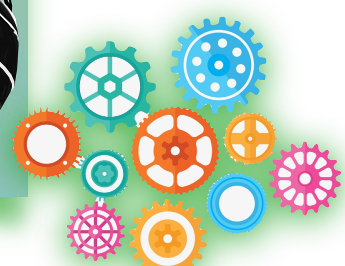
≈10,442,258 min

(derived from De Villiers et al. 2008, Perkins & Lidz 2021, & Davis et al. 2004)

Estimated from the CHILDES Treebank (Pearl & Sprouse 2013)







Dickson, Pearl, & Futrell 2022, 2024, in prep.

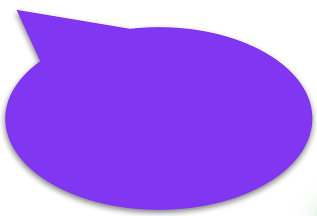
We'll have the modeled child learn from the same kind of input children encounter, for the same amount of time.

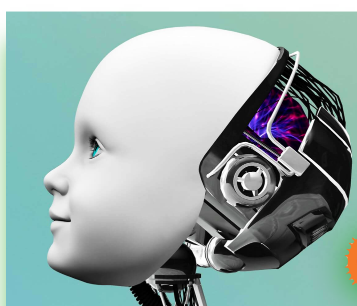
#

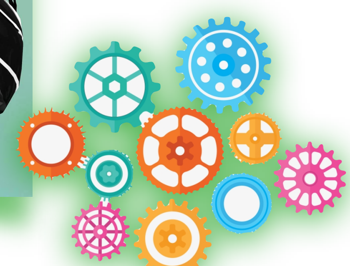
≈**2.15 million** *wh*-dependencies

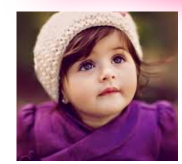
(derived from Hoff-Ginsberg 1998 and Rowe 2012)

Estimated from the CHILDES Treebank (Pearl & Sprouse 2013)

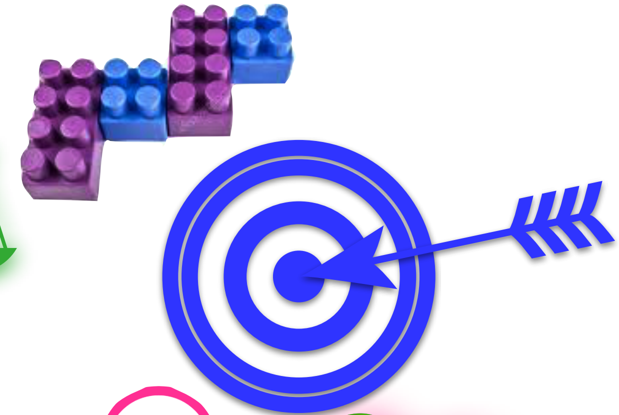




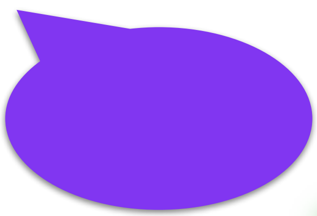


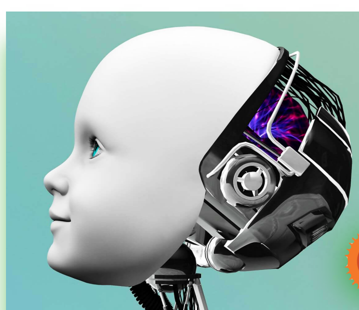


Dickson, Pearl, & Futrell 2022, 2024, in prep.



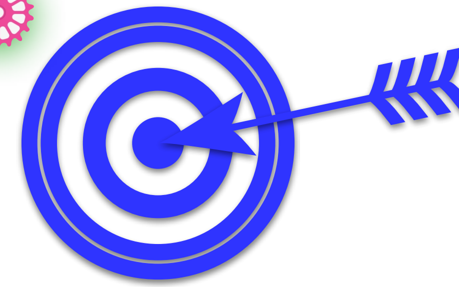
So how did the modeled child do?



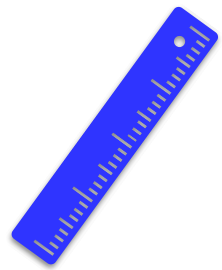


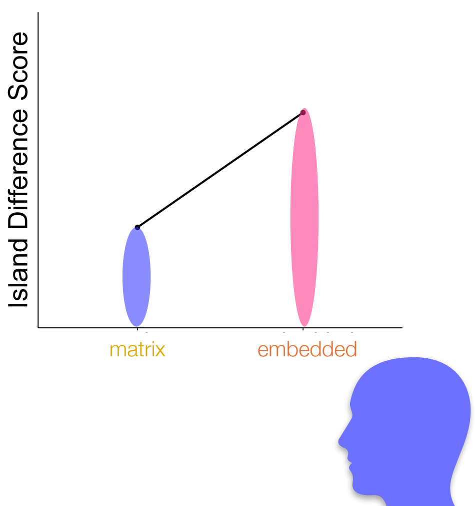


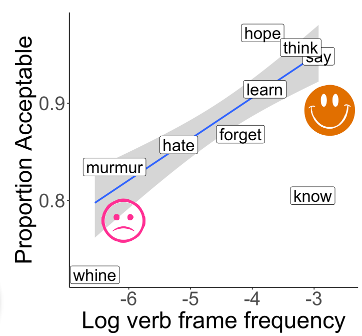
Dickson, Pearl, & Futrell 2022, 2024, in prep.

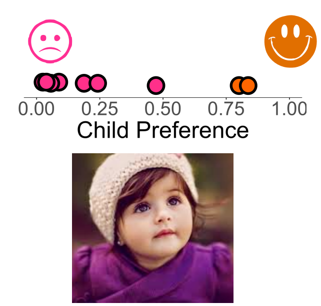



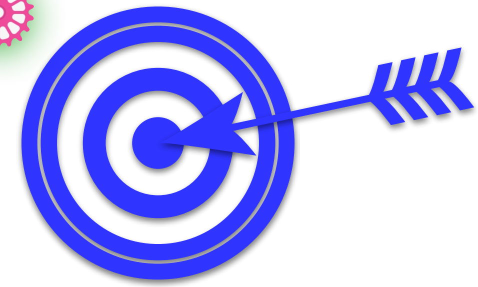
A reminder of the measurable target behavior patterns



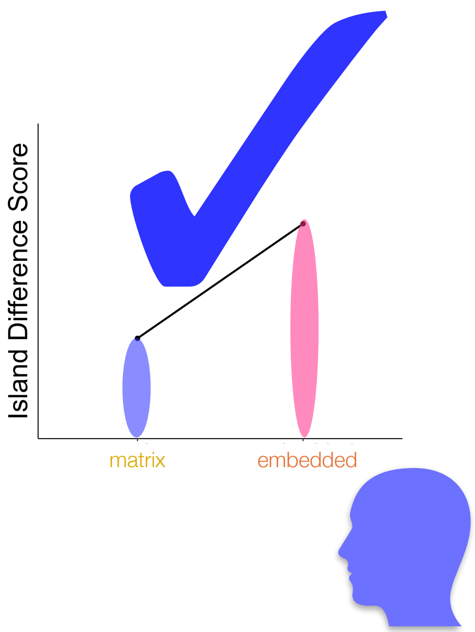


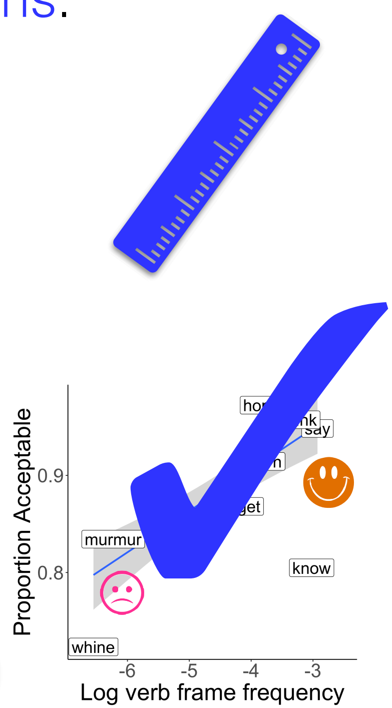




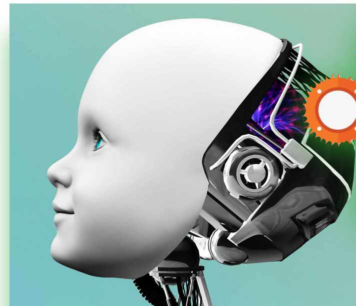
Dickson, Pearl, & Futrell 2022, 2024, in prep.

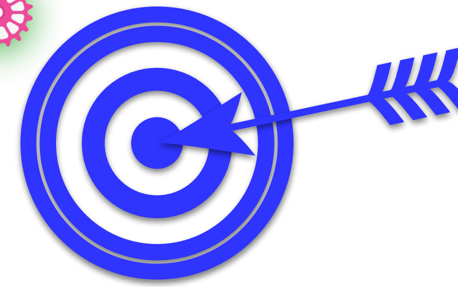
Our modeled child can generate almost all of these target patterns.



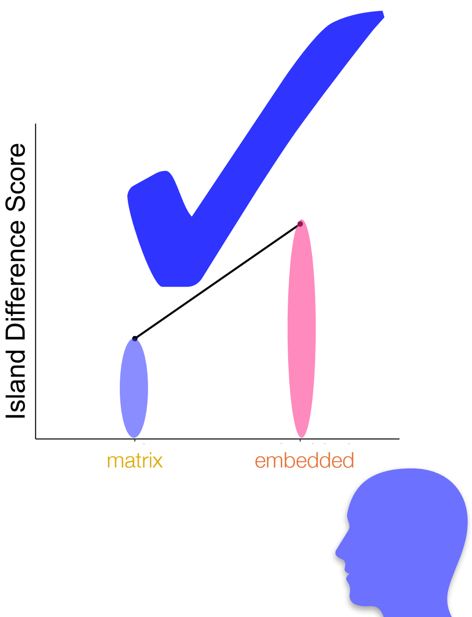


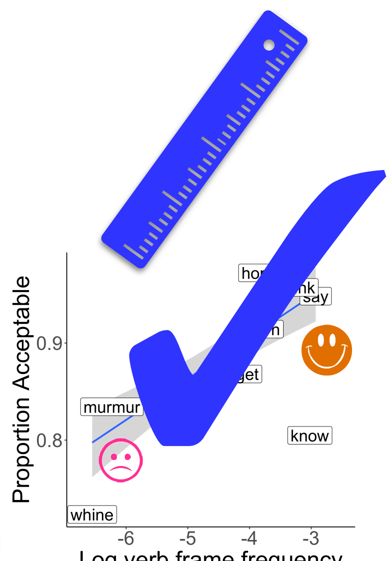
Dickson, Pearl, & Futrell 2022, 2024, in prep.

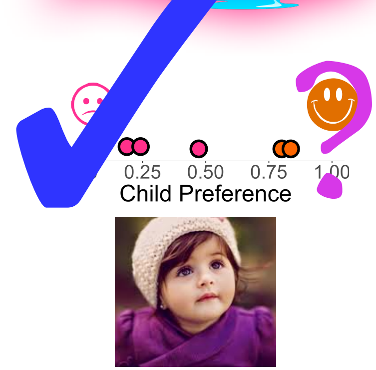




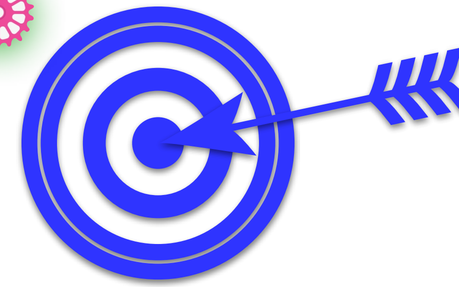
This means the modeled child, who encoded the "efficient building blocks" learning theory, was able to generate almost all of children's target behavior.



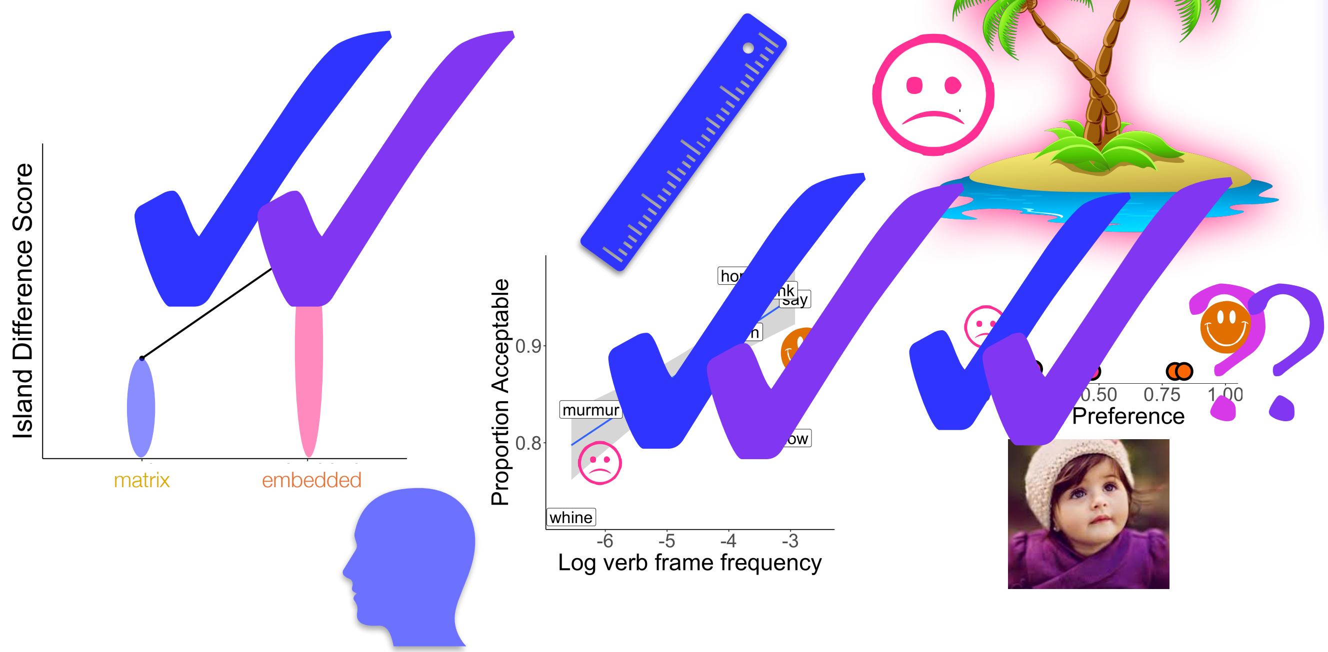




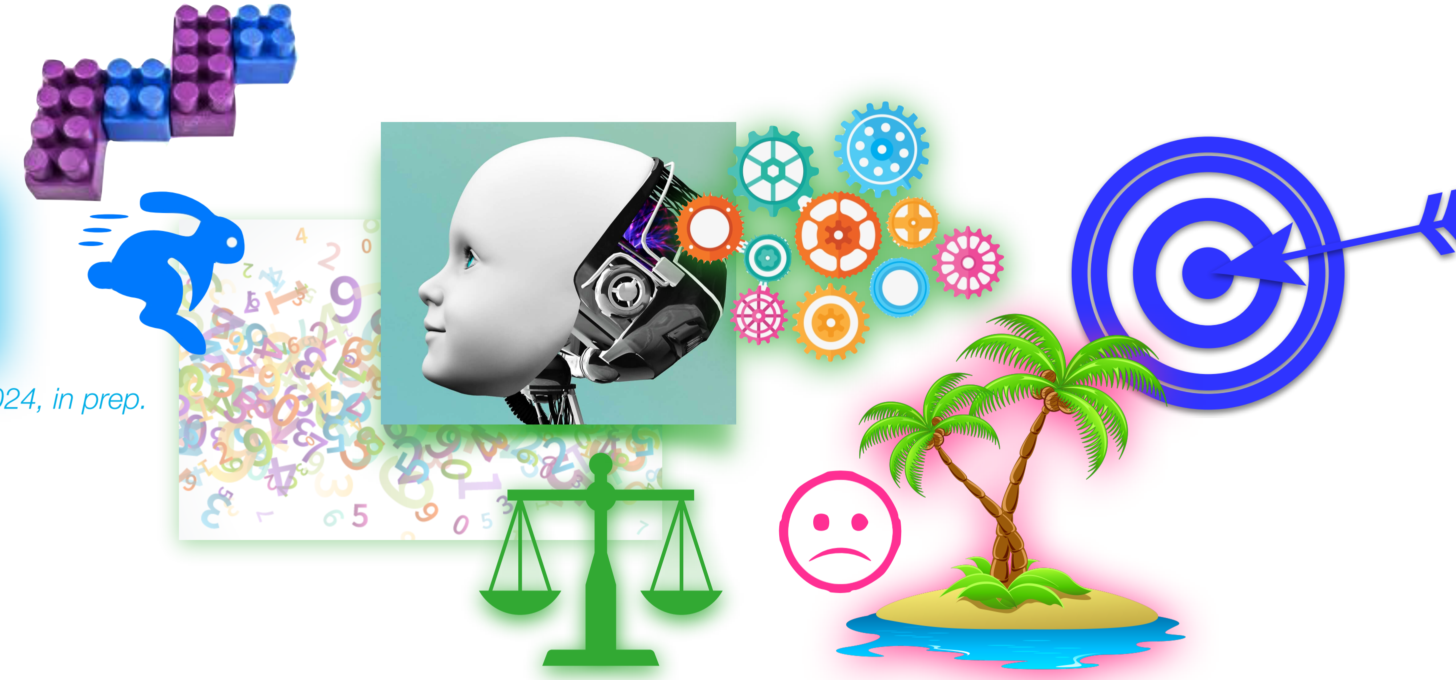
Dickson, Pearl, & Futrell 2022, 2024, in prep.



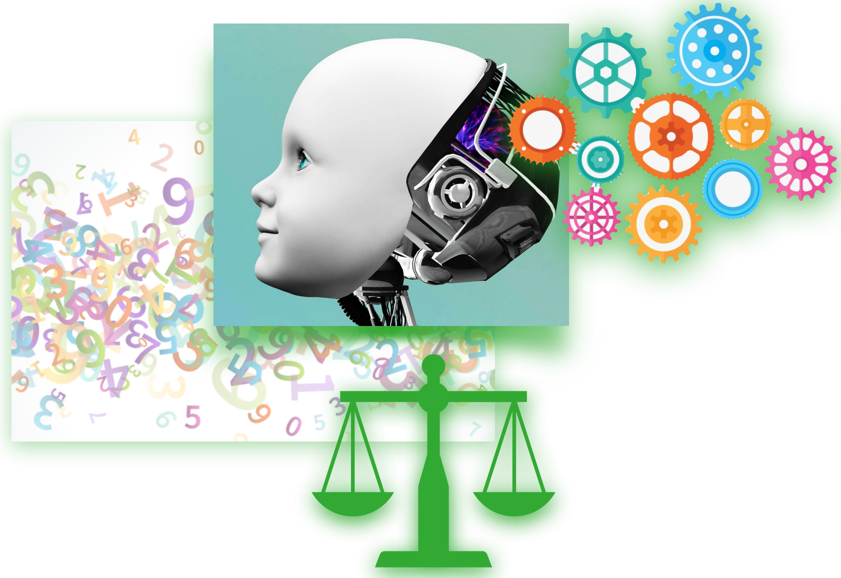
It turns out this is also true even if the modeled child has child-like memory constraints that cause it to forget some of its input.



Dickson, Pearl, & Futrell 2022, 2024, in prep.

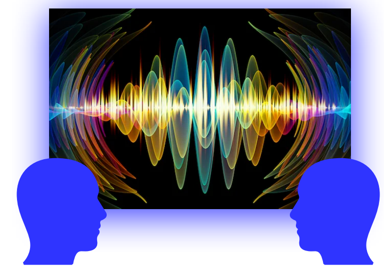


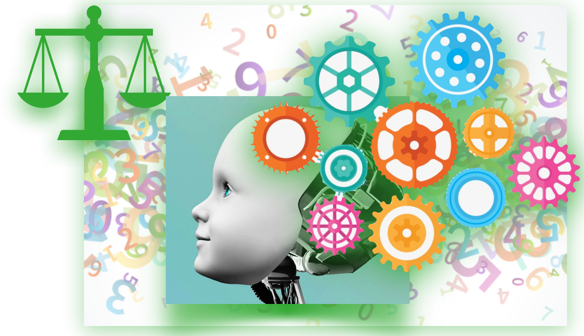
Takeaway: This learning theory (implemented by the modeled child using math) is pretty good at capturing children's target behavior. So, it may be a pretty good explanation for how children acquire syntactic island knowledge from their input.



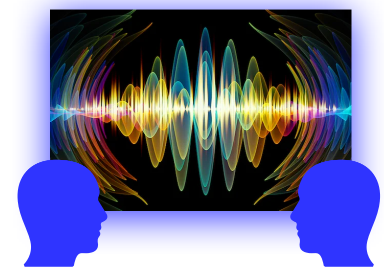
Some other discoveries from my research group,
using computational cognitive modeling

Children transform the input signal they encounter in order to learn.

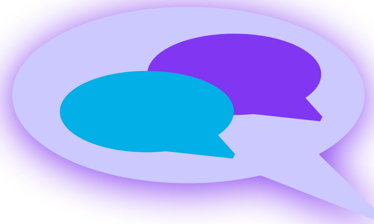




Sometimes acquisition success may result only when the data intake for acquisition is a selective subset of the available input.



(*basic word order*: Pearl 2005a,b, 2007, Pearl and Weinberg 2007; *metrical stress*: Pearl 2007, 2008, 2009, 2011, Pearl, Ho and Detrano 2014, 2016, Pearl 2017; *English anaphoric one*: Pearl 2007, Pearl and Lidz 2009; *syntactic islands*: Pearl and Sprouse 2013a,b, Pearl 2014, Pearl and Sprouse 2015; *English passive*: Nguyen and Pearl 2019, 2021)



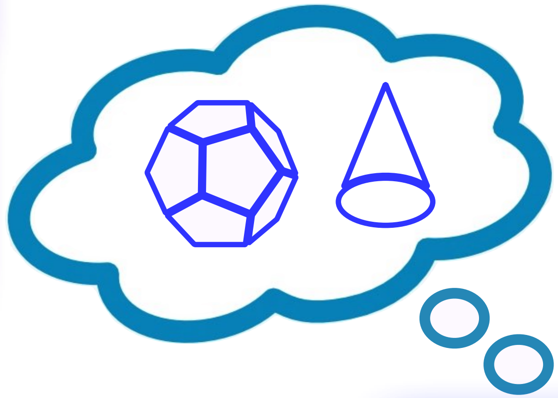
However, sometimes acquisition success may also occur by taking a broader perspective on what counts as relevant data.

(Pearl 2023a; *English anaphoric one*: Pearl and Mis 2011, 2016; *syntactic islands*: Pearl and Sprouse 2013a,b, Pearl 2014, Pearl and Sprouse 2015, Pearl 2017, Bates and Pearl 2019, Pearl and Bates 2022; *English passive*: Nguyen and Pearl 2018, 2019, 2021).

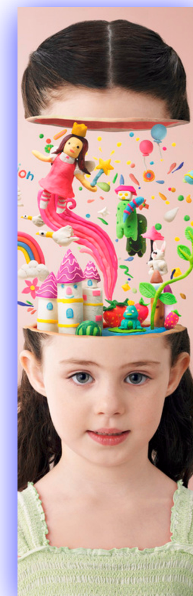
Children’s knowledge during language development may be different than we thought.

To learn some types of linguistic knowledge, children may need to have language-specific knowledge built into their minds — however the exact form of this knowledge may be different than what we previously thought.

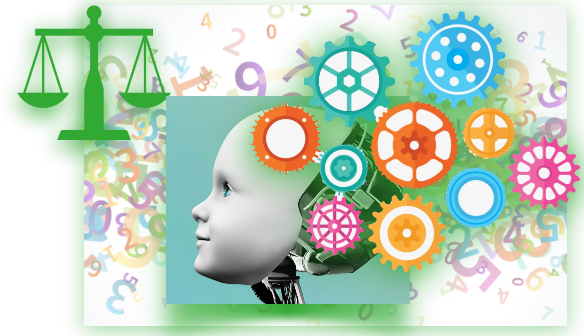
(*English anaphoric one*: Pearl and Lidz 2009, Pearl and Mis 2011, 2016; *syntactic islands*: Pearl and Sprouse 2013a,b, Pearl 2014, Pearl and Sprouse 2015, Dickson, Pearl and Futrell 2022; *linking theories*: Pearl and Sprouse 2019, 2021)



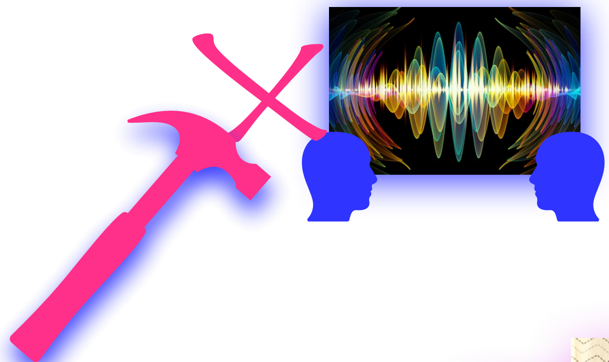
Children’s linguistic knowledge may sometimes be far more well-developed than we realize earlier than we realize, with strong similarities between child and adult representations



(*closed-class syntactic categories*: Bates, Pearl and Braunwald 2018; *quantifier scope ambiguity resolution*: Savinelli, Scontras and Pearl 2017, 2018, Scontras and Pearl 2021; *adjective ordering preferences*: Bar-Sever, Lee, Scontras and Pearl 2018; *pronoun interpretation*: Forsythe and Pearl 2019, Pearl and Forsythe under review)

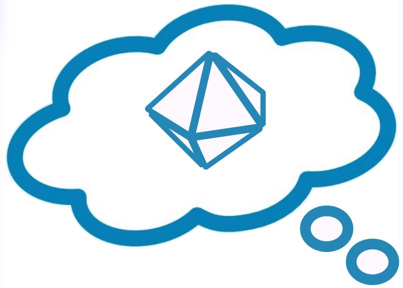


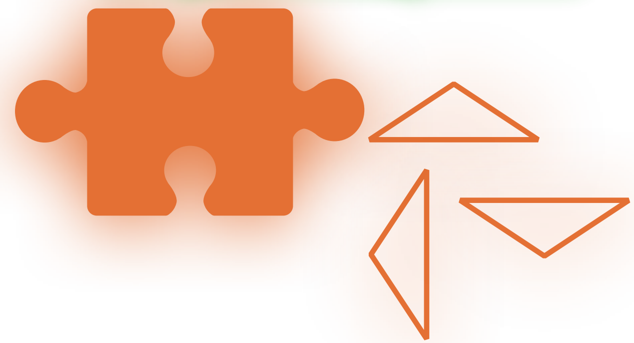
"Different" doesn't automatically mean "worse" when it comes to language development.



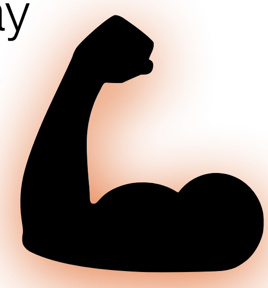
While there is certainly input variation across socio-economic status, the same language learning outcome could still occur, despite the variation. So, interventions targeted at "fixing" the input aren't likely to be effective.

syntactic islands: Bates and Pearl 2019, Pearl and Bates 2022





Even if the representations of very young children may not match adult representations, they can still be "good enough" for helping other acquisition processes get started.



early speech segmentation: Phillips and Pearl 2012, 2014a,b, 2015a,b,c, Pearl and Phillips 2018; *early syntactic categorization*: Bar-Sever and Pearl 2016

Learners with processing constraints (like children) may sometimes learn better than learners with fewer limitations ("less is more").

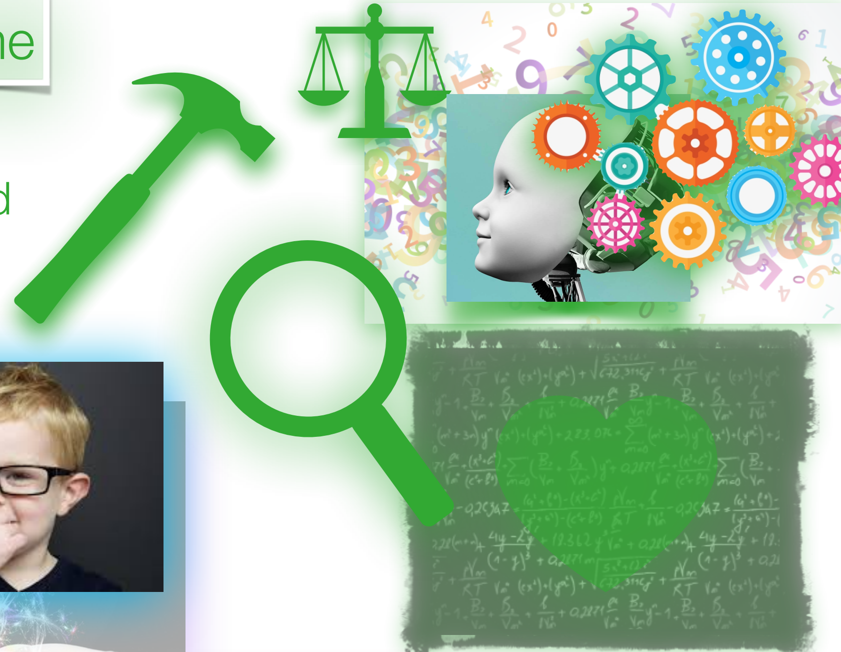
speech segmentation: Pearl, Goldwater and Steyvers 2010, 2011, Phillips and Pearl 2012, 2015c

Take home

Computational cognitive modeling is one way to use math to investigate the magical process of child language acquisition

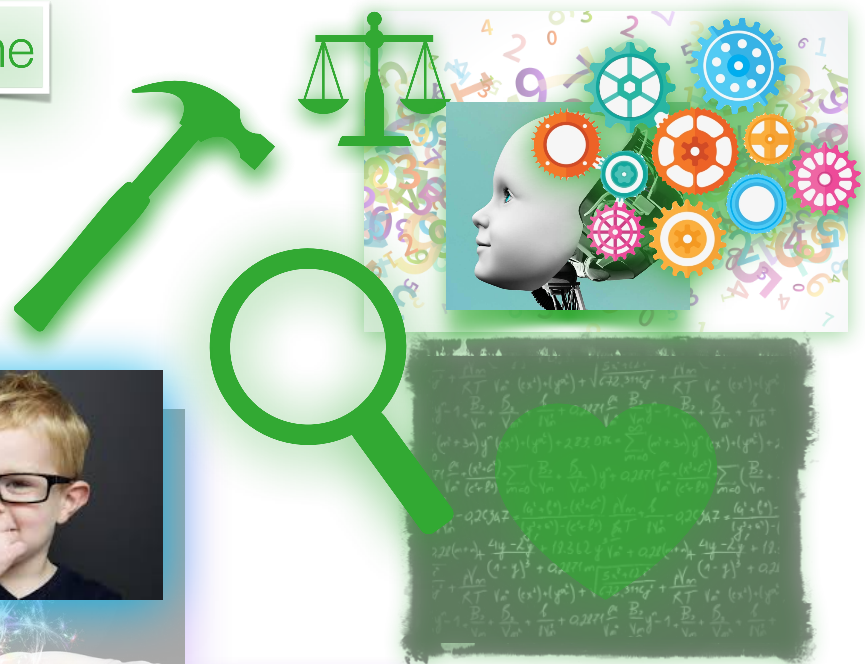
Take home

It allows us to implement learning theories concretely, evaluate them, and better understand how they (and potentially children) work.



Take home

So let's keep using this wonderful tool to investigate child language acquisition!



Thank you!

Niels Dickson	Richard Futrell	Jon Sprouse	Alandi Bates
			

BUCLD 2018   UCSD Linguistics 2020   ForMA Group 2020
UMD Linguistics 2020   BUCLD 2021   SCiL 2022
UArizona Linguistics 2022   UChicago LEAP 2022
UPenn 2023   Pomona Acquisition Workshop 2024
UCI QuantLang Collective

Computation of Language Laboratory
UC Irvine

Lisa S. Pearl
Professor
Department of Language Science
SSPB 2219
University of California, Irvine
lpearl@uci.edu