Integrating conceptual and syntactic cues to understand the development of English verb classes

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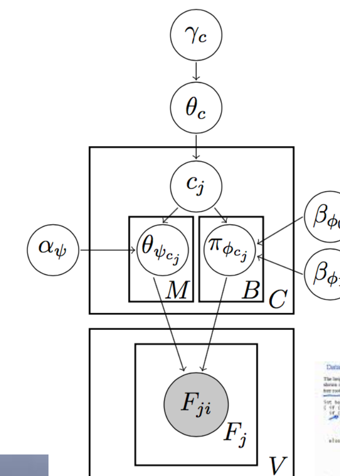
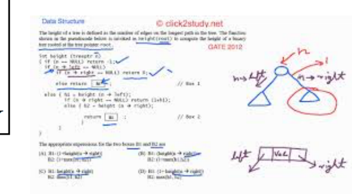
done-to

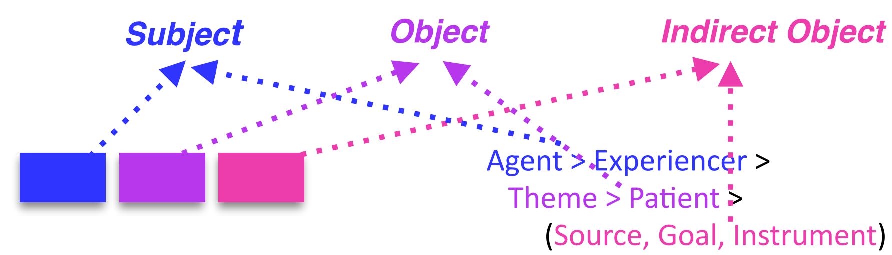
The ice melted.

The penguin climbed.

doer







July 24, 2017

Symposium on advances in distributional models of language and meaning (Math Psych/ICCM)

Today's plan

Verb classes

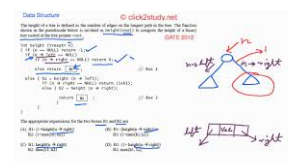
done-to

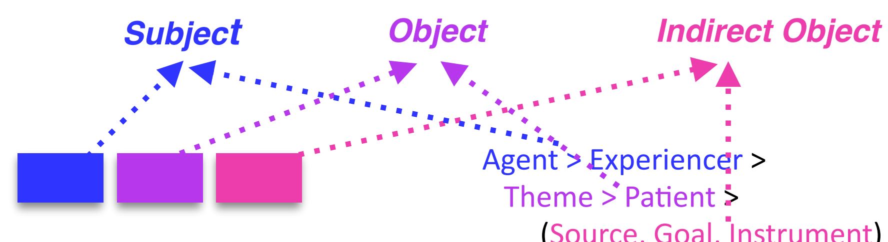
The ice melted.

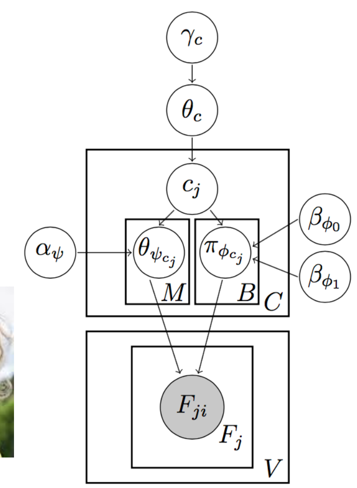
The penguin climbed.

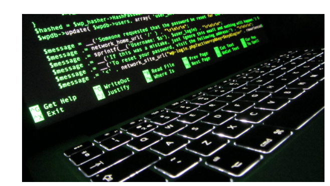
doer

Computational modeling

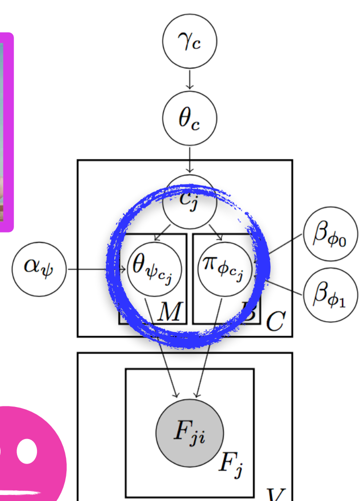


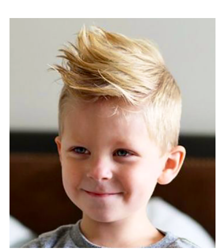


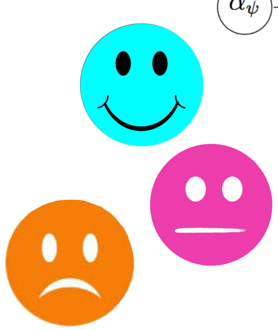




Results & implications







Verb classes

Verbs allow a variety of options for where their arguments appear …

try

She tried to melt the ice.

**It tried that she melted the ice.*

seem

The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.

Verb classes

Verbs allow a variety of options for where their arguments appear and how they're interpreted.

try

***doer**$_{melt}$*
***doer**$_{tried}$*
She tried to melt the ice.

doer$_{melted}$
**It tried that she melted the ice.*

seem

***doer**$_{climb}$*
The penguin seemed to climb the hill.

doer$_{climb}$
It seemed that the penguin climbed the hill.

Verb classes

Verbs allow a variety of options for where their arguments appear and how they're interpreted.

try

doer$_{melt}$
doer$_{tried}$
She tried to melt the ice.

**It tried that she melted the ice.*

seem

doer$_{climb}$
The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.

melt

done-to$_{melted}$
The ice melted.

doer$_{climbed}$
The penguin climbed.

climb

Verb classes

Each verb has **certain linguistic patterns of behavior**, which are shared with other verbs in the same verb class.

want need

subject-control

try

***doer**$_{melt}$*

***doer**$_{tried}$*

She tried to melt the ice.

**It tried that she melted the ice.*

appear

subject-raising

seem

***doer**$_{climb}$*

The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.

***done-to**$_{melted}$*

The ice melted.

melt

unaccusative

break fall

***doer**$_{climbed}$*

The penguin climbed.

climb

unergative

laugh dance

Verb classes

How do we tell how a new verb will behave?

The water seemed to blick.

want need

subject-control

try

doer$_{melt}$

doer$_{tried}$

She tried to melt the ice.

*It tried that she melted the ice.

appear

subject-raising

seem

doer$_{climb}$

The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.

done-to$_{melted}$

The ice melted.

melt

unaccusative

break fall

doer$_{climbed}$

The penguin climbed.

climb

unergative

laugh dance

Verb classes

We can recognize that it belongs to a specific verb class,
and use that knowledge to predict its behavior.

The water seemed to blick.

want need

subject-control

doer$_{\textit{melt}}$

try

doer$_{\textit{tried}}$

She tried to melt the ice.

**It tried that she melted the ice.*

appear

subject-raising

seem

doer$_{\textit{climb}}$

The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.

done-to$_{\textit{melted}}$

The ice melted.

doer$_{\textit{climbed}}$

The penguin climbed.

blick melt

unaccusative

break fall

climb

unergative

laugh dance

done-to$_{\textit{blicked}}$

The water blicked.

Verb classes

This is what we think kids are doing, too.

The water seemed to blick.

want need

subject-control

try

doer$_{melt}$

doer$_{tried}$

She tried to melt the ice.

**It tried that she melted the ice.* (marked with a leading *)

appear

subject-raising

seem

doer$_{climb}$

The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.

done-to$_{melted}$

The ice melted.

blick melt

unaccusative

break fall

doer$_{climbed}$

The penguin climbed.

climb

unergative

laugh dance

done-to$_{blicked}$

The water blicked.

Verb classes

Important developmental step:
Grouping verbs into useful **classes** based on their **behavior**.

melt
unaccusative
break fall

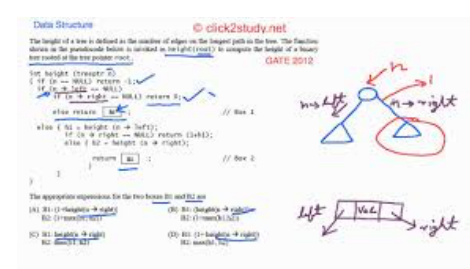
want need
subject-control
try

appear
subject-raising
seem

climb
unergative
laugh dance

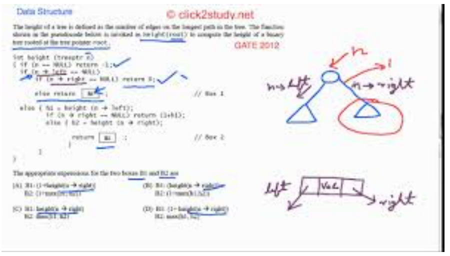
So how might children do this?

And how can we test different proposals about how they might do this?



Today's plan

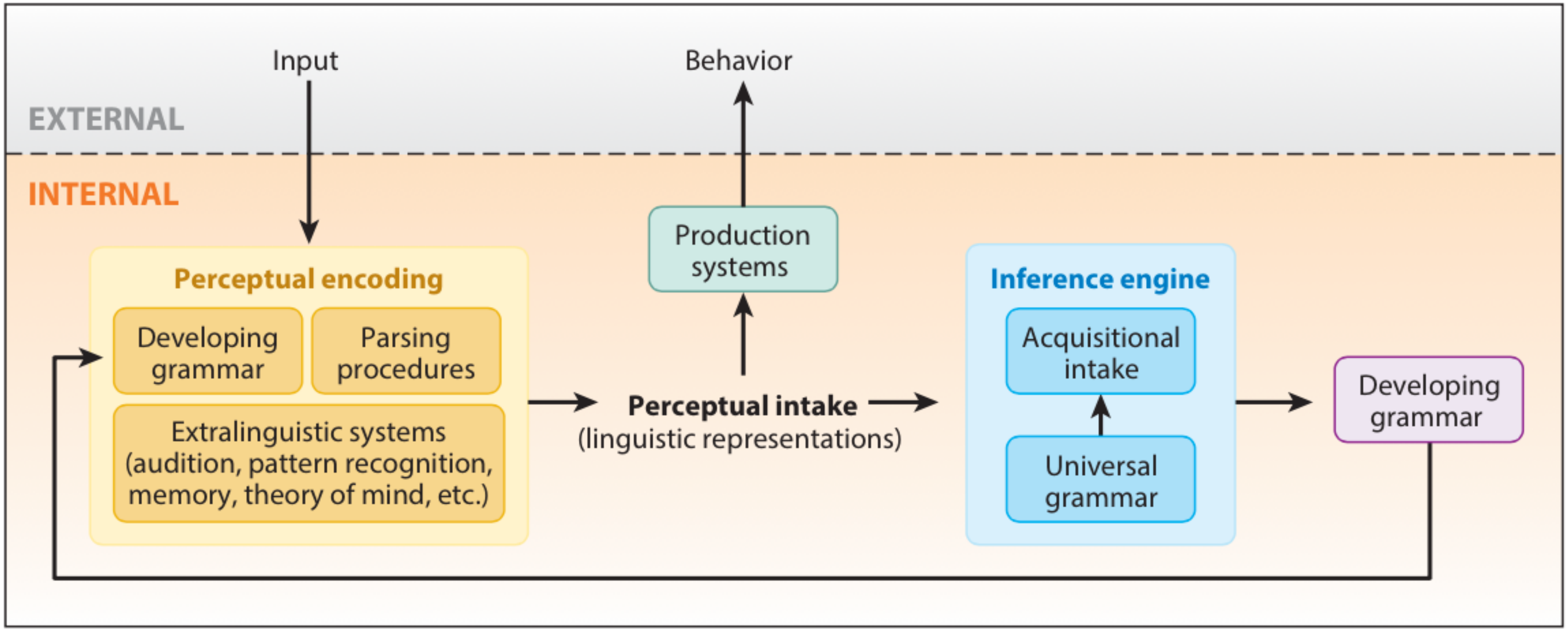
Computational modeling of language acquisition



A brief overview

Language acquisition = Information processing task

Language acquisition = Information processing task

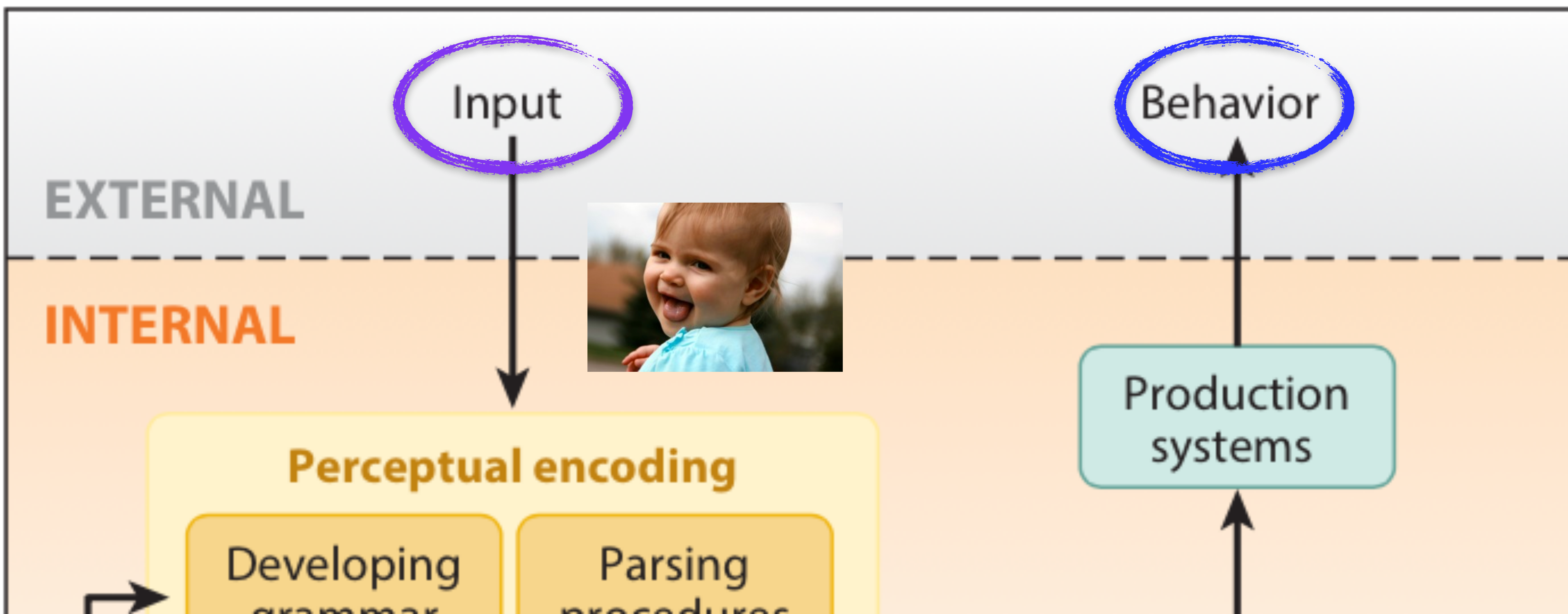


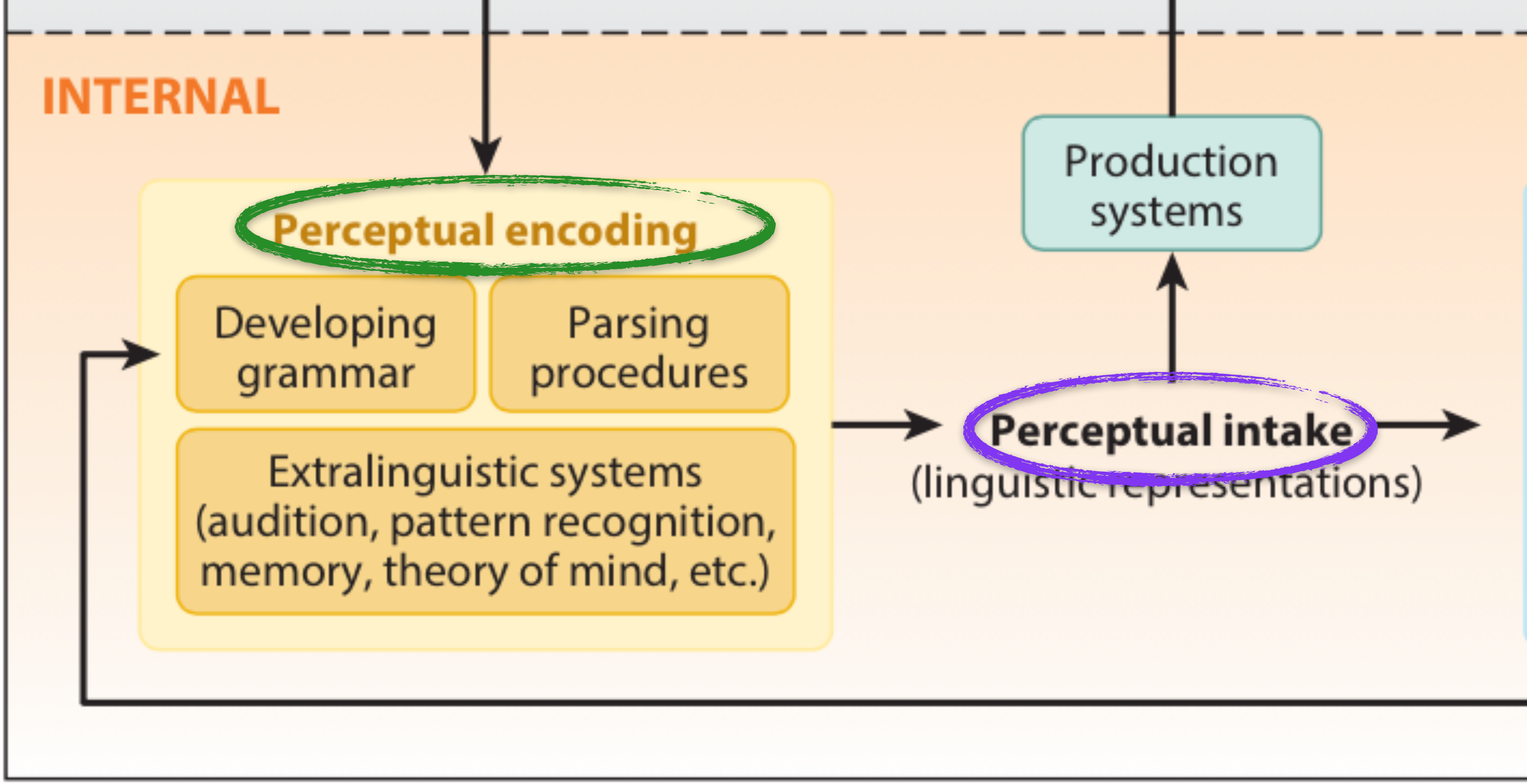
Lidz & Gagliardi 2015

A framework that makes components of the acquisition task more explicit.

A framework that makes components of the acquisition task more explicit.

Distinguishes between things external to the child that we can observe (input signal, child's behavior) vs. things internal to the child (everything else).

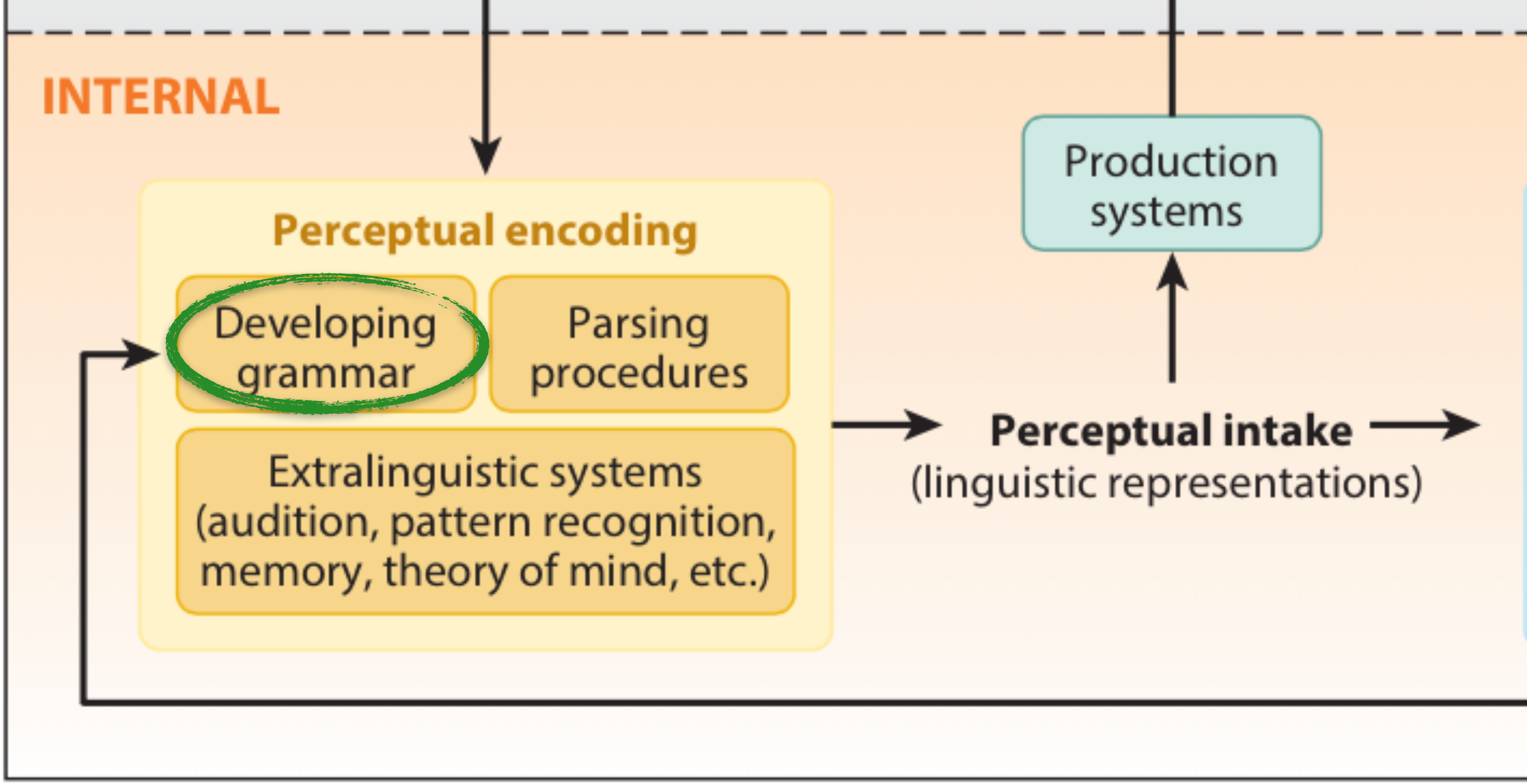




Lidz & Gagliardi 2015

Perceptual encoding:

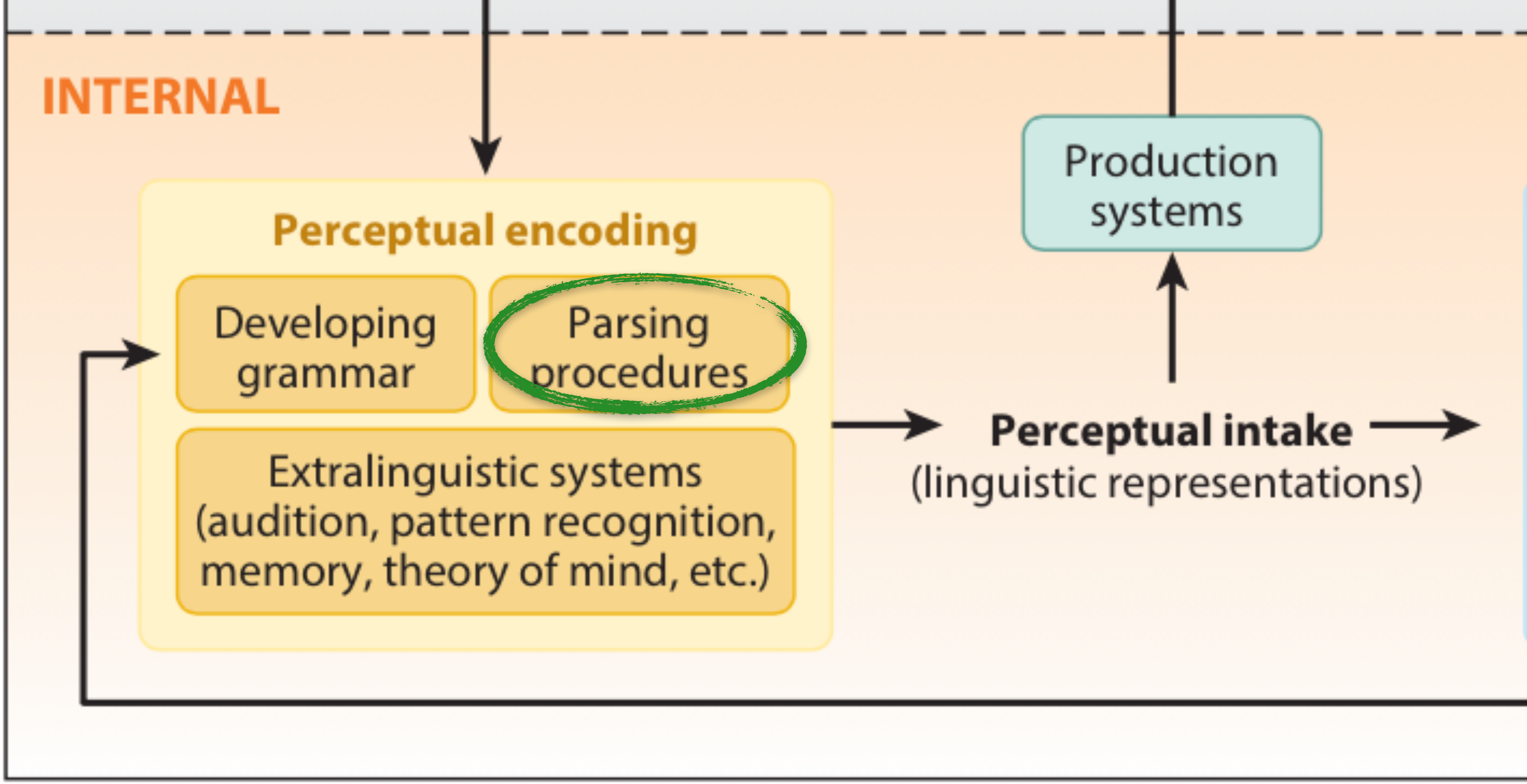
Turning the input signal into an internal linguistic representation = perceptual intake.



Lidz & Gagliardi 2015

Perceptual encoding:

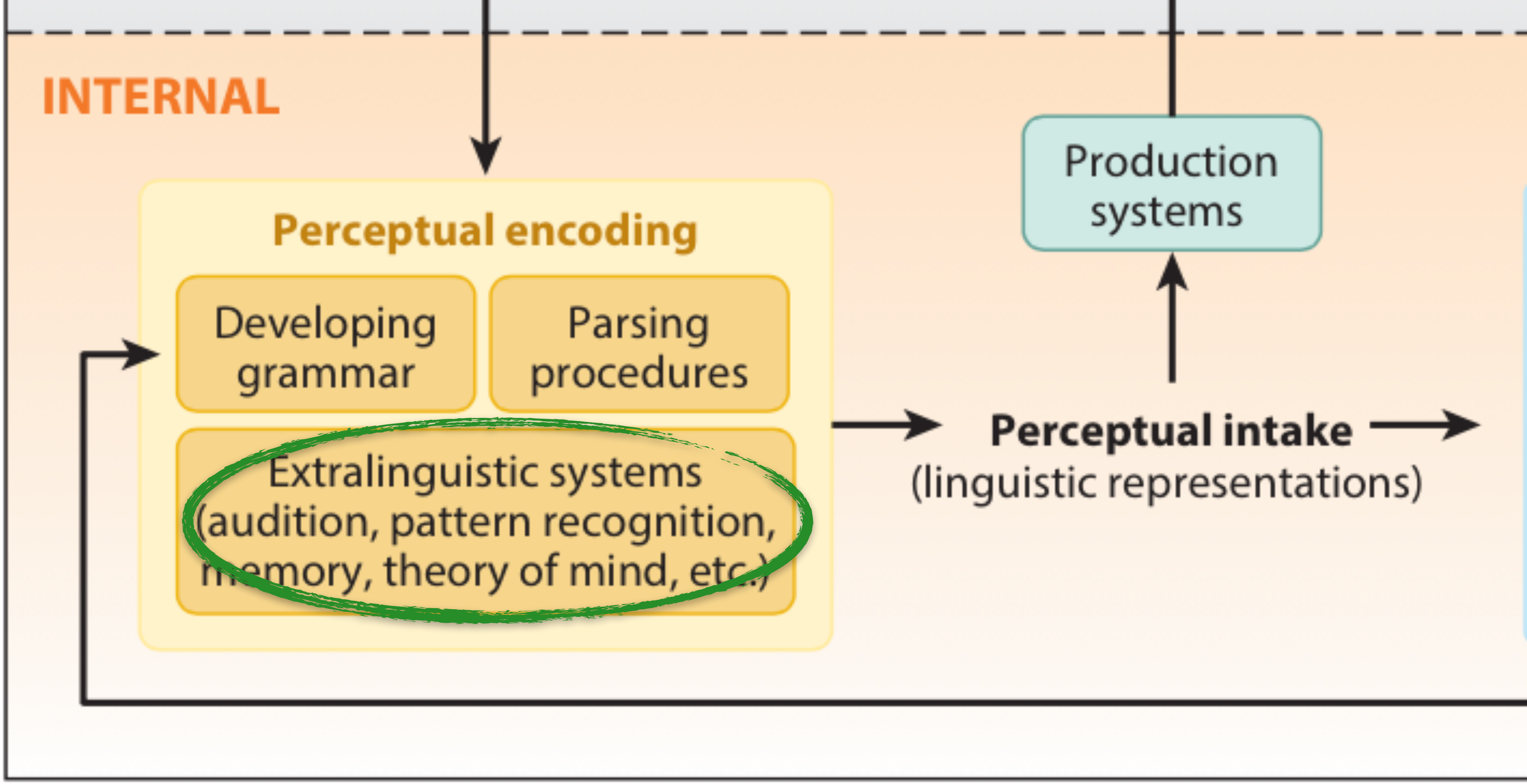
Involves current grammar



Lidz & Gagliardi 2015

Perceptual encoding:

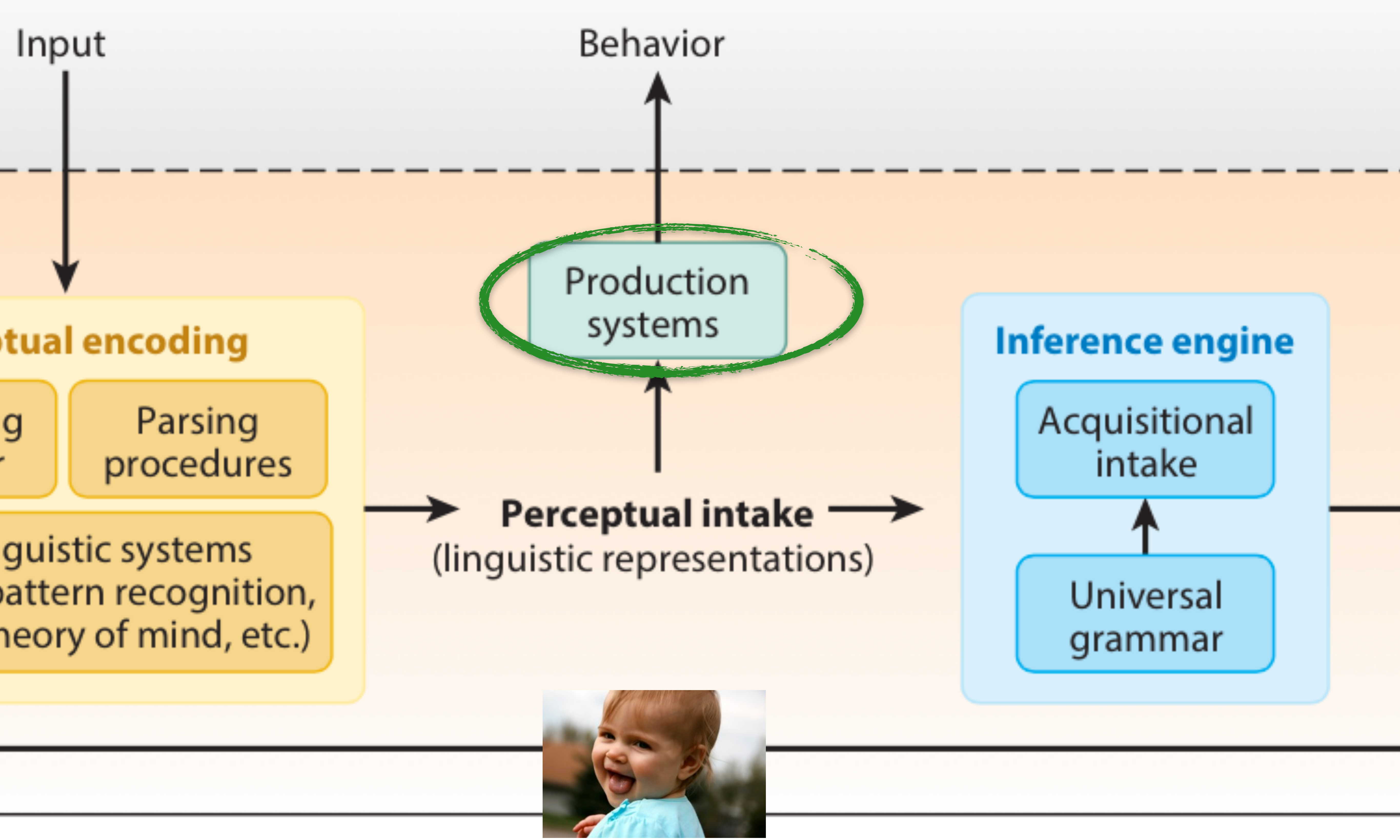
Involves current grammar being deployed in real time to parse the input



Lidz & Gagliardi 2015

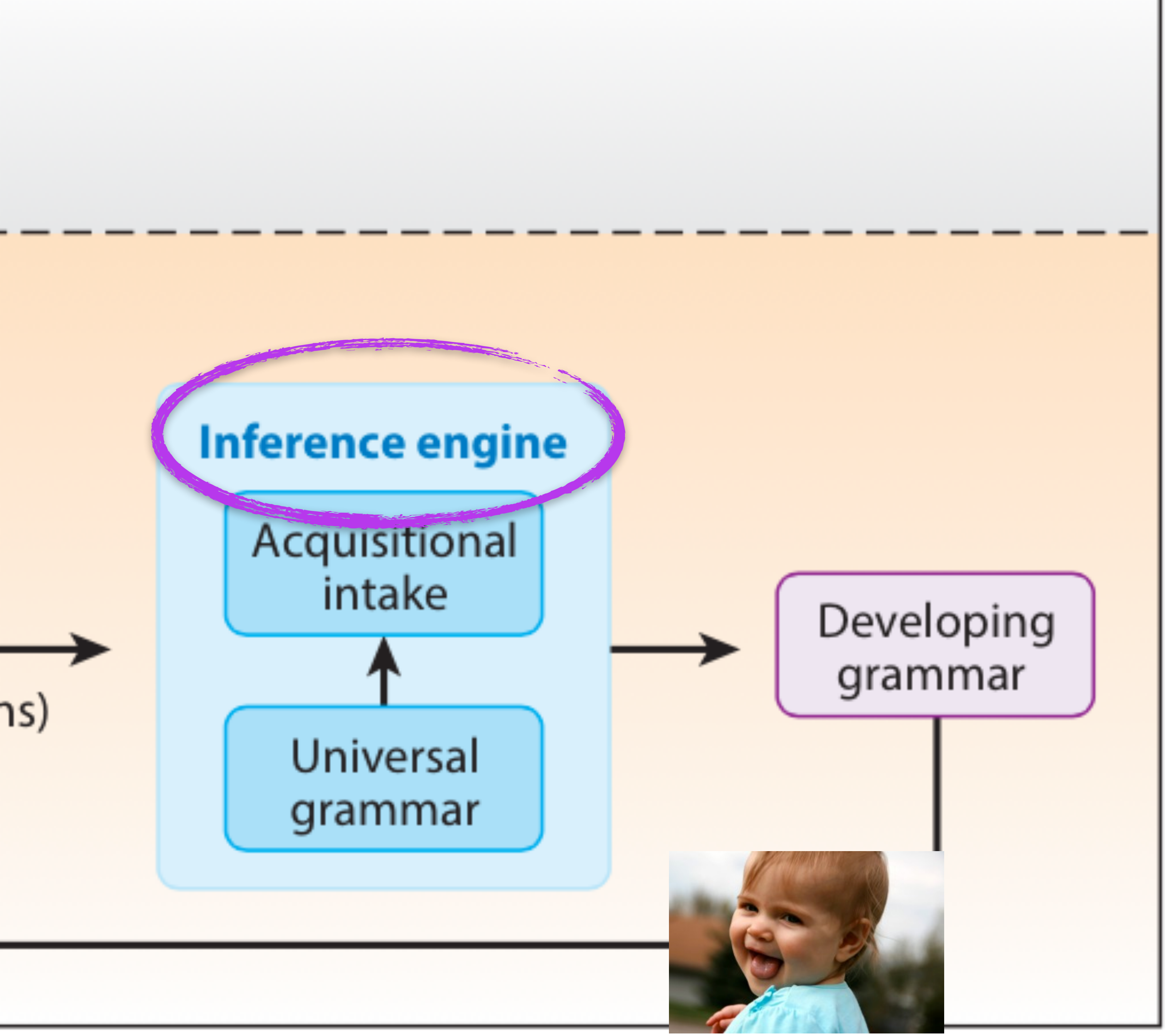
Perceptual encoding:

Involves current grammar being deployed in real time to parse the input, often drawing on extralinguistic systems



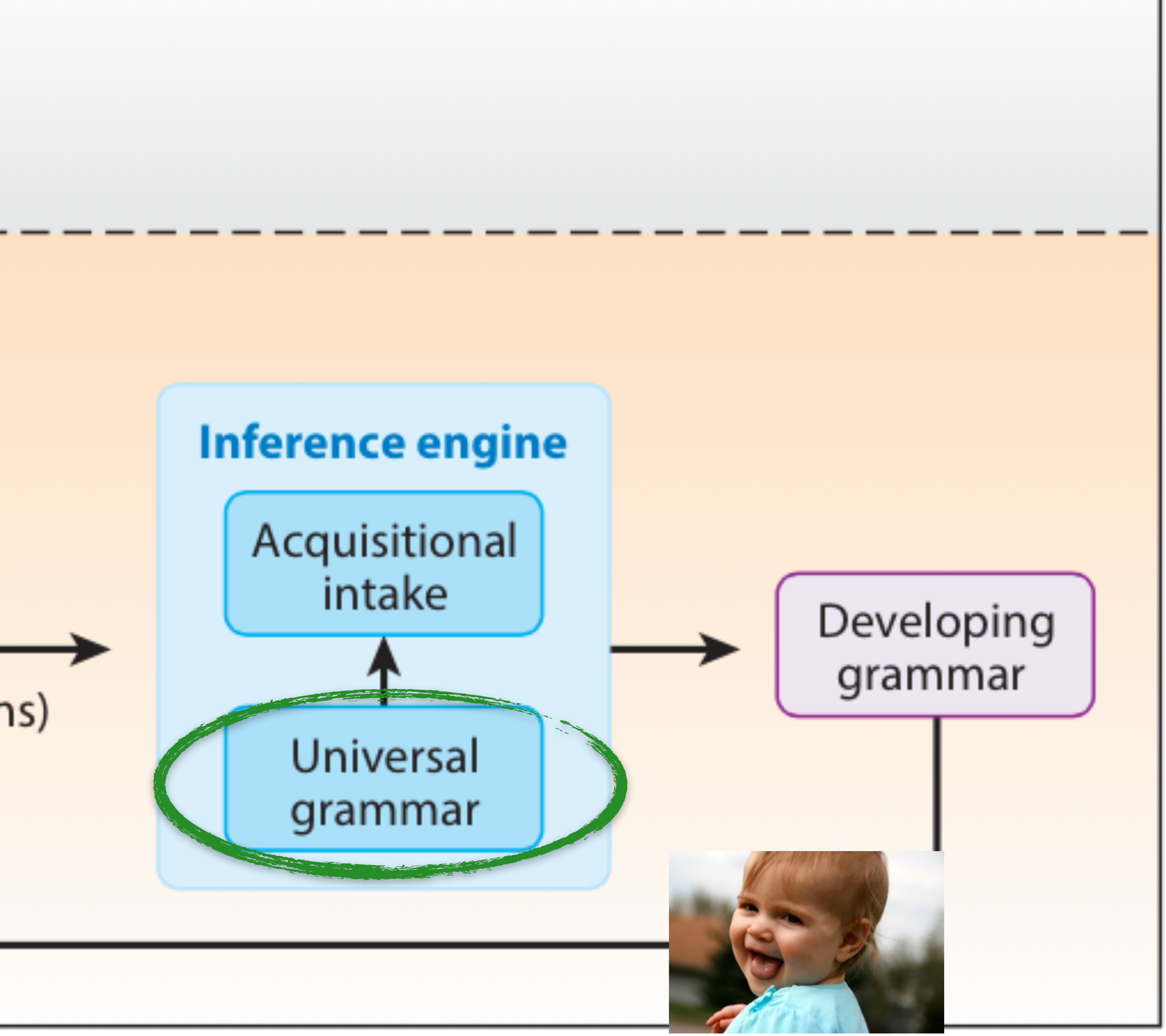
Generating observable behavior

Involves current linguistic representations being used by production systems.



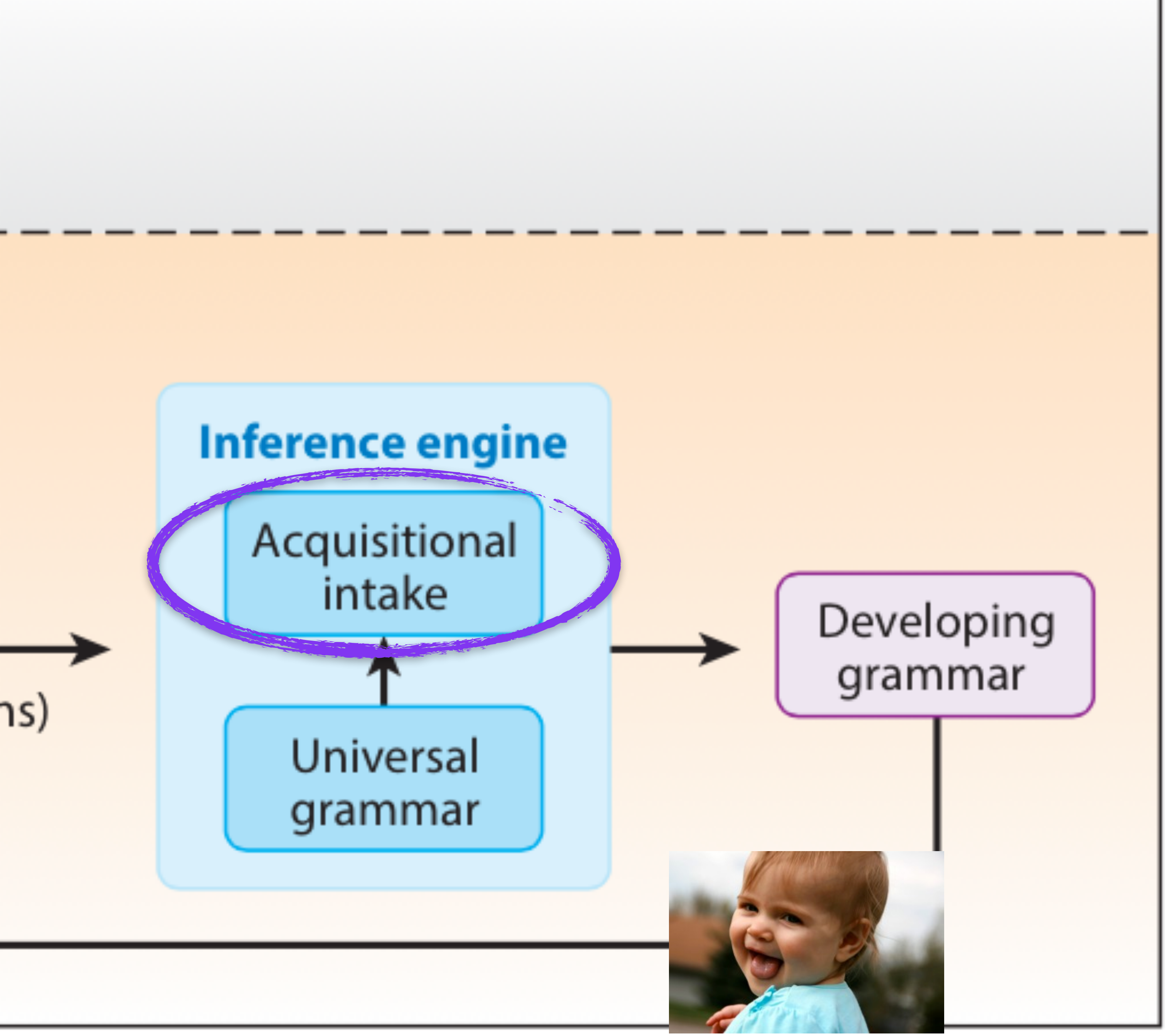
Doing inference

Generalization happens



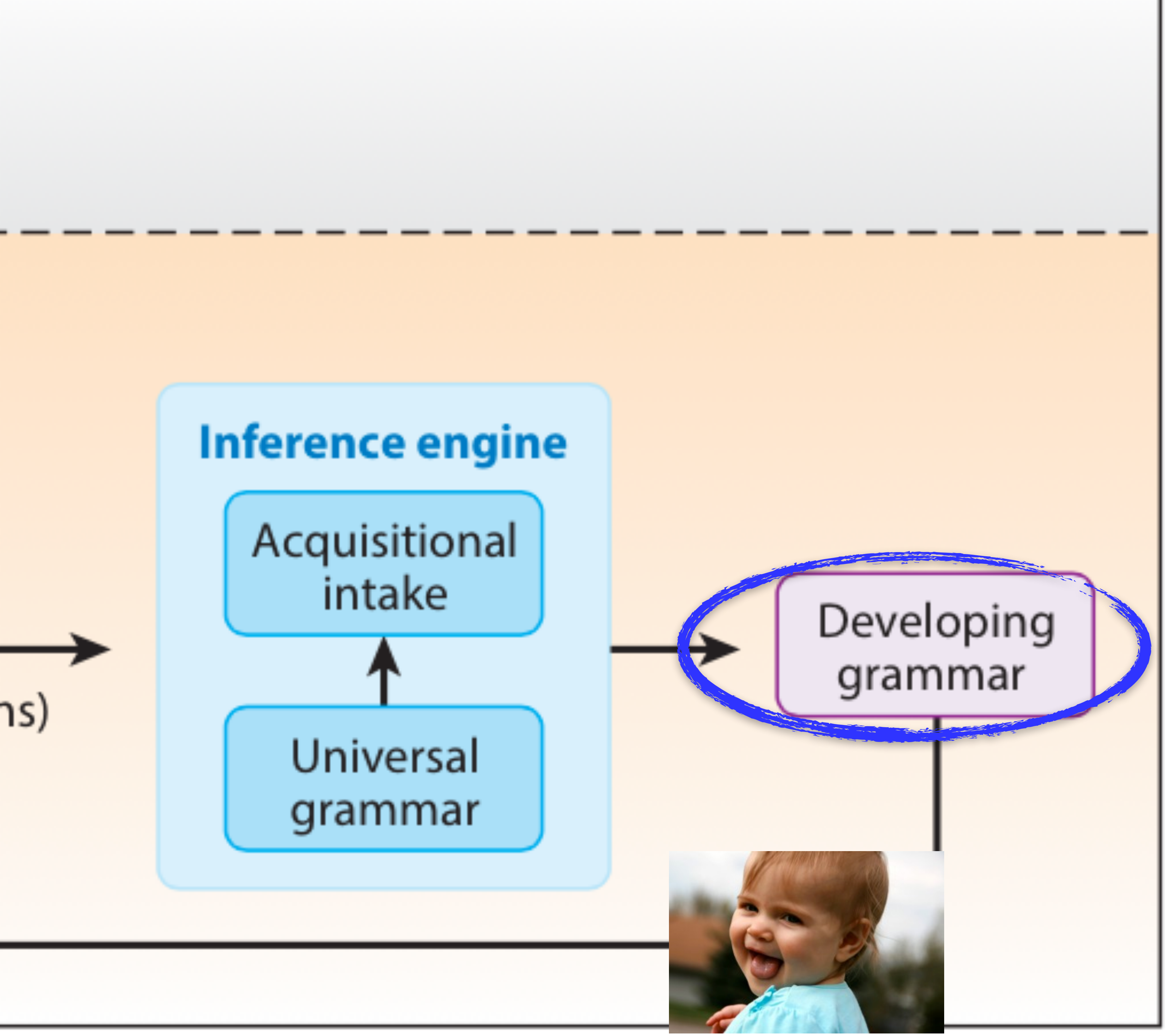
Doing inference

Generalization happens by using existing learning biases, (some of which may be innate and language-specific)



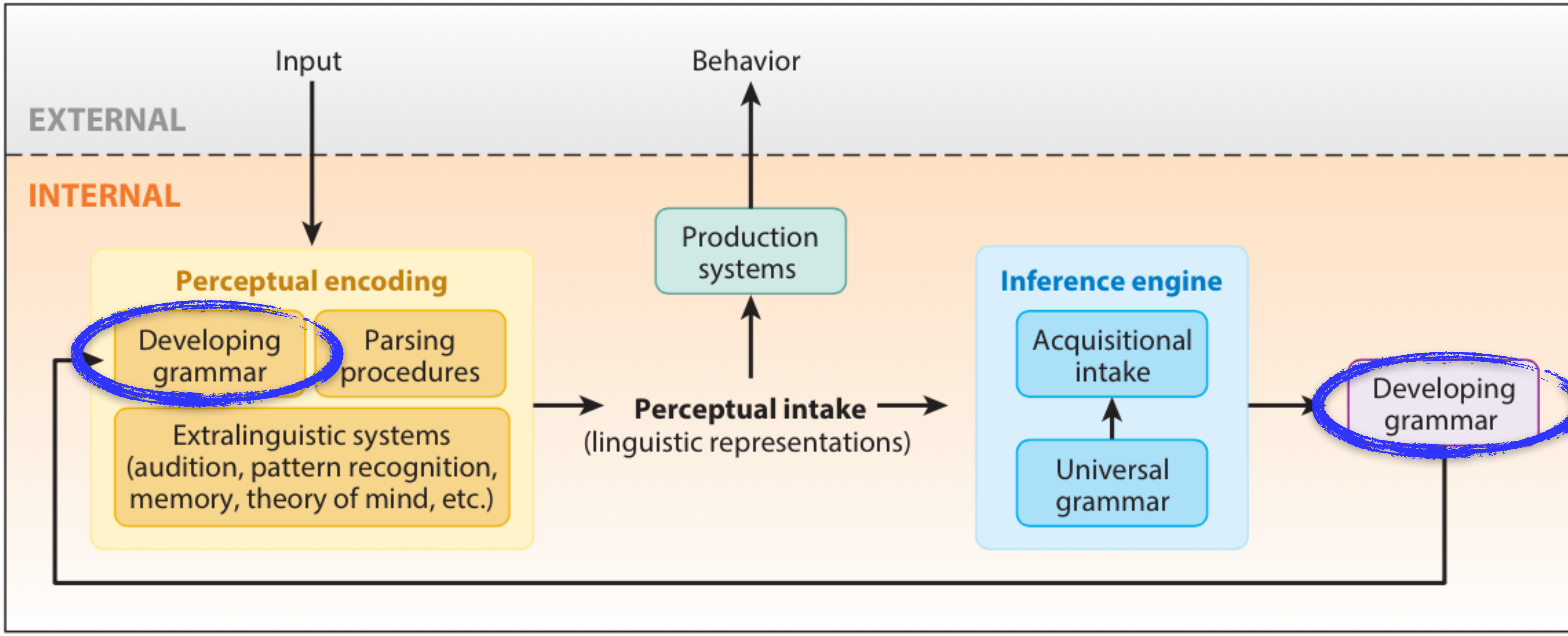
Doing inference

Generalization happens by using existing learning biases, (some of which may be innate and language-specific) operating over the acquisitional intake — what's perceived as relevant for acquisition



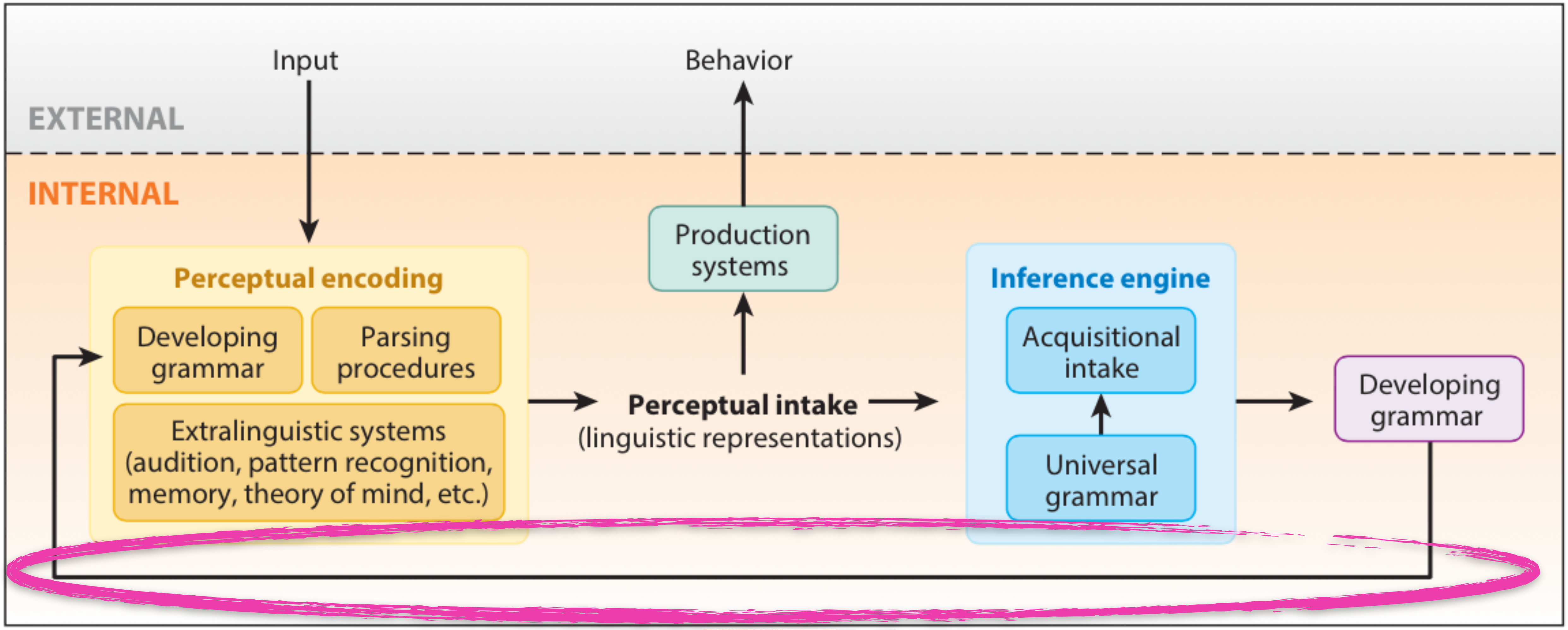
Doing inference

Generalization happens by using existing learning biases, (some of which may be innate and language-specific) operating over the acquisitional intake — what's perceived as relevant for acquisition to produce the most up-to-date hypotheses about linguistic knowledge



Lidz & Gagliardi 2015

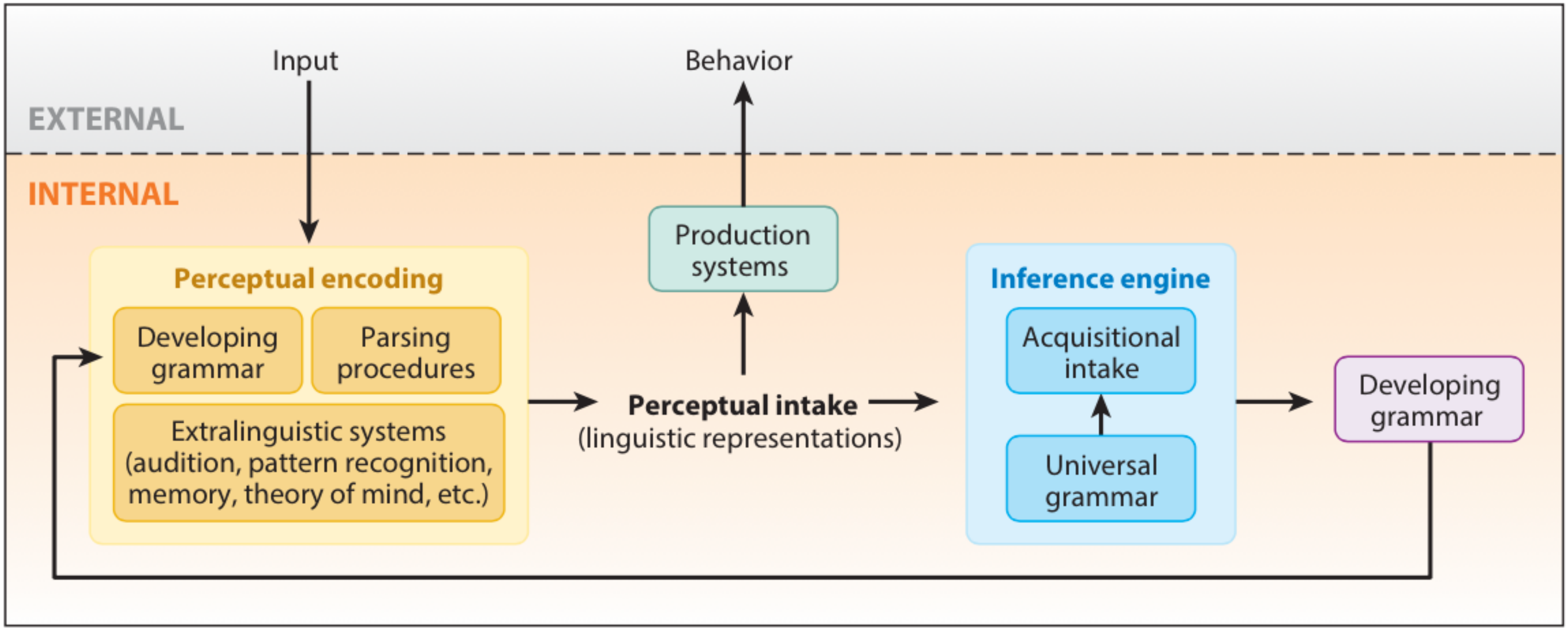
The current linguistic hypotheses are
used in subsequent perceptual encoding



Lidz & Gagliardi 2015

This whole process **happens over and over again** throughout the learning period

This is language acquisition



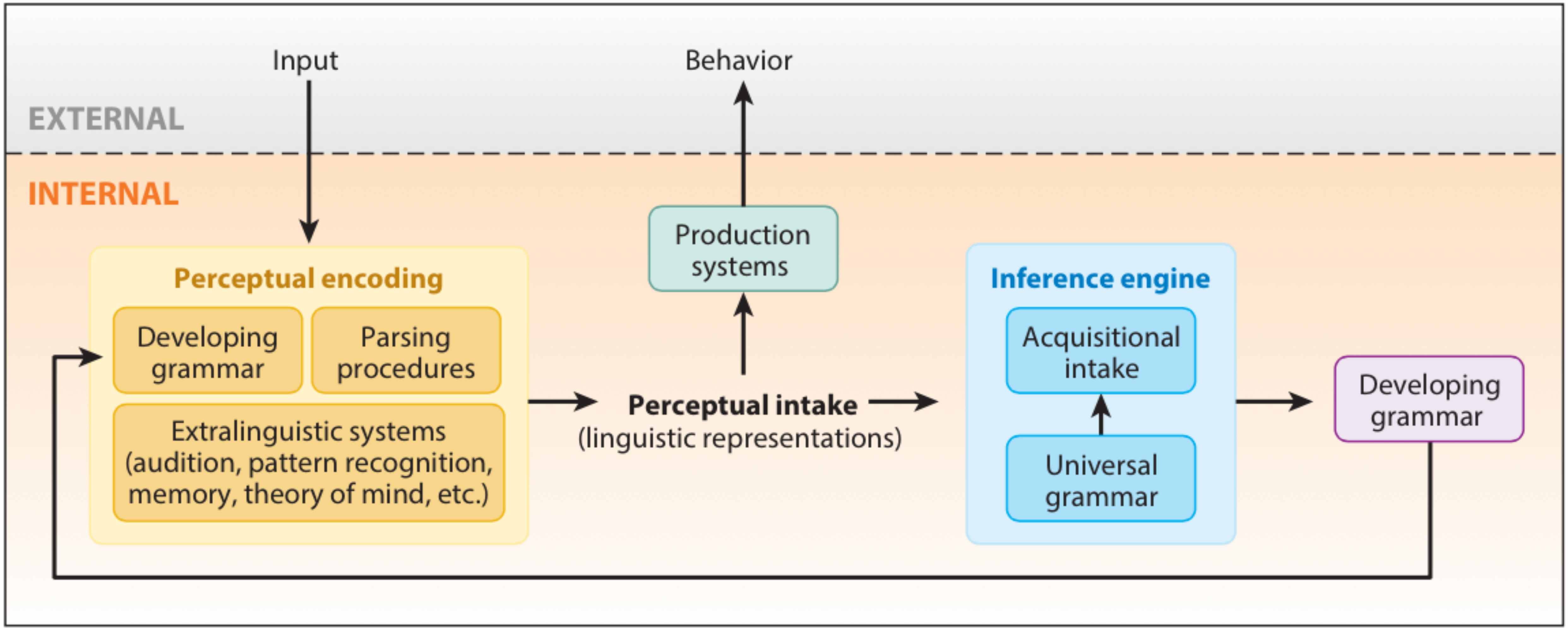
Lidz & Gagliardi 2015

Corpus Experimental

Theoretical Computational

An informative computational model of language acquisition captures these important pieces in an empirically-grounded way.

This is language acquisition

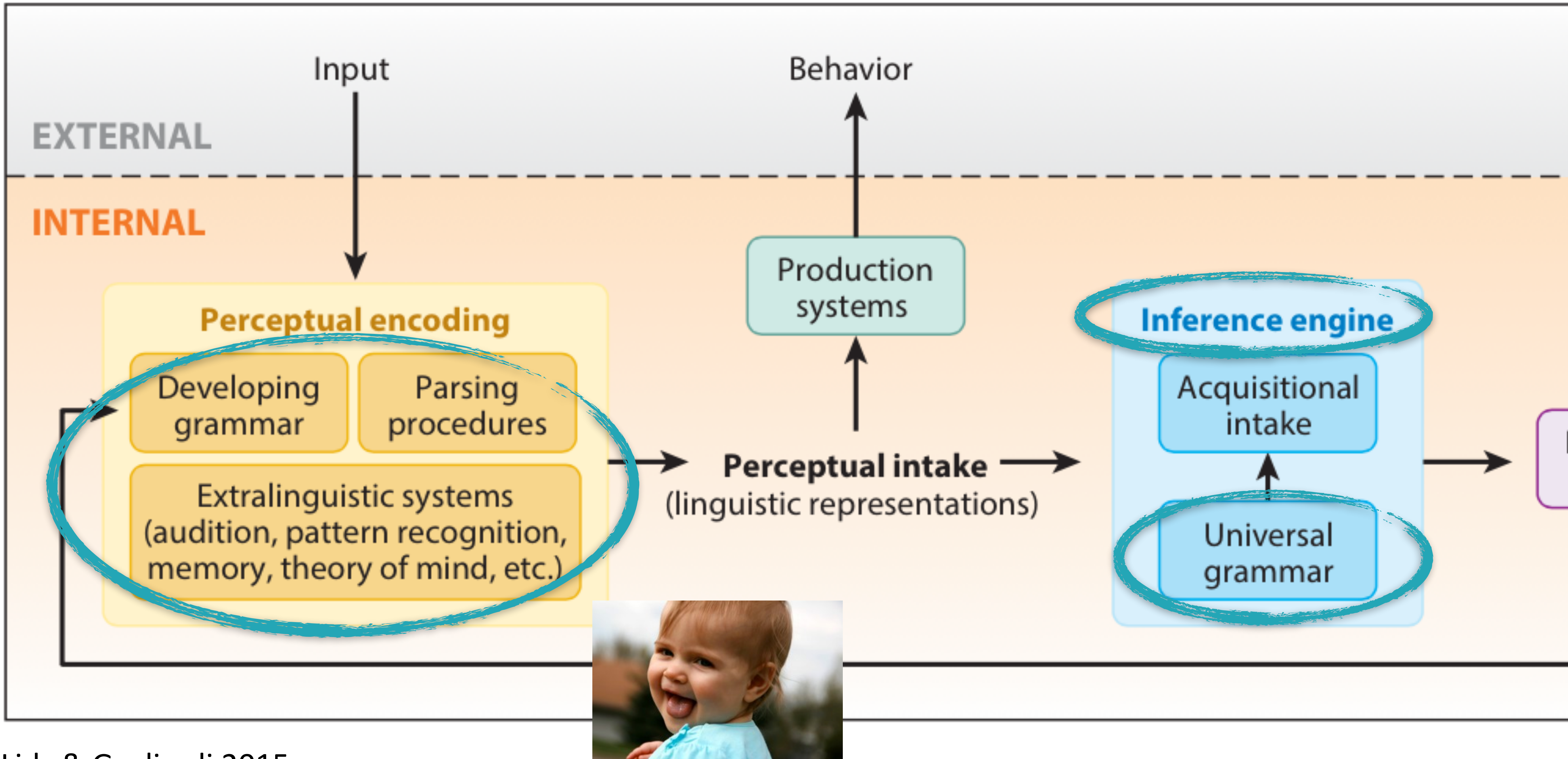


Lidz & Gagliardi 2015

Informative computational models =
informative about the learning strategies children use

Learning strategies children use

A successful learning strategy is an existence proof that linguistic knowledge is attainable using the knowledge, learning biases, and capabilities comprising that strategy.



Lidz & Gagliardi 2015

Learning strategies children use

This is what we want to evaluate with computational modeling.

The penguin tried to climb.

The ice seemed to melt.

appear

subject-raising

seem

want

subject-control

try need

climb

melt

unaccusative

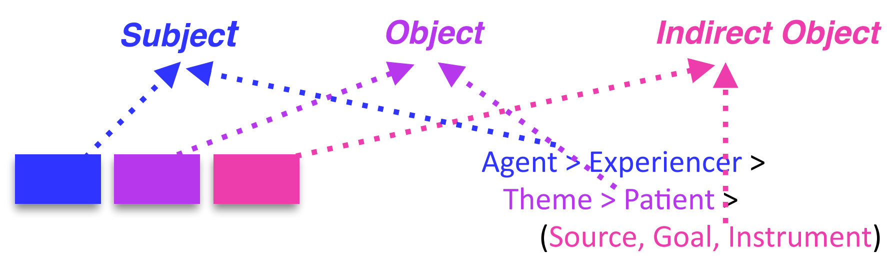
unergative

break fall

laugh dance

Today's plan

Computational modeling



Information available and how to use it

Information available

The penguin tried
to climb.

The ice seemed
to melt.

want
subject-control
try need

climb
unergative
laugh dance

appear
subject-raising
seem

melt
unaccusative
break fall

Syntactic cues

Syntactic frame

Children are very adept at using syntactic bootstrapping to learn useful generalizations about how verbs behave (e.g., Fisher et al. 2010, Gutman et al. 2015, Harrigan et al. 2016).

Information available

The ice seemed to melt.

appear

subject-raising

seem

want

subject-control

try need

melt

unaccusative

break fall

climb

unergative

laugh dance

Syntactic cues

Syntactic frame

The penguin **tried** to climb.

NP ___ $S_{nonfinite}$ -surface morphology

NP ___**+past** $S_{nonfinite}$ +surface morphology

Information available

want
subject-control
try need

climb
unergative
laugh dance

appear
subject-raising
seem

melt
unaccusative
break fall

Syntactic frame

NP ___ $S_{nonfinite}$ -surfmorph

NP ___$_{\textbf{+past}}$ $S_{nonfinite}$ +surfmorph

Conceptual cues

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Information available

melt

climb **unaccusative**

unergative break fall

laugh dance

Syntactic frame

NP ___ $S_{nonfinite}$ -surfmorph

NP ___$_{\mathbf{+past}}$ $S_{nonfinite}$ +surfmorph

Conceptual cues

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Becker 2009, Kirby 2009, Kirby 2010,
Becker 2014, Becker 2015, Hartshorne et al. 2015

It's useful:
It can distinguish verb behaviors like raising vs. control verbs, and psych object-experiencer verbs.

appear seem

subject-raising

ask beg

object-raising

try want believe

subject-control **object-control**

need

surprise annoy

psych object-experiencer

worry

Information available

want

subject-control

try need

appear

subject-raising

seem

climb

unergative

laugh dance

melt

unaccusative

break fall

Syntactic frame

NP ___ $S_{nonfinite}$ -surfmorph

NP $\_\_\__{+past}$ $S_{nonfinite}$ +surfmorph

Conceptual cues

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Becker 2009, Kirby 2009, Kirby 2010,
Becker 2014, Becker 2015, Hartshorne et al. 2015

Children use it:

Young children have been shown to use this cue in experimental studies.

Information available

The penguin tried
to climb.

The ice seemed
to melt.

want

subject-control

try need

climb

unergative

laugh dance

appear

subject-raising

seem

melt

unaccusative

break fall

Syntactic frame

NP ___ $S_{nonfinite}$ -surfmorph

NP ___$_{\text{+past}}$ $S_{nonfinite}$ +surfmorph

Animacy

+animate

The penguin tried
to climb.

-animate

The ice seemed
to melt.

Conceptual cues

Thematic roles

Children could use them:

Thematic roles that indicate event participant roles are salient to very young children.

(<10 months: Gordon 2003; 6 months: Hamlin, Wynn, & Bloom 2007, Hamlin, Wynn, Bloom, & Mahajan 2011)

doer = Agent

done-to = Patient

Information available

Conceptual cues + Syntactic-semantic knowledge
Thematic roles and how to use them

Syntax **She** melted **the ice** with **a blow dryer**.
Subject *Object* *Indirect Object*

Syntactic frame

NP ___ $S_{nonfinite}$ -surfmorph

NP ___$_{+past}$ $S_{nonfinite}$ +surfmorph

Animacy

+animate
The penguin tried to climb.

-animate
The ice seemed to melt.

How do we get from here to here?

Thematic roles **Agent**, **Experiencer**, **Patient**, **Theme**, **Goal**, **Source**, **Instrument**…

Information available

Conceptual cues + Syntactic-semantic knowledge

Thematic roles and how to use them

Syntax **She** melted **the ice** with **a blow dryer**.

Subject ***Object*** ***Indirect Object***

Syntactic frame

NP ___ $S_{\text{nonfinite}}$ -surfmorph

NP ___$_{\text{+past}}$ $S_{\text{nonfinite}}$ +surfmorph

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

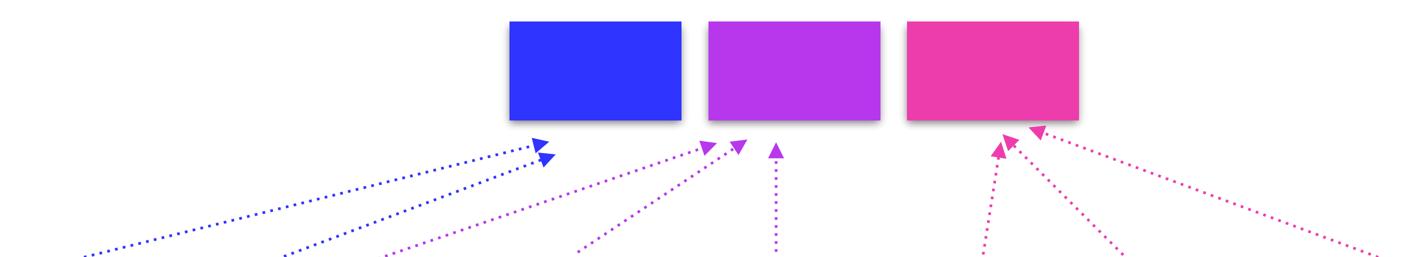
Theories of prior knowledge

Intermediate representations

Thematic roles map to one of three categories.

The Uniformity of Theta Assignment Hypothesis

Baker 1988, Baker 1997, Dowty 1991, Fillmore 1968, Grimshaw 1990, Jackendoff 1987, Perlmutter & Postal 1984, Speas 1990



Thematic roles **Agent**, **Experiencer**, **Patient**, **Theme**, **Goal**, **Source**, **Instrument**…

Information available

Conceptual cues + Syntactic-semantic knowledge

Thematic roles and how to use them

Syntax **She** melted **the ice** with **a blow dryer**.

Subject *Object* *Indirect Object*

Syntactic frame

NP ____ $S_{nonfinite}$ -surfmorph

NP $\_\_\_\__{+past}$ $S_{nonfinite}$ +surfmorph

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Mapping to Syntax

Theories of prior knowledge

Intermediate representations

These categories map to syntactic positions.

Thematic roles map to one of three categories.

UTAH

Thematic roles **Agent**, **Experiencer**, **Patient**, **Theme**, **Goal**, **Source**, **Instrument**…

Information available

Conceptual cues + Syntactic-semantic knowledge

Thematic roles and how to use them

Syntax **She** melted **the ice** with **a blow dryer**.

Subject *Object* *Indirect Object*

Syntactic frame

NP ___ $S_{nonfinite}$ -surfmorph

NP $\_\_\__{+past}$ $S_{nonfinite}$ +surfmorph

Mapping to Syntax

Animacy

+animate

The penguin tried to climb.

Theories of prior knowledge

-animate

The ice seemed to melt.

Intermediate representations

UTAH

Thematic roles are ordered with respect to each other.

The (relativized) **UTAH**

Larson 1988, Larson 1990

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

Thematic roles **Agent**, **Experiencer**, **Patient**, **Theme**, **Goal**, **Source**, **Instrument**…

Information available

Conceptual cues + Syntactic-semantic knowledge

Thematic roles and how to use them

Syntax **She** melted **the ice** with **a blow dryer**.

Subject *Object* *Indirect Object*

Syntactic frame

NP ____ $S_{nonfinite}$ -surfmorph

NP ____$_{+past}$ $S_{nonfinite}$ +surfmorph

Mapping to Syntax

Whichever ones are present map in order to syntactic positions.

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Theories of prior knowledge

Intermediate representations

UTAH

rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

Thematic roles **Agent**, **Experiencer**, **Patient**, **Theme**, **Goal**, **Source**, **Instrument…**

Information available

Conceptual cues + Syntactic-semantic knowledge

Thematic roles and how to use them

Syntax **She** melted **the ice** with **a blow dryer**.

Subject *Object* *Indirect Object*

Syntactic frame

NP ___ $S_{nonfinite}$ -surfmorph

NP $\_\_\__{+past}$ $S_{nonfinite}$ +surfmorph

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Mapping to Syntax

Theories of prior knowledge

Standard UTAH and rUTAH implementations typically assume the mapping is also known a priori

Intermediate representations

UTAH

rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

Thematic roles **Agent**, **Experiencer**, **Patient**, **Theme**, **Goal**, **Source**, **Instrument**…

Information available

Conceptual cues + Syntactic-semantic knowledge

Thematic roles and how to use them

Syntax **She** melted **the ice** with **a blow dryer**.

Subject *Object* *Indirect Object*

Syntactic frame

NP ___ $S_{nonfinite}$ -surfmorph

NP ___$_{+past}$ $S_{nonfinite}$ +surfmorph

But these are separate components

Mapping to Syntax

Animacy

+animate

The penguin tried to climb.

Theories of prior knowledge

-animate

The ice seemed to melt.

Intermediate representations

UTAH

rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

Thematic roles **Agent**, **Experiencer**, **Patient**, **Theme**, **Goal**, **Source**, **Instrument**…

Information available

Conceptual cues + Syntactic-semantic knowledge

Thematic roles and how to use them

Syntax **She** melted **the ice** with **a blow dryer**.

Subject *Object* *Indirect Object*

Syntactic frame

NP ___ $S_{nonfinite}$ -surfmorph

NP $\_\_\__{+past}$ $S_{nonfinite}$ +surfmorph

Whether children expect a mapping a priori impacts how they perceive the intake for acquisition

Mapping to Syntax

Animacy

+animate

The penguin tried to climb.

Theories of prior knowledge

-animate

The ice seemed to melt.

Intermediate representations

UTAH

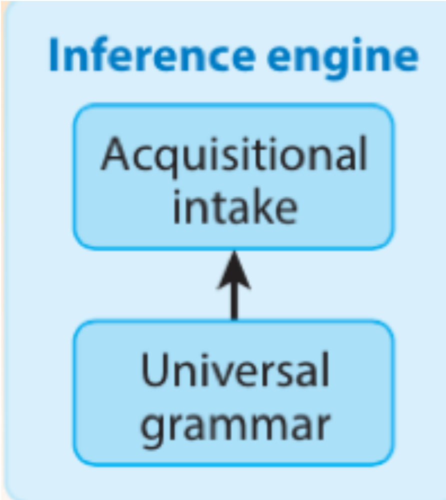
rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

Thematic roles **Agent**, **Experiencer**, **Patient**, **Theme**, **Goal**, **Source**, **Instrument**…



Information available

+expect a mapping

Salient when mapping doesn't hold:
Interpreted as movement

Syntax

The ice was melted by the girl.

Subject *Indirect Object*

done-to *doer*

Mapping to Syntax

Theories of prior knowledge

Unexpected by UTAH

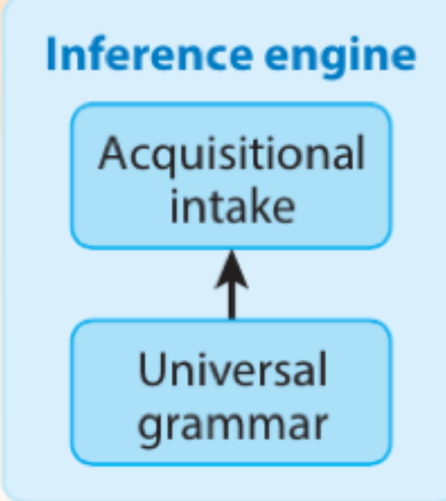
Intermediate representations

UTAH

rUTAH

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

Thematic roles Agent, Experiencer, Patient, Theme, Goal, Source, Instrument…



Information available

+expect a mapping

Salient when mapping doesn't hold:
Interpreted as movement

Syntax

The ice was melted by the girl.

Subject *Indirect Object*

2nd highest *Highest*

Mapping to Syntax

Theories of prior knowledge

Unexpected by rUTAH

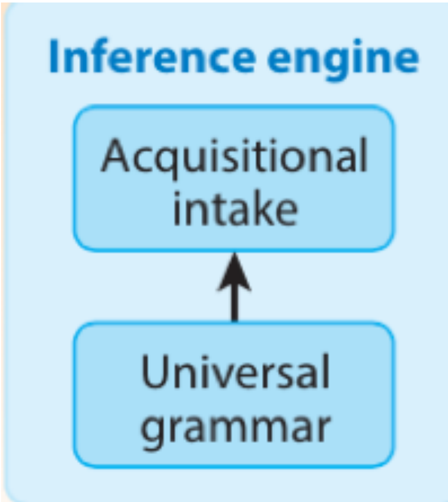
Intermediate representations

UTAH

rUTAH

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

Thematic roles Agent, Experiencer, Patient, Theme, Goal, Source, Instrument…



Information available

-expect a mapping

Children track grammatical positions of intermediate representations

melt
done-to: Subject
doer: Indirect Object

Syntax

The ice was melted by the girl.

Subject *Indirect Object*

done-to *doer*

Mapping to Syntax

Theories of prior knowledge

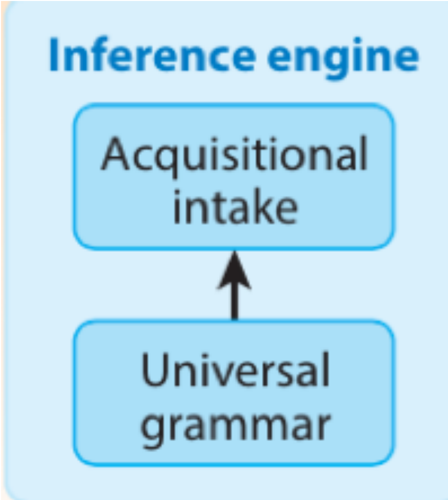
Intermediate representations

UTAH

rUTAH

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

Thematic roles **Agent, Experiencer, Patient, Theme, Goal, Source, Instrument…**



Information available

-expect a mapping

Children track grammatical positions of intermediate representations

Syntax

The ice was melted by the girl.

Subject *Indirect Object*

2nd highest ***Highest***

melt
2nd highest: Subject
Highest: Indirect Object

Mapping to Syntax

Theories of prior knowledge

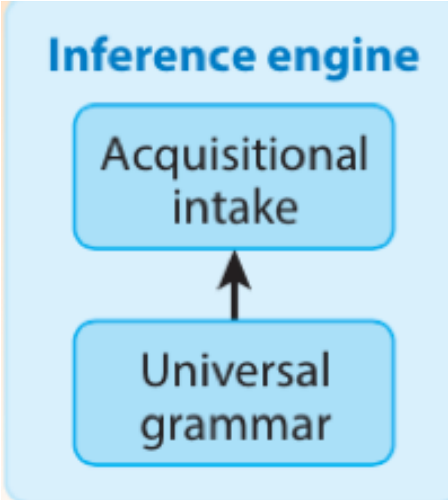
Intermediate representations

UTAH

rUTAH

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

Thematic roles **Agent, Experiencer, Patient, Theme, Goal, Source, Instrument…**



Information available

Conceptual cues + Syntactic-semantic knowledge

Thematic roles and how to use them

Syntax **The ice was melted by the girl.**

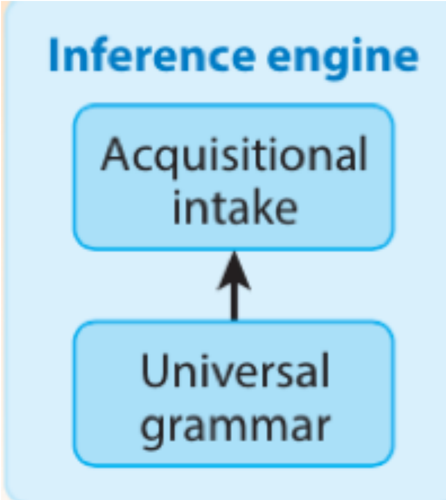
Subject *Indirect Object*

Mapping to Syntax **+expmap** **-expmap**

Intermediate representations **UTAH** **rUTAH**

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

Thematic roles **Agent, Experiencer, Patient, Theme, Goal, Source, Instrument…**



Information available

Syntactic frame

NP ____ $S_{nonfinite}$ -surfmorph

NP ____$_{+past}$ $S_{nonfinite}$ +surfmorph

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Thematic roles and how to use them

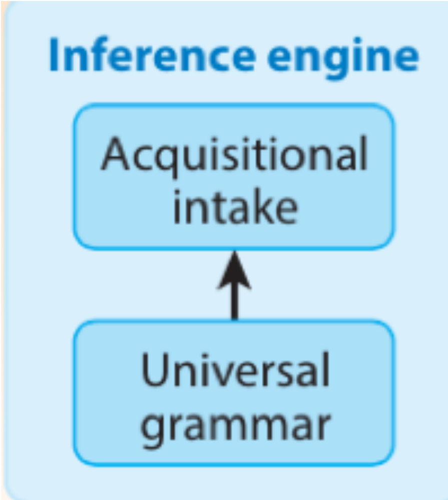
UTAH -expmap *Subject* *Object* *Indirect Object*

Agent > Experiencer > rUTAH +expmap *Subject* *Object* *Indirect Object*

Theme > Patient >

(Source, Goal, Instrument)

movement?



Potential learning strategies

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Syntactic frame

NP ____ $S_{nonfinite}$ -surfmorph

NP ____$_{+past}$ $S_{nonfinite}$ +surfmorph

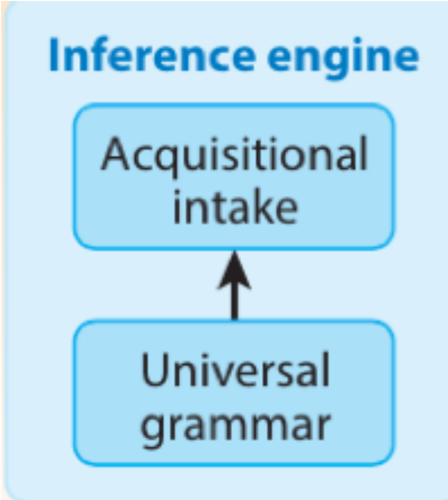
Thematic roles and how to use them

UTAH -expmap *Subject* *Object* *Indirect Object*

Agent > Experiencer > Theme > Patient > (Source, Goal, Instrument)

rUTAH +expmap *Subject* *Object* *Indirect Object*

movement?



Potential learning strategies

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Syntactic frame

Choice 1

NP ____ $S_{nonfinite}$ -surfmorph

NP ____$_{+past}$ $S_{nonfinite}$ +surfmorph

Thematic roles and how to use them

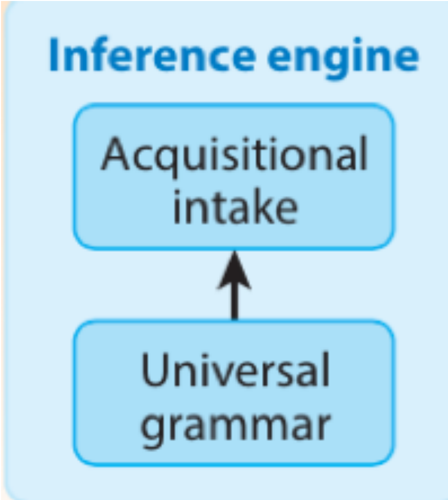
UTAH -expmap *Subject* *Object* *Indirect Object*

Agent > **Experiencer** > rUTAH +expmap *Subject* *Object* *Indirect Object*

Theme > **Patient** >

(**Source, Goal, Instrument**)

movement?



Potential learning strategies

Animacy

+animate
The penguin tried to climb.

-animate
The ice seemed to melt.

Syntactic frame

Choice 1

NP ___ $S_{nonfinite}$ -surfmorph

NP ___**+past** $S_{nonfinite}$ +surfmorph

Thematic roles and how to use them

UTAH

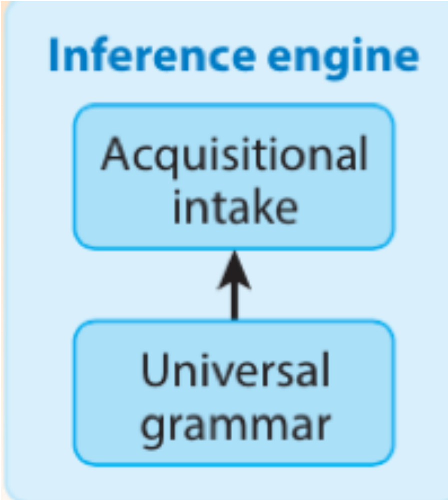
Choice 2

Agent > Experiencer > rUTAH
Theme > Patient >
(Source, Goal, Instrument)

-expmap *Subject* *Object* *Indirect Object*

+expmap *Subject* *Object* *Indirect Object*

movement?



Potential learning strategies

Animacy

+animate

The penguin tried to climb.

-animate

The ice seemed to melt.

Syntactic frame

Choice 1

NP ___ $S_{nonfinite}$ -surfmorph

NP ___$_{\textbf{+past}}$ $S_{nonfinite}$ +surfmorph

Thematic roles and how to use them

UTAH

Choice 2

Agent > Experiencer > rUTAH

Theme > Patient >

(Source, Goal, Instrument)

Choice 3

Subject ***Object*** ***Indirect Object*** -expmap

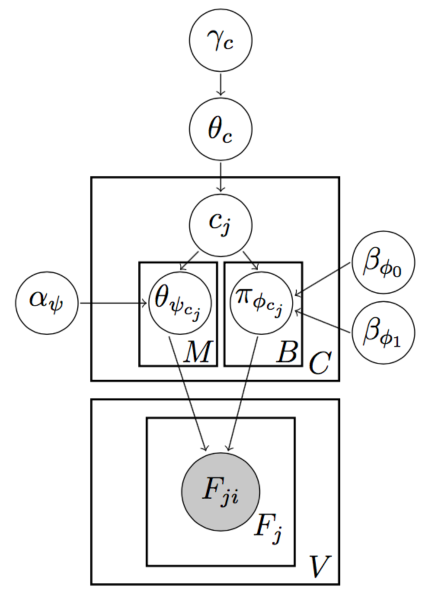
Subject ***Object*** ***Indirect Object*** +expmap

movement?

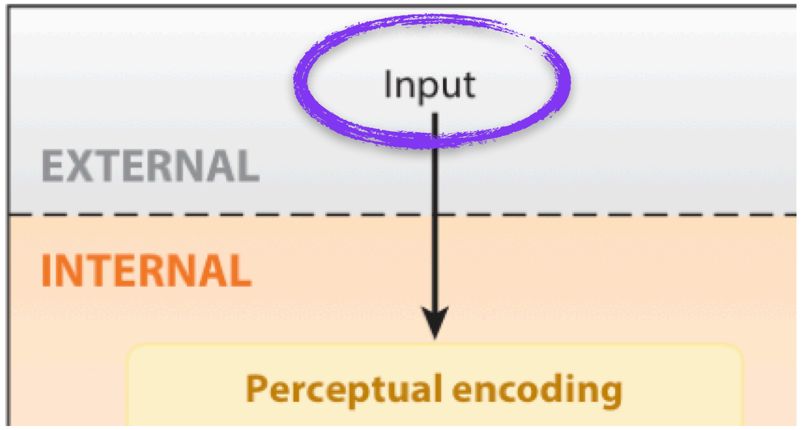
3 binary choices = 8 strategies

Today's plan

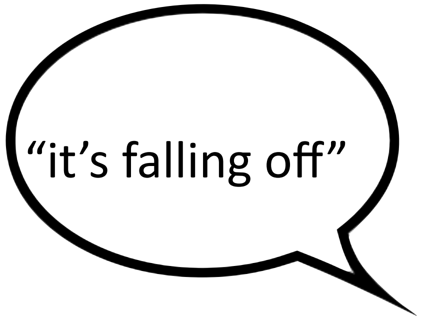
Computational modeling



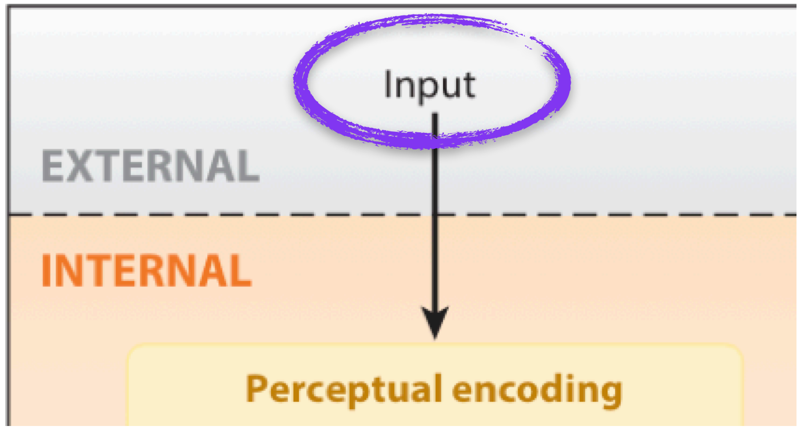
How do we model this?



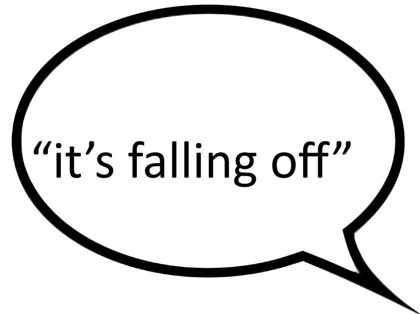
Goal: Model the developmental trajectory from 3 to 4 to 5 years old



Input



Goal: Model the developmental trajectory from 3 to 4 to 5 years old



Input:

Samples of child-directed speech

CHILDES Treebank

<3yrs

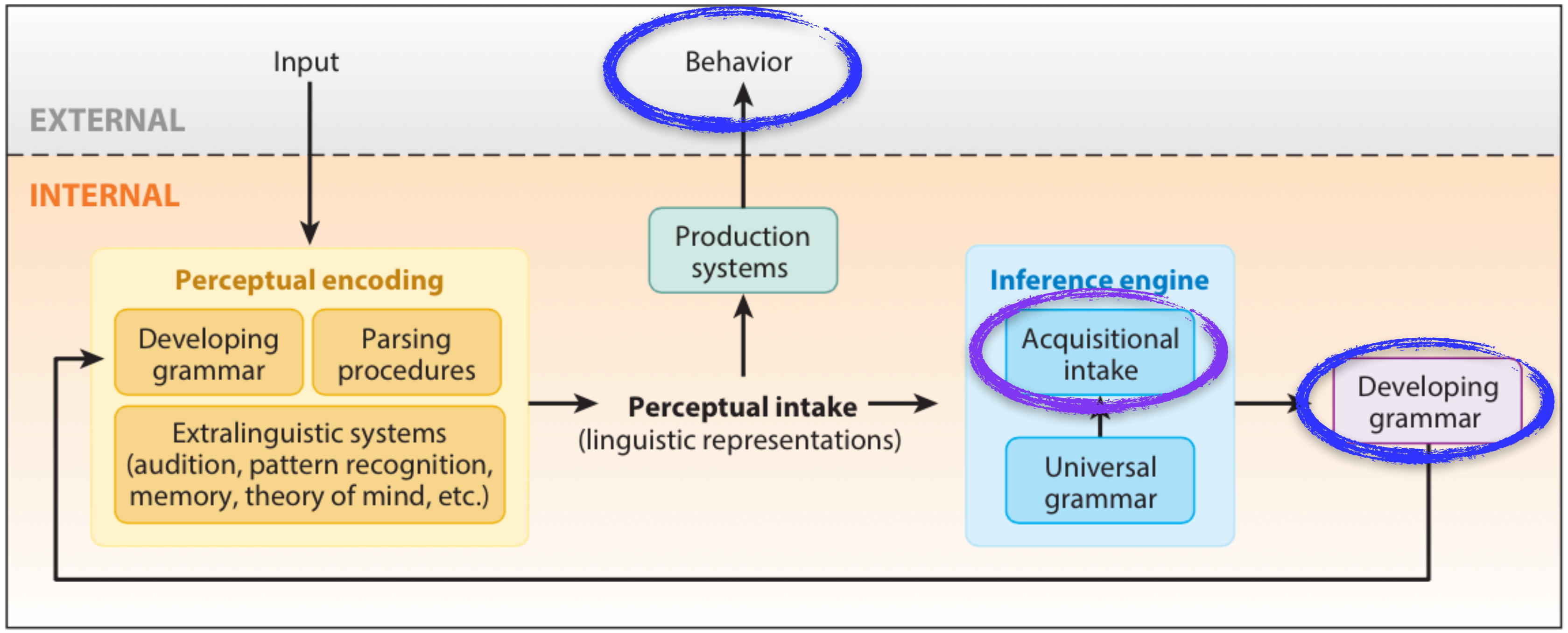
18 and 32 months
~40,000 utterances
239 verbs

<4yrs

18 and 48 months
~51,000 utterances
267 verbs

<5yrs

18 and 58 months
~56,500 utterances
284 verbs



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**



Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/ behavior?

-surfmorph

NP ____ $S_{nonfinite}$

+animate

+surfmorph

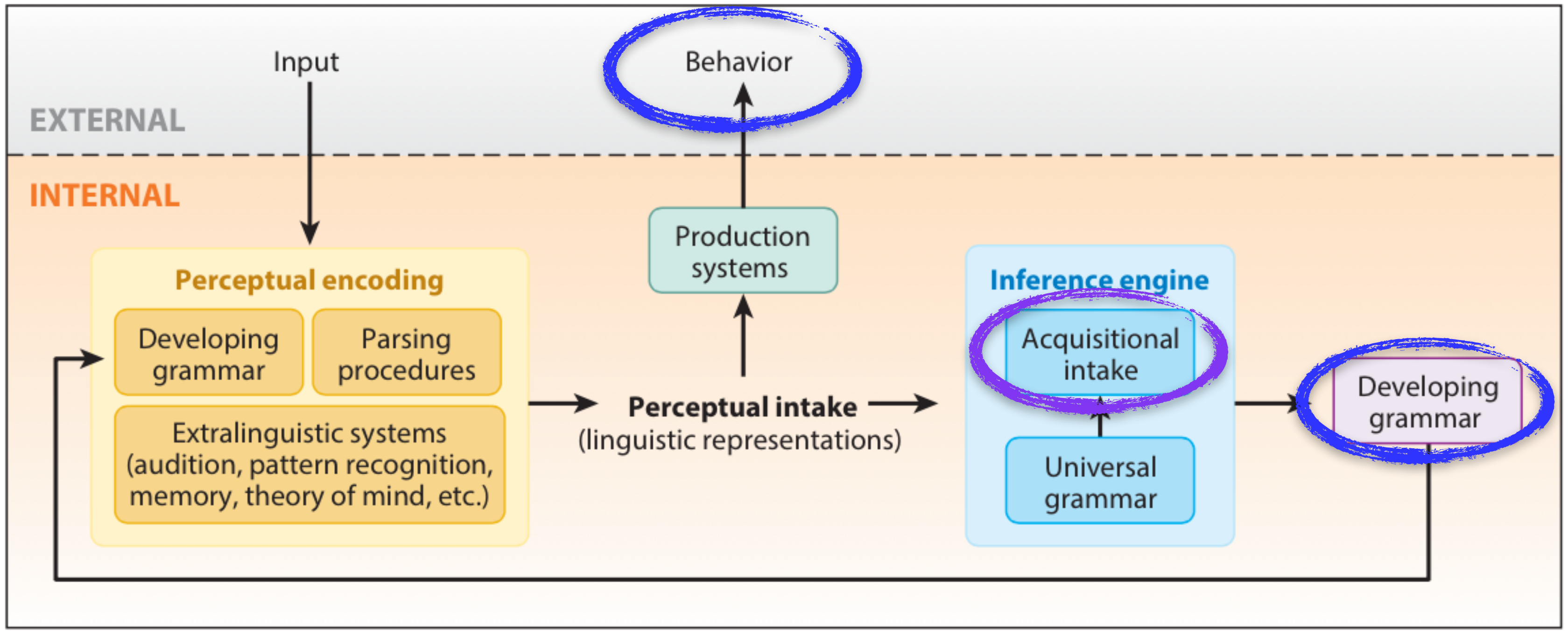
NP ____**+past** $S_{nonfinite}$

UTAH

rUTAH **Agent > Experiencer >**
Theme > Patient >
(Source, Goal, Instrument)

-expmap ***Subject*** ***Object*** ***Indirect Object***

+expmap *movement?*



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**



Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

Ideal learner model: not concerned with the cognitive limitations and incremental learning restrictions children have.

Concerned with what assumptions are useful for children to have.

-surfmorph

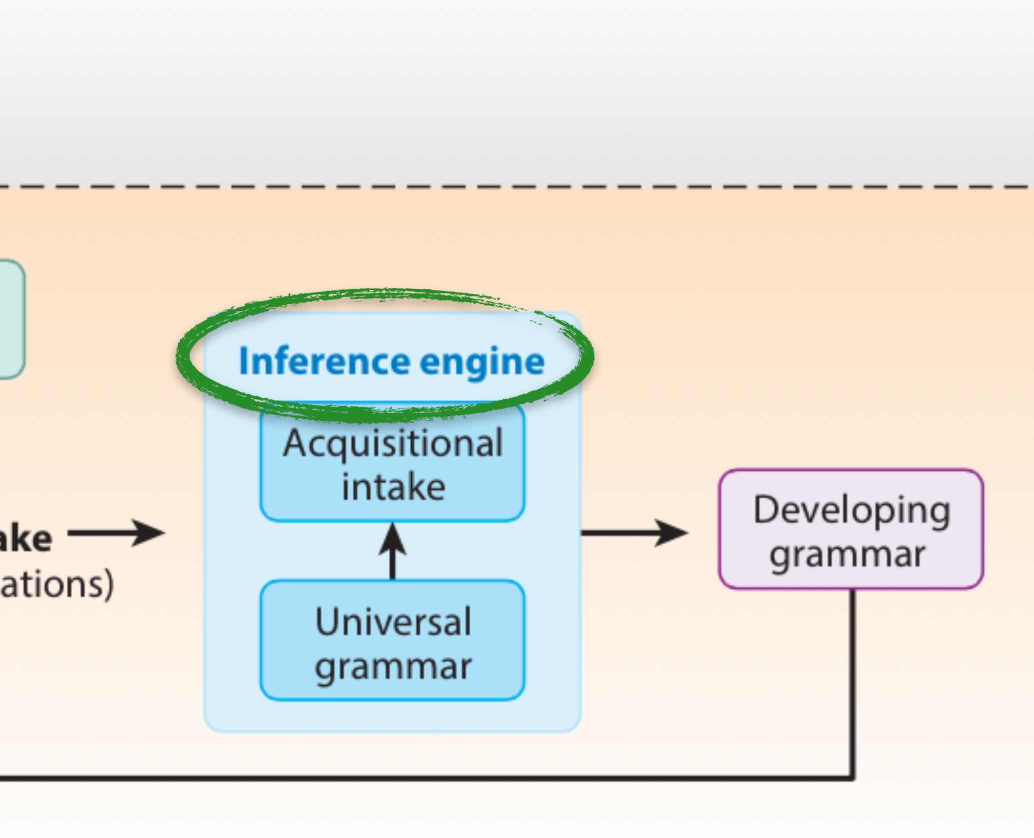
+surfmorph

UTAH

rUTAH

-expmap

+expmap

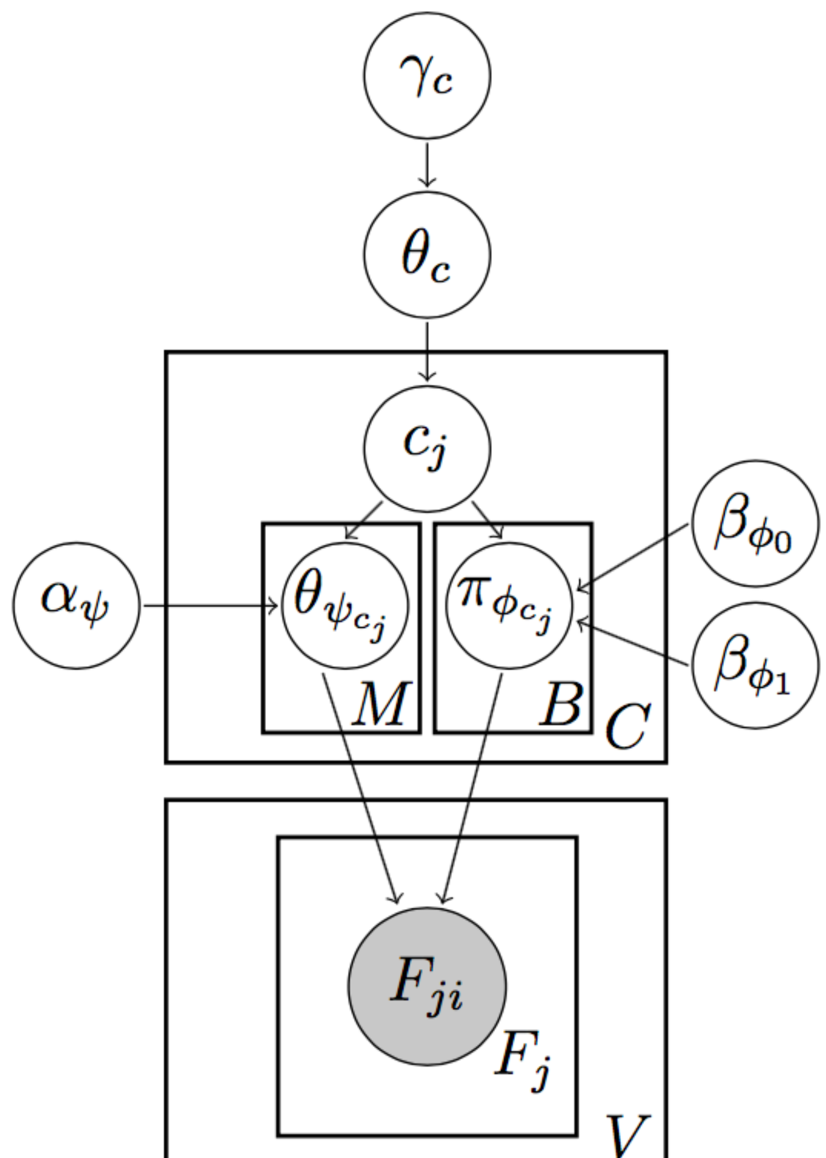


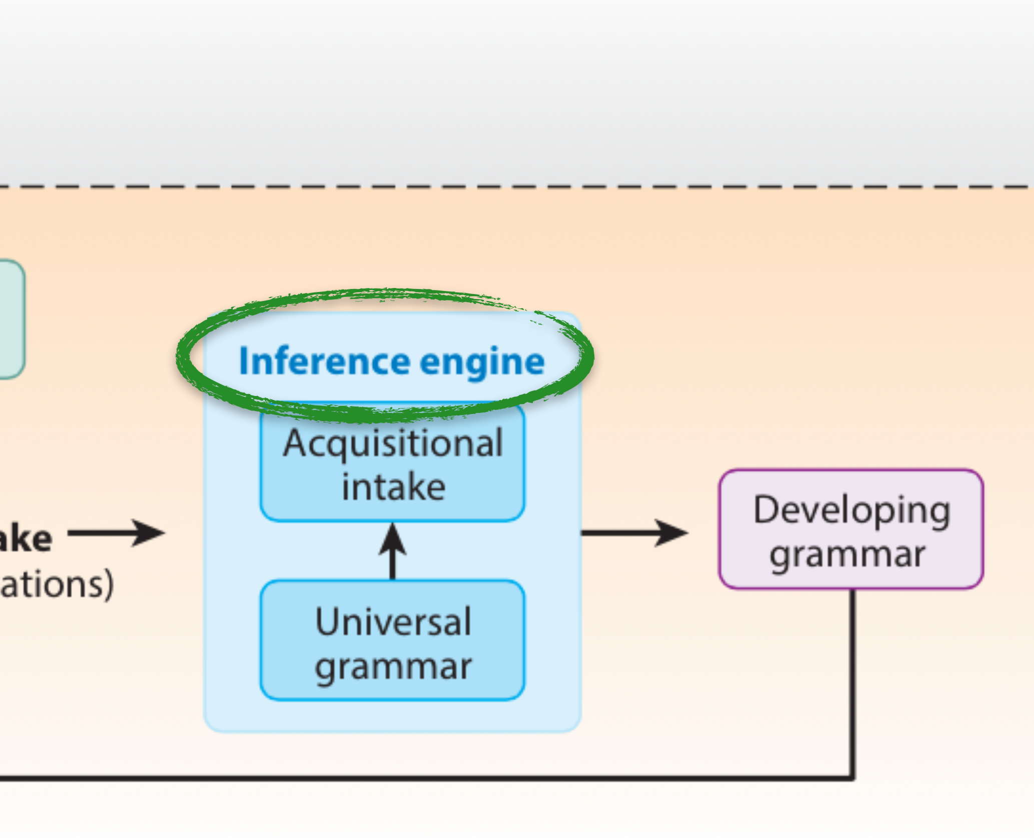
Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs <4yrs <5yrs



Learners use a generative model of how the observable data for each verb are created.



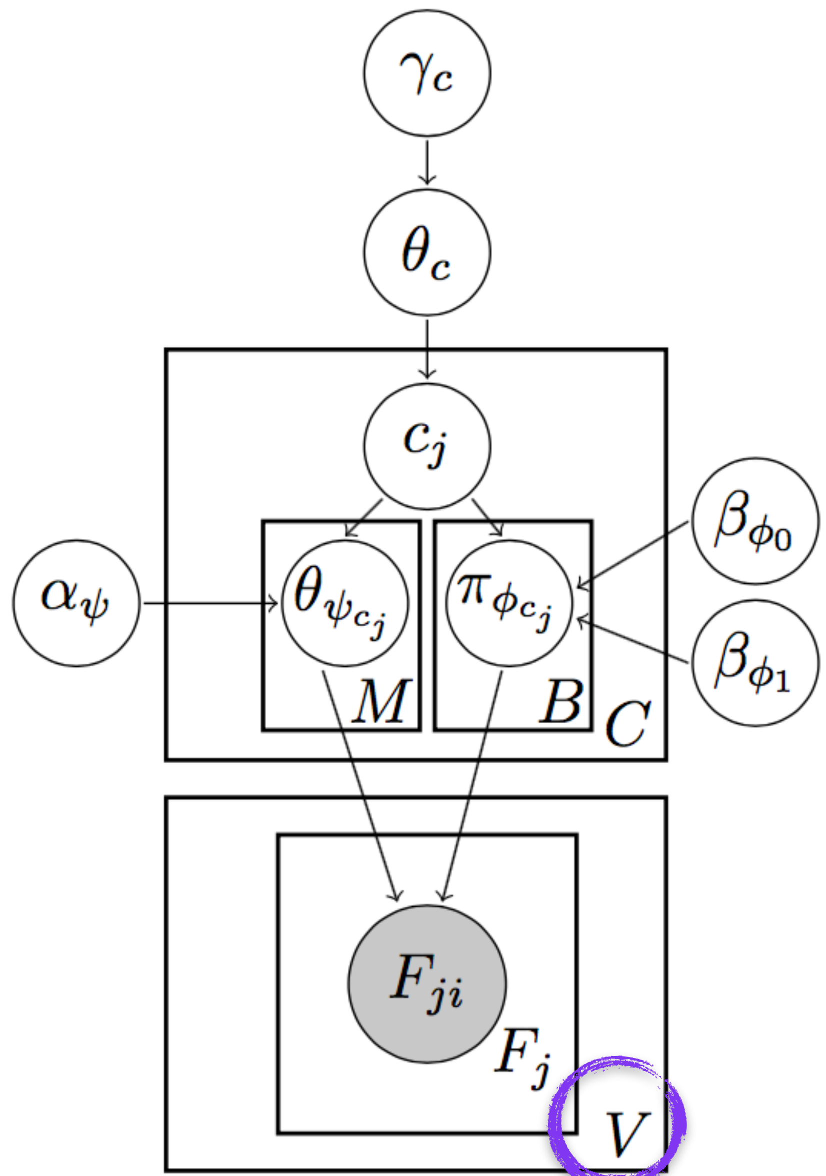


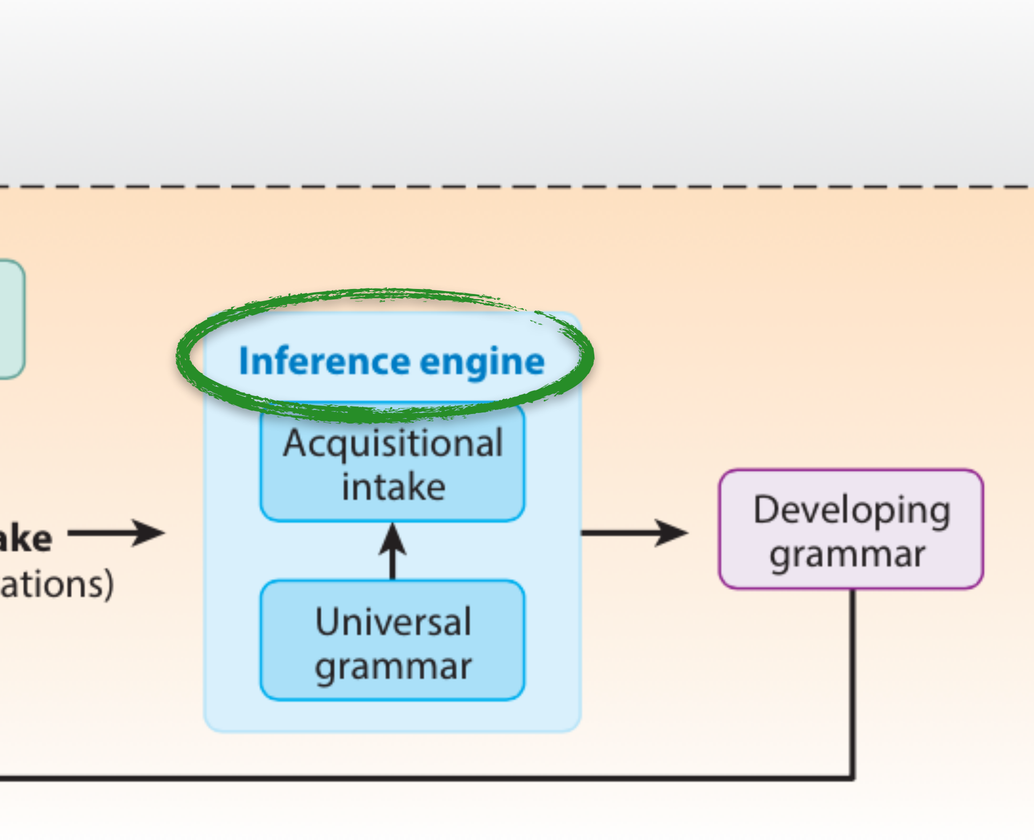
Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

Learners use a generative model of how the observable data for each verb are created.

FALL

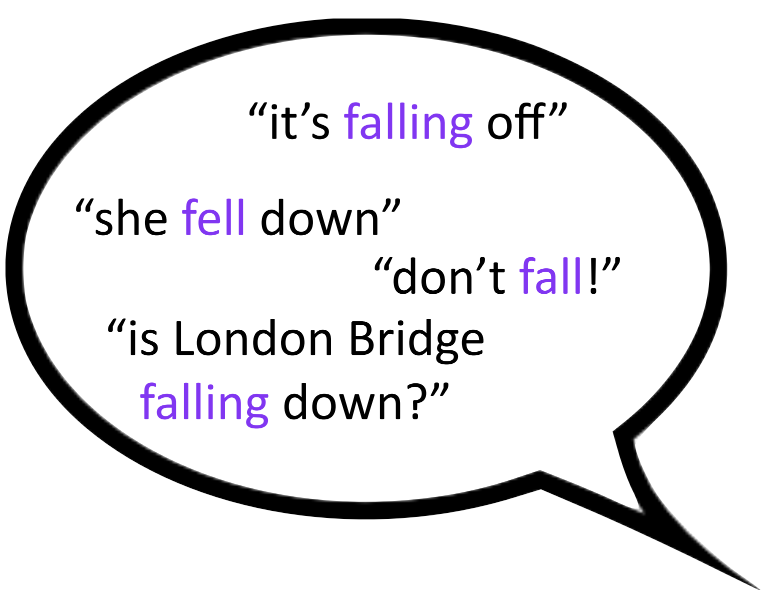


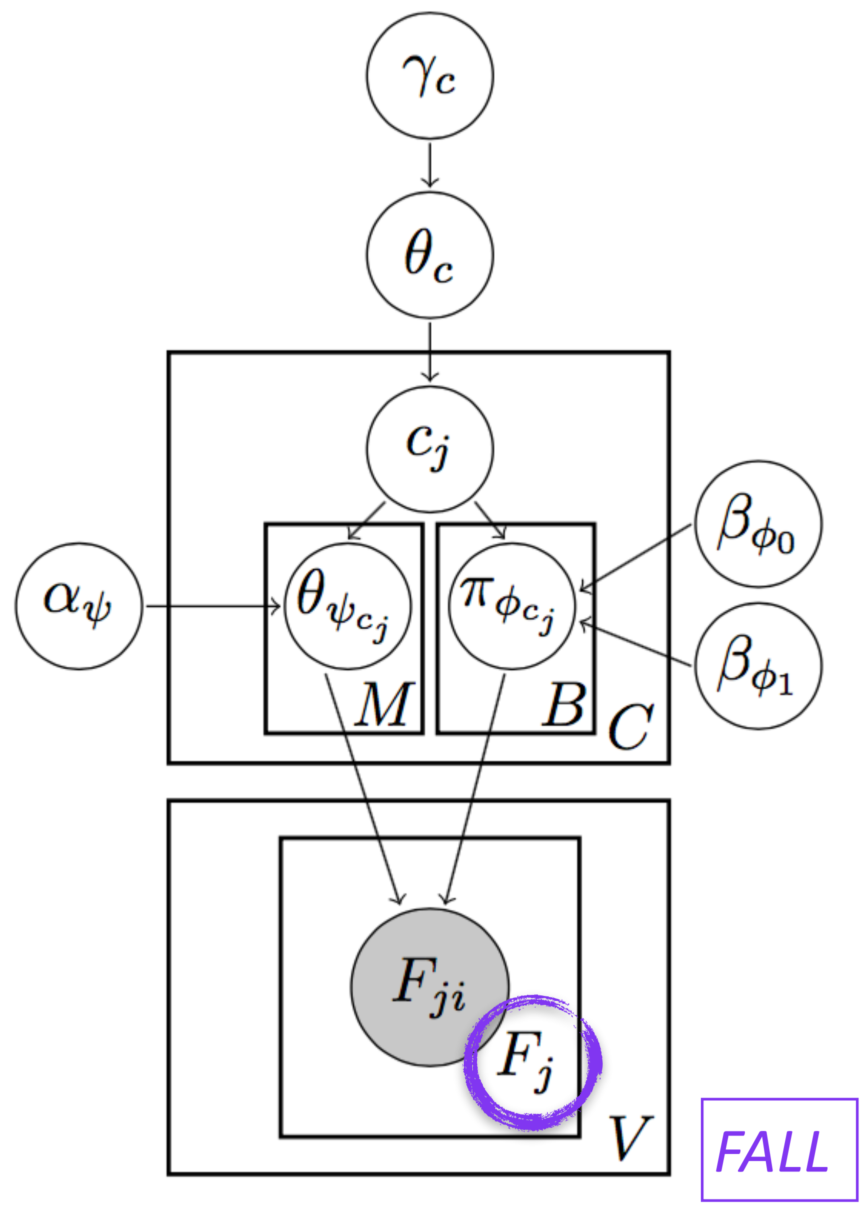


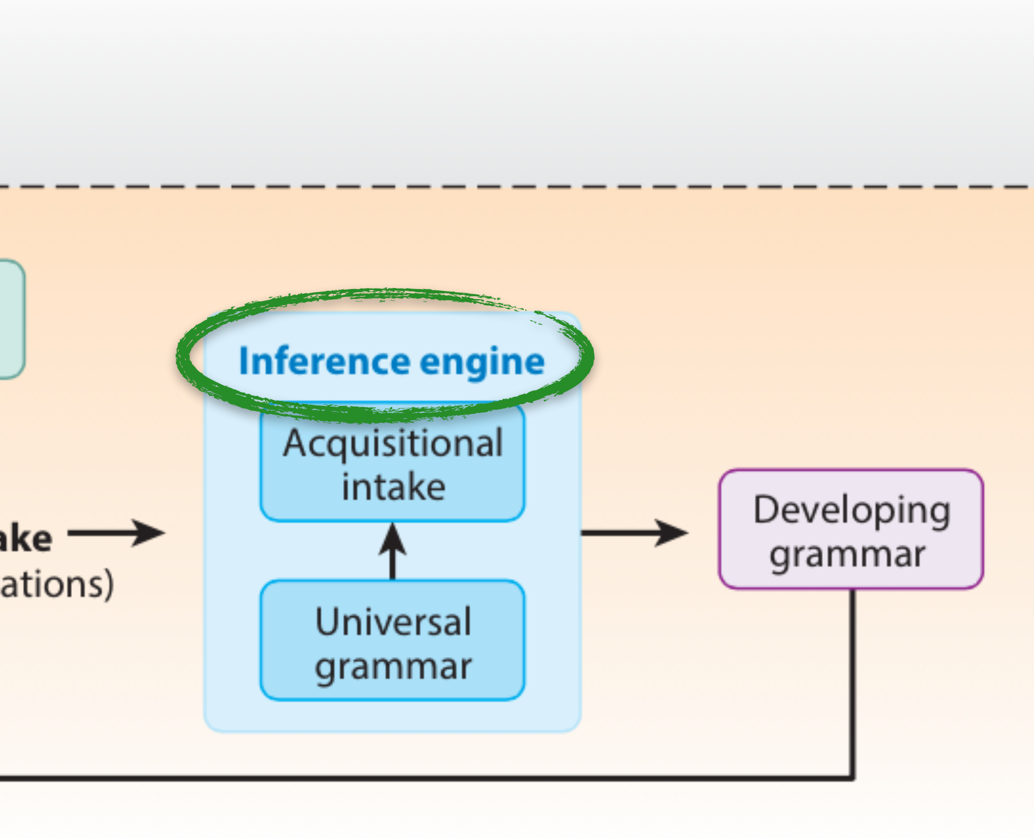
Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs <4yrs <5yrs

Each verb appears in a certain number of instances in the input.







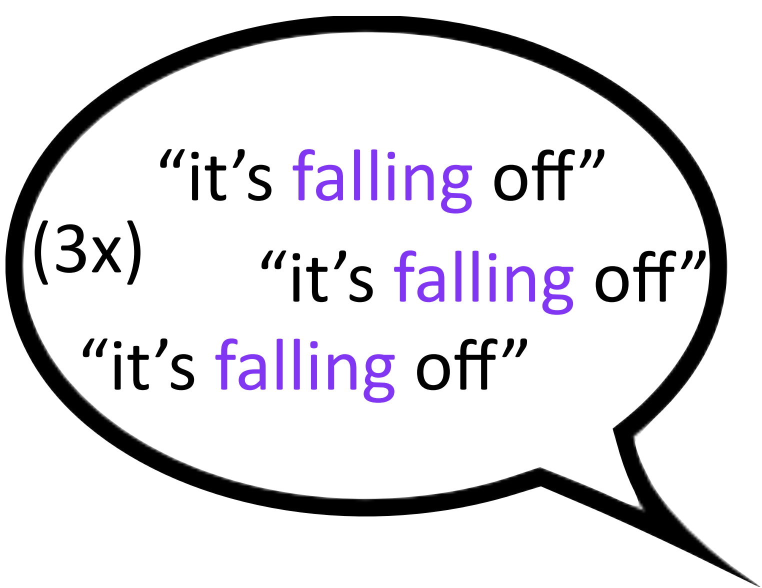
Goal: Model the developmental trajectory from 3 to 4 to 5 years old

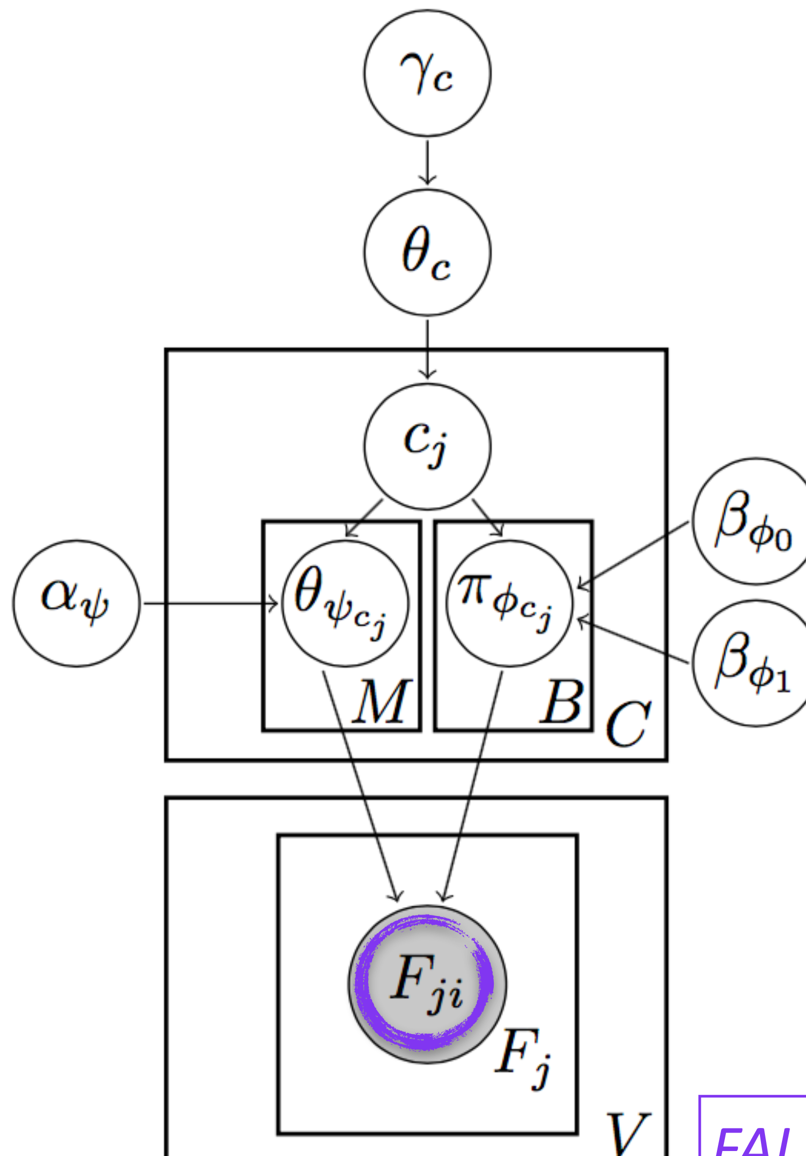
<3yrs

<4yrs

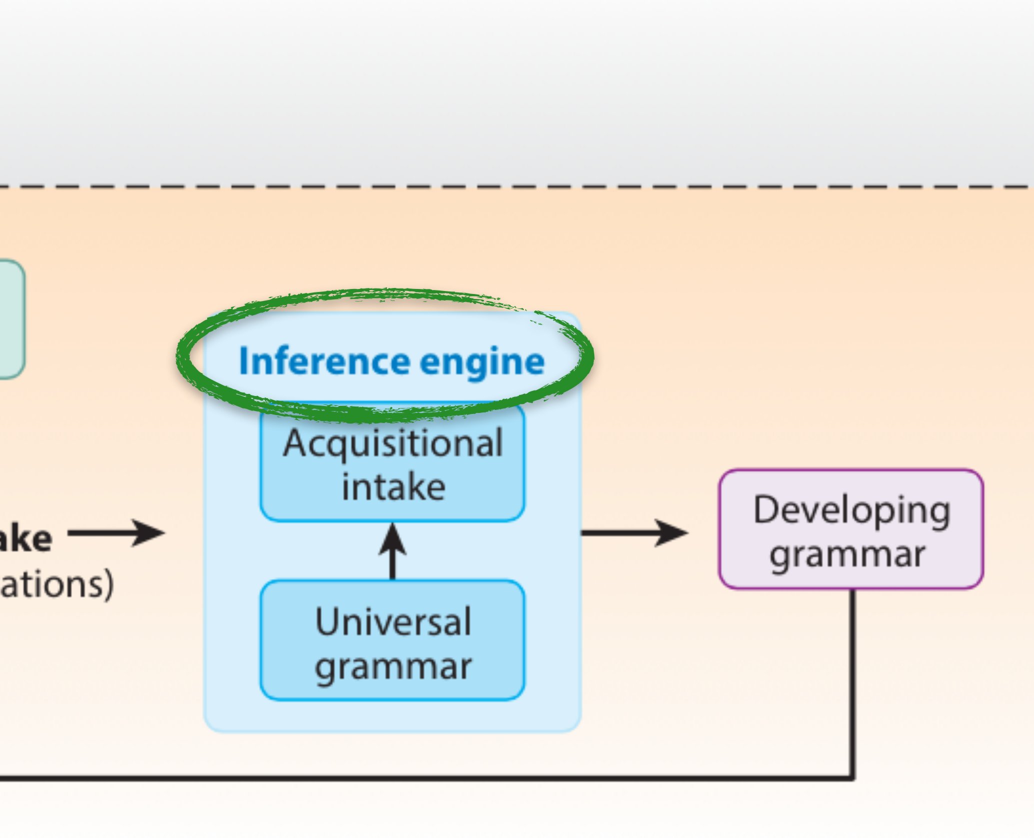
<5yrs

Each instance is observed some number of times.





FALL



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

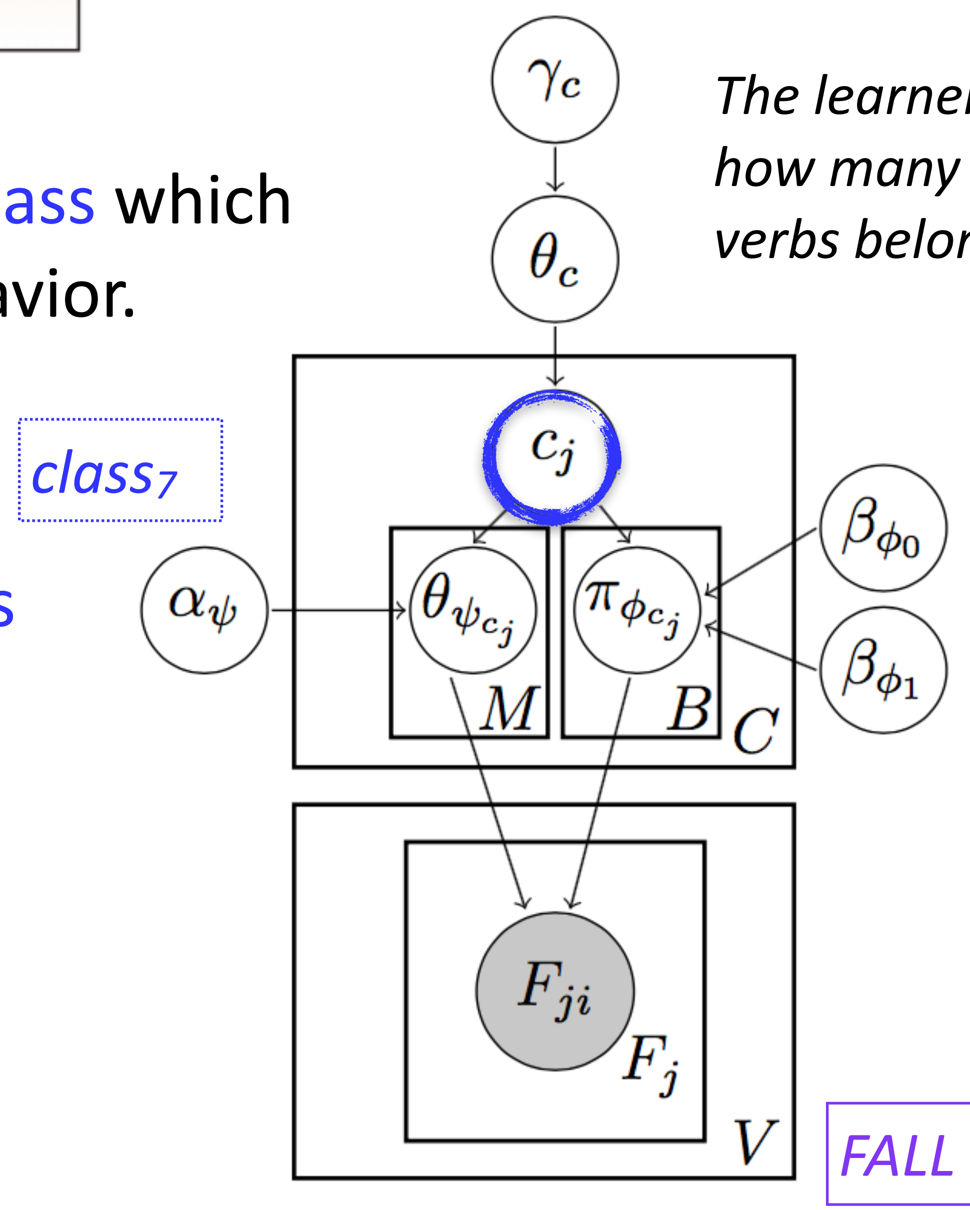
<3yrs <4yrs <5yrs

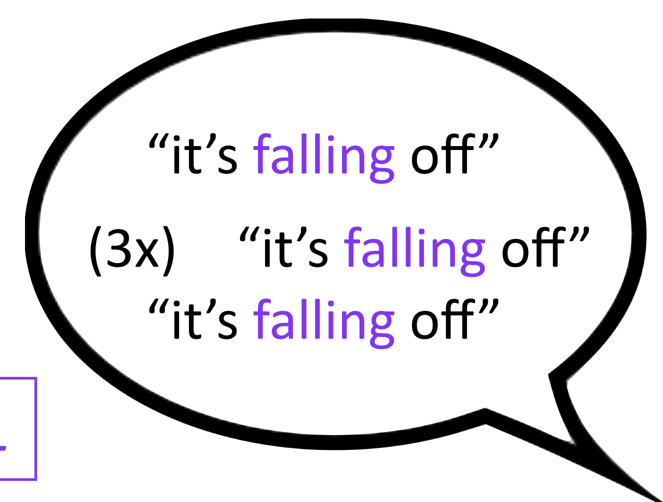


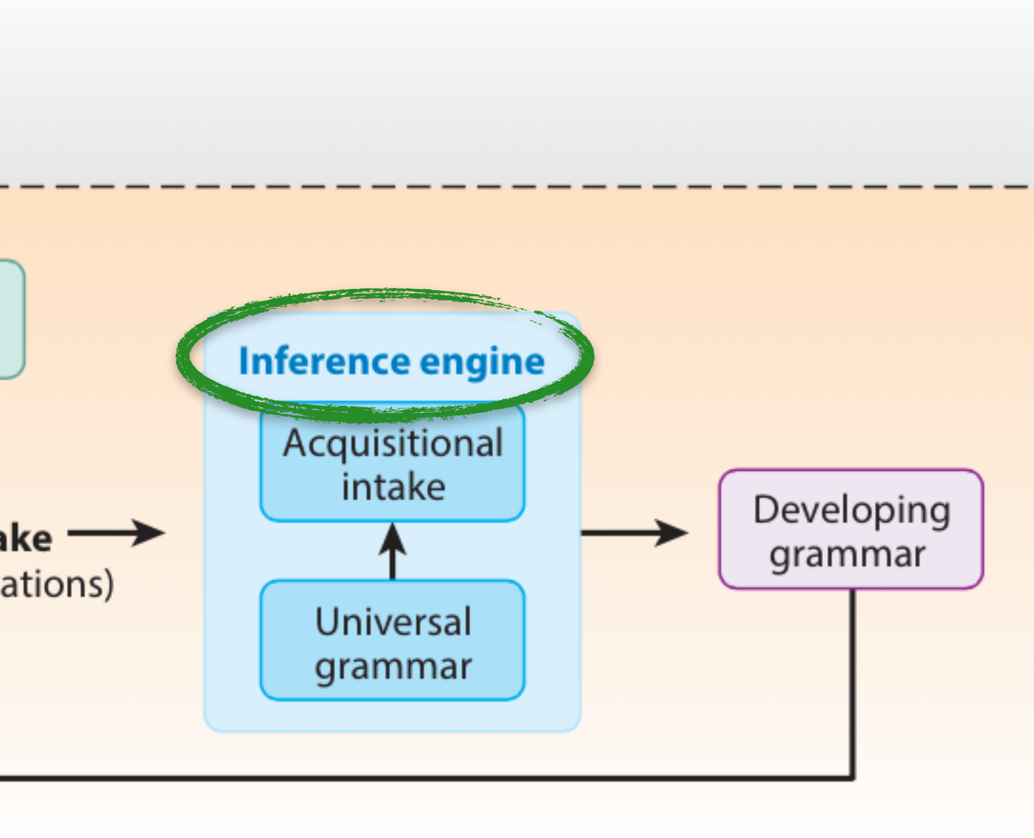
The learner doesn't know beforehand how many classes there are or which verbs belong to which.

Each verb belongs to some class which determines its linguistic behavior.

Objective: Infer verb class





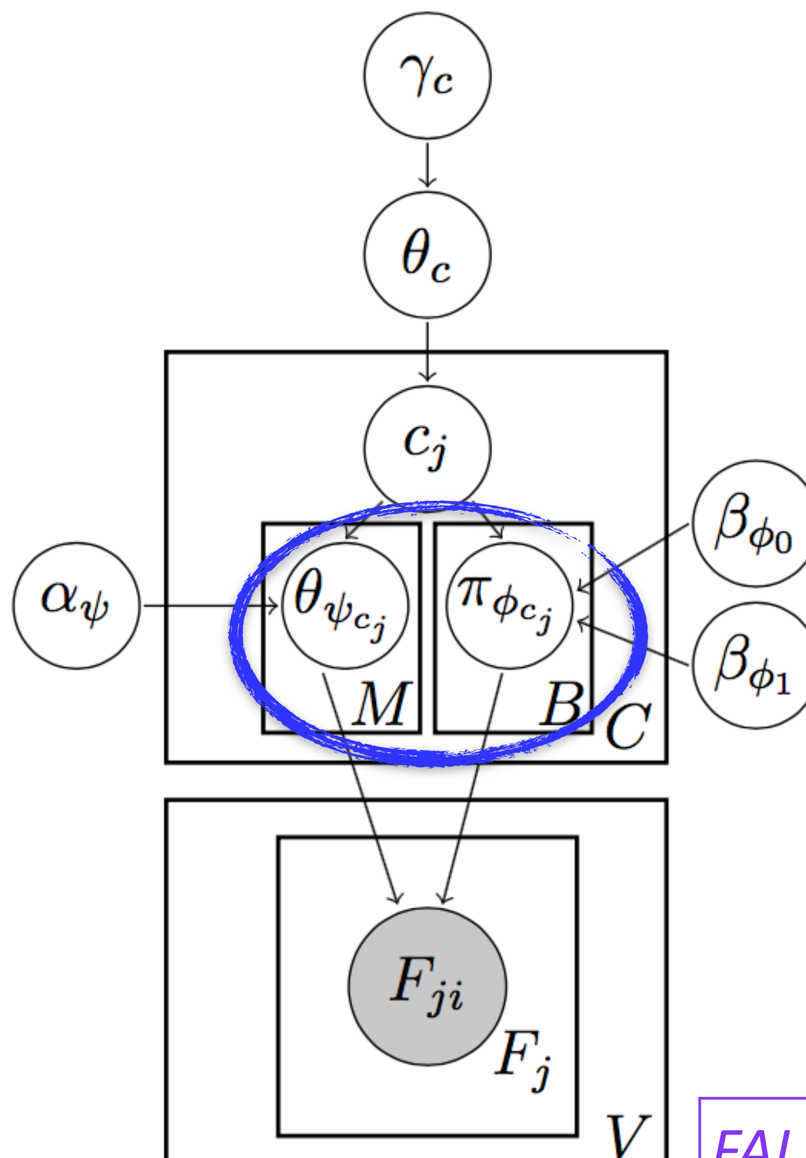


Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs <4yrs <5yrs



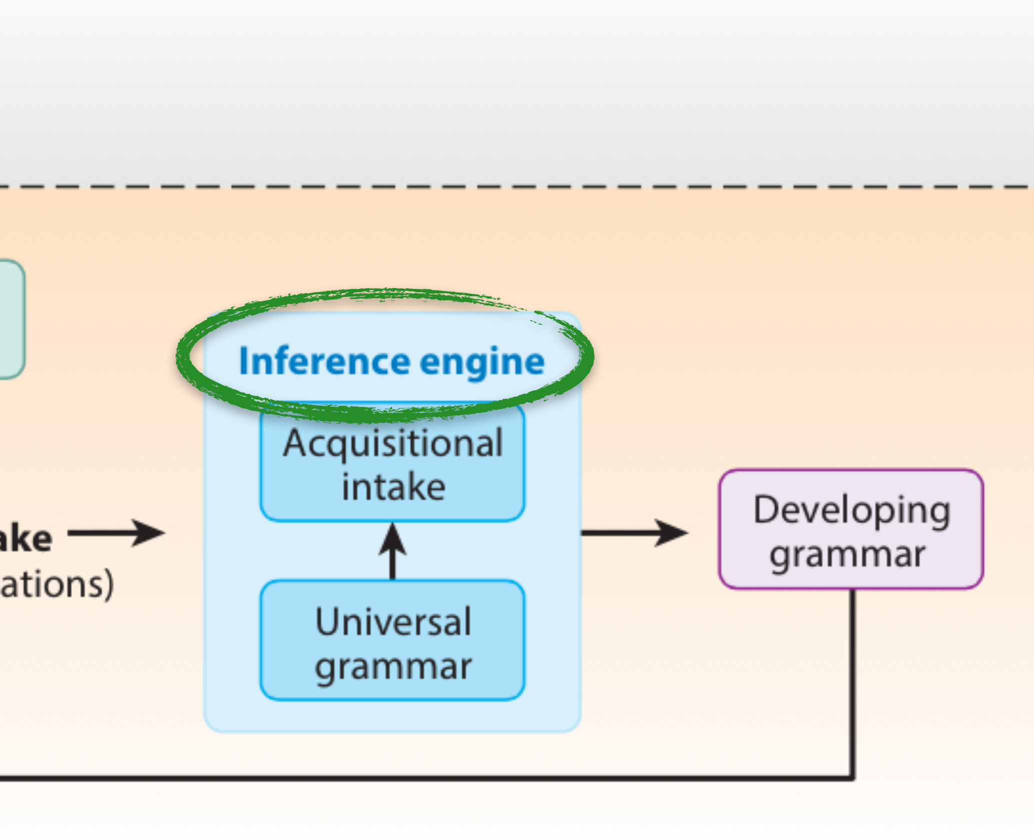
Depending on the verb class, the observed usage will have certain characteristics.



FALL

class₇

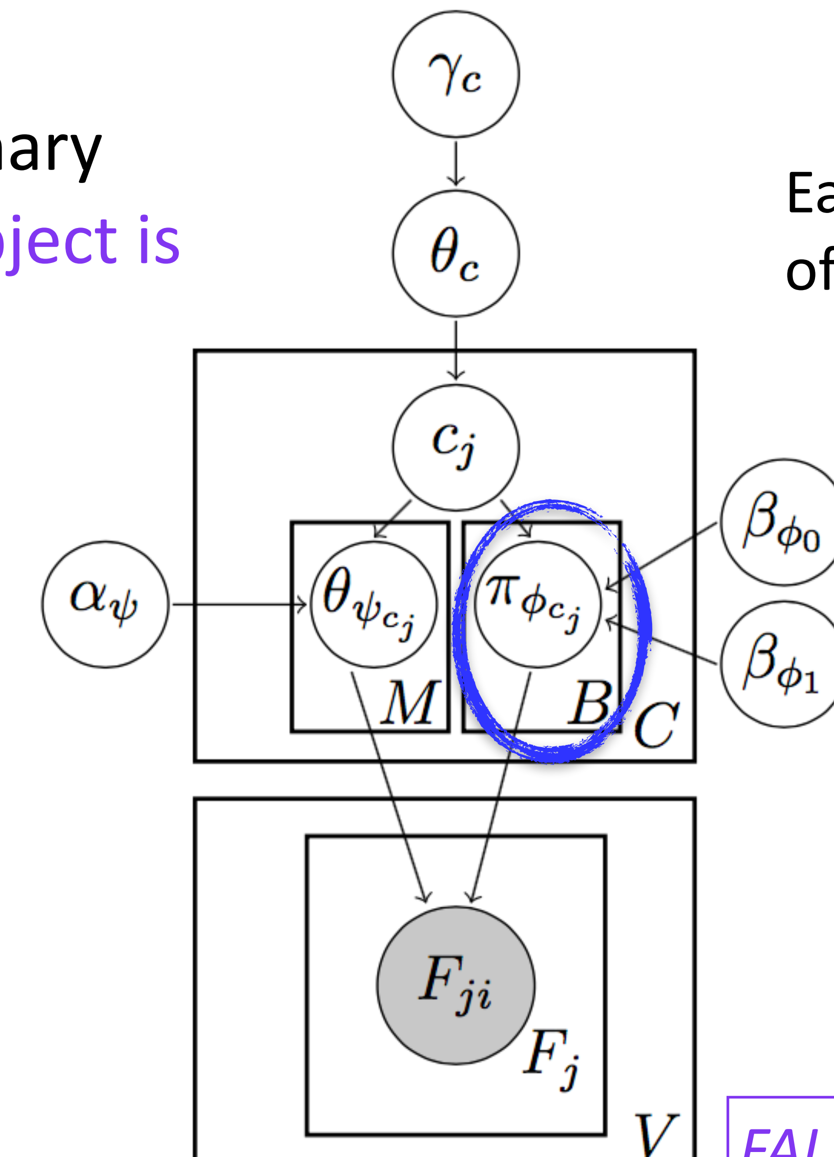
"it's falling off"
(3x) "it's falling off"
"it's falling off"



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

These characteristics include binary choices such as whether the subject is animate or not.



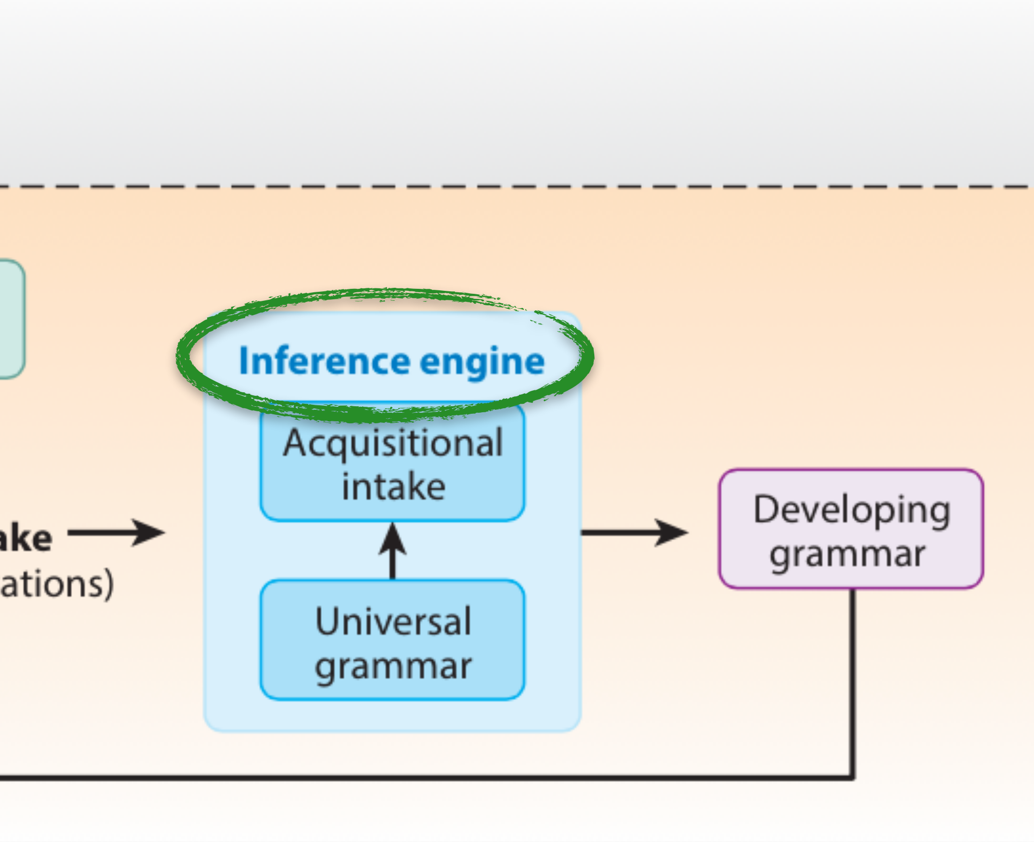
Each class has a probability of preferring each option.

class$_7$

+anim	*Subject*	*-anim*
0.3		*0.7*

-anim
"it's falling off"
(3x) "it's falling off"
"it's falling off"

FALL



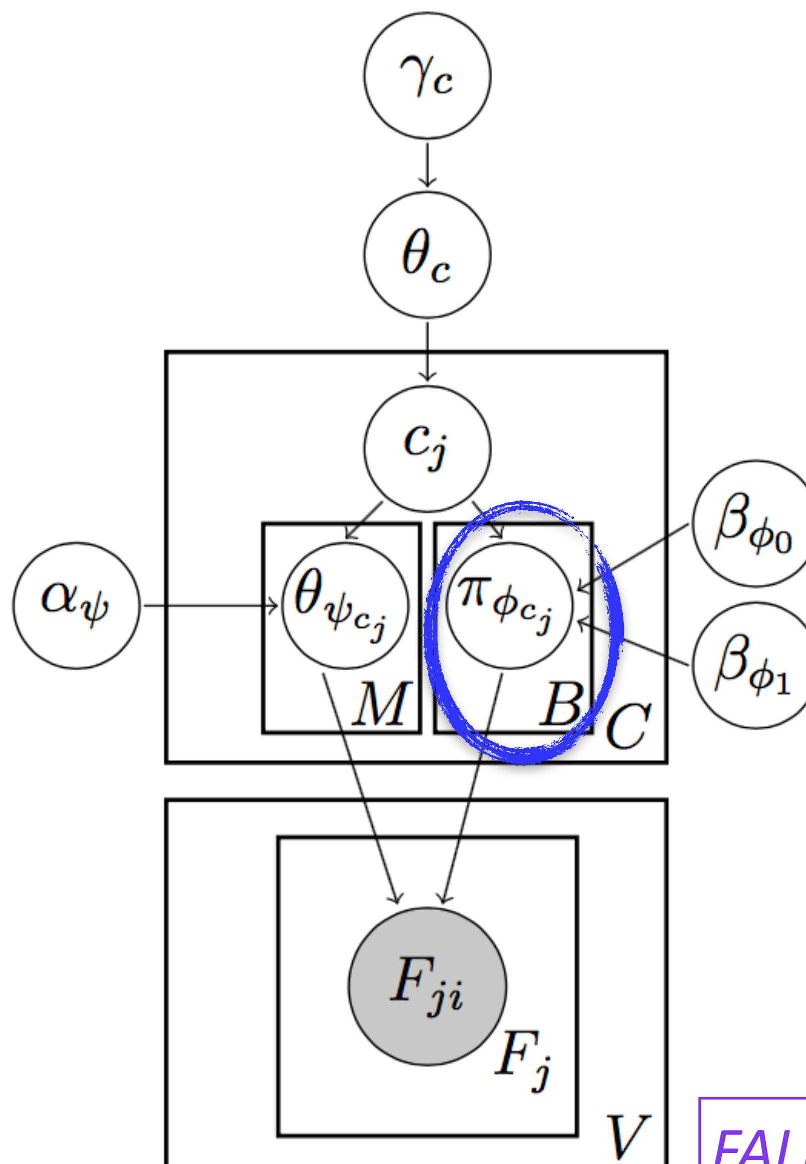
Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**



Binary choices:

- +/-animate subject
- +/-animate object
- +/-animate indirect object
- +/-movement (when +exp-mapping)



class₇

+anim	*Subject*	*-anim*
0.3		*0.7*

+animate

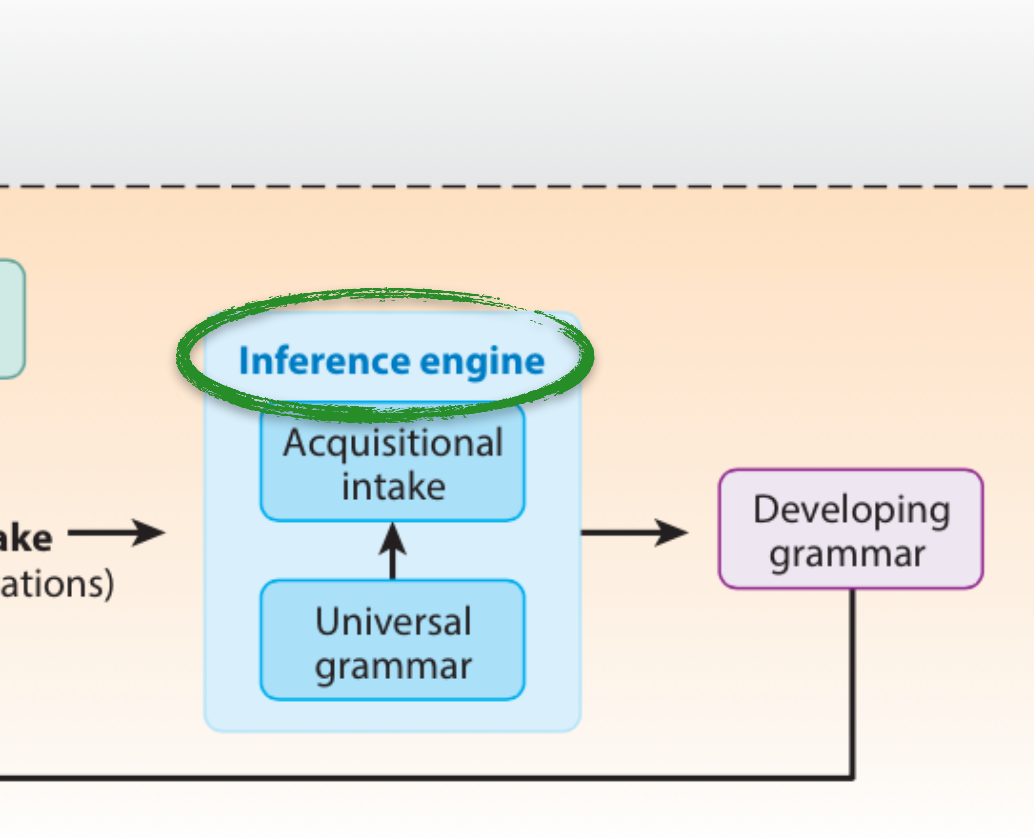
-animate

Subject *Object* *Indirect Object*

movement?

-anim
"it's falling off"
(3x) "it's falling off"
"it's falling off"

FALL



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs <4yrs <5yrs

These characteristics include multinomial choices such as which syntactic frame a verb appears in.

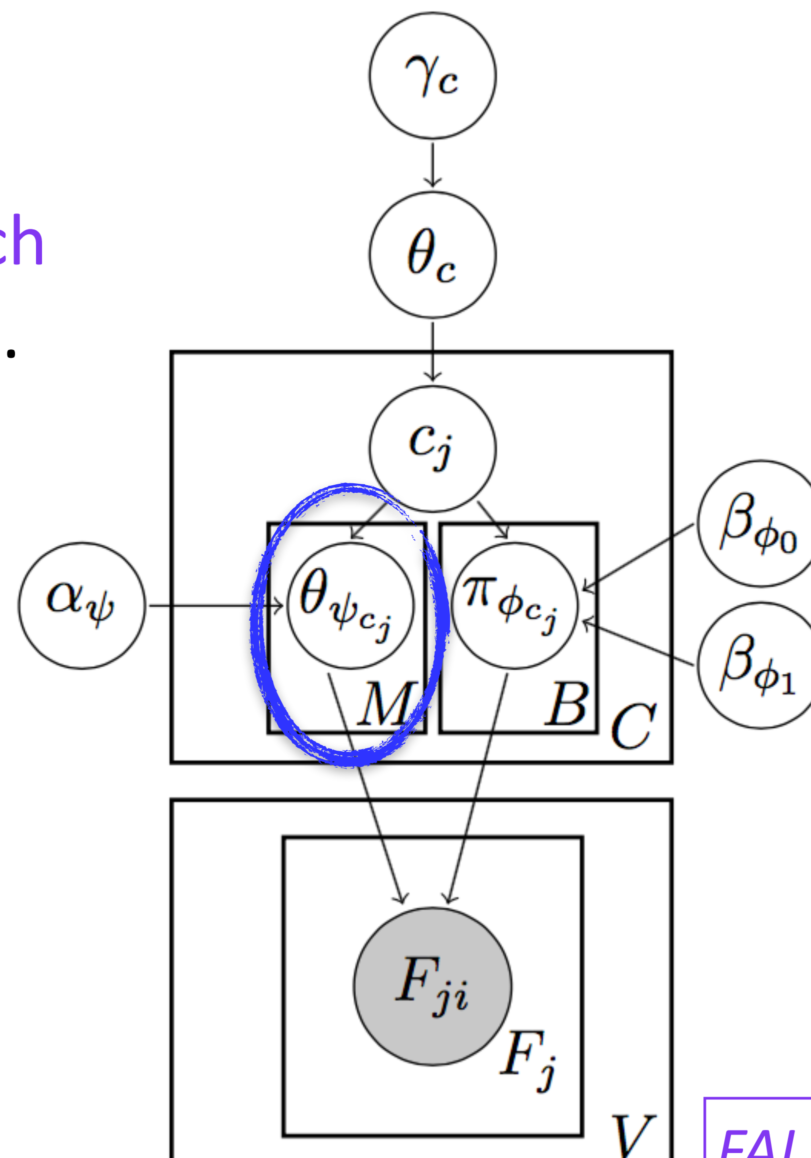
Each class has a probability of preferring each option.

NP V PRT 0.3

NP V 0.25

…

NP V S 0



class₇

+anim *Subject* *-anim*

0.3 *0.7*

-anim

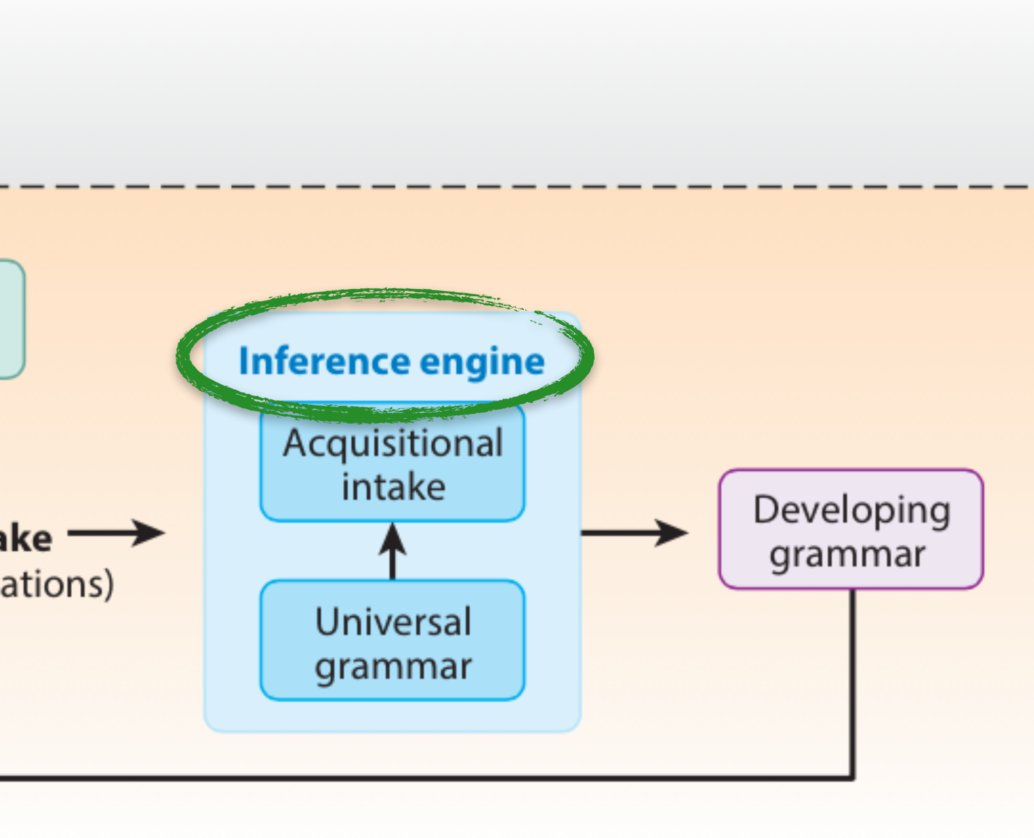
"it's falling off"

(3x) *NP V PRT*

"it's falling off"

"it's falling off"

FALL



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs <4yrs <5yrs

Multinomial choices:

which syntactic frame is used *NP V PRT*

(if -exp-mapping)

position of doer/Highest role

position of done-to/next-highest role

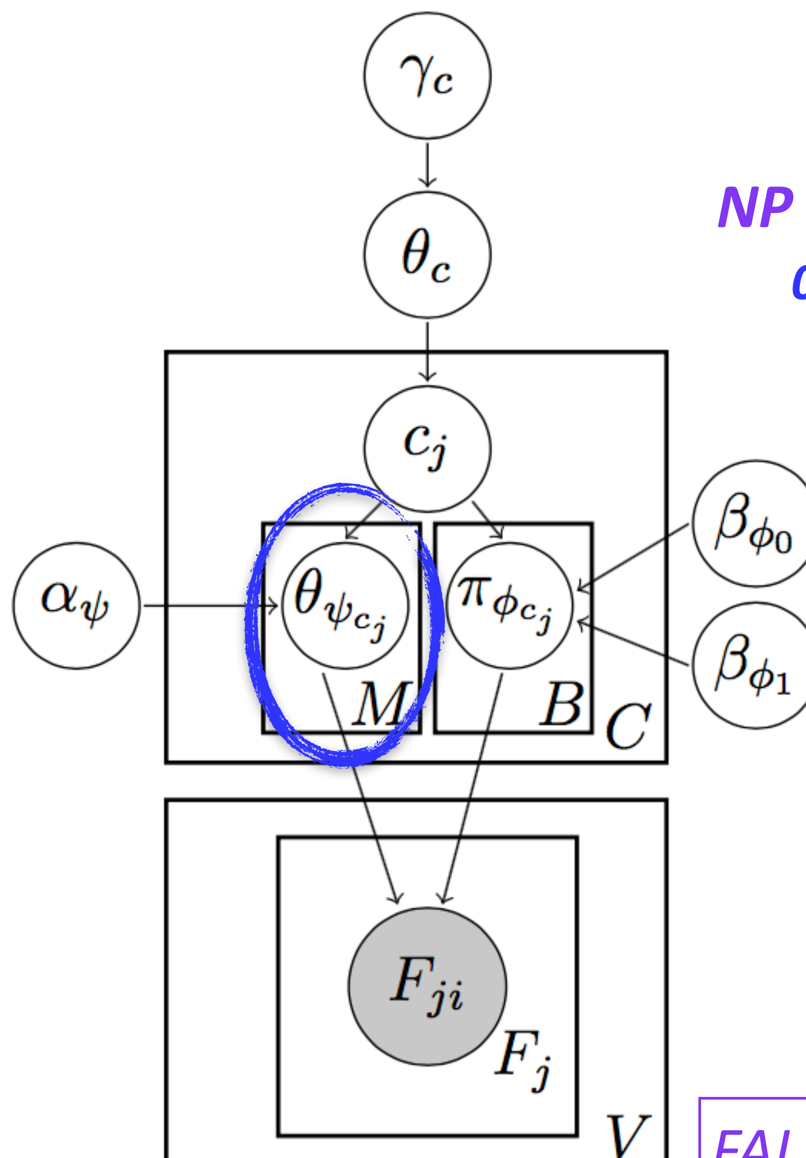
position of done-by/third-highest role

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

Subject *Object* *Indirect Object*



NP V ...

NP V PRT 0.3 *NP V* 0.25 *NP V S* 0

class7

+anim 0.3 *Subject* *-anim* 0.7

FALL

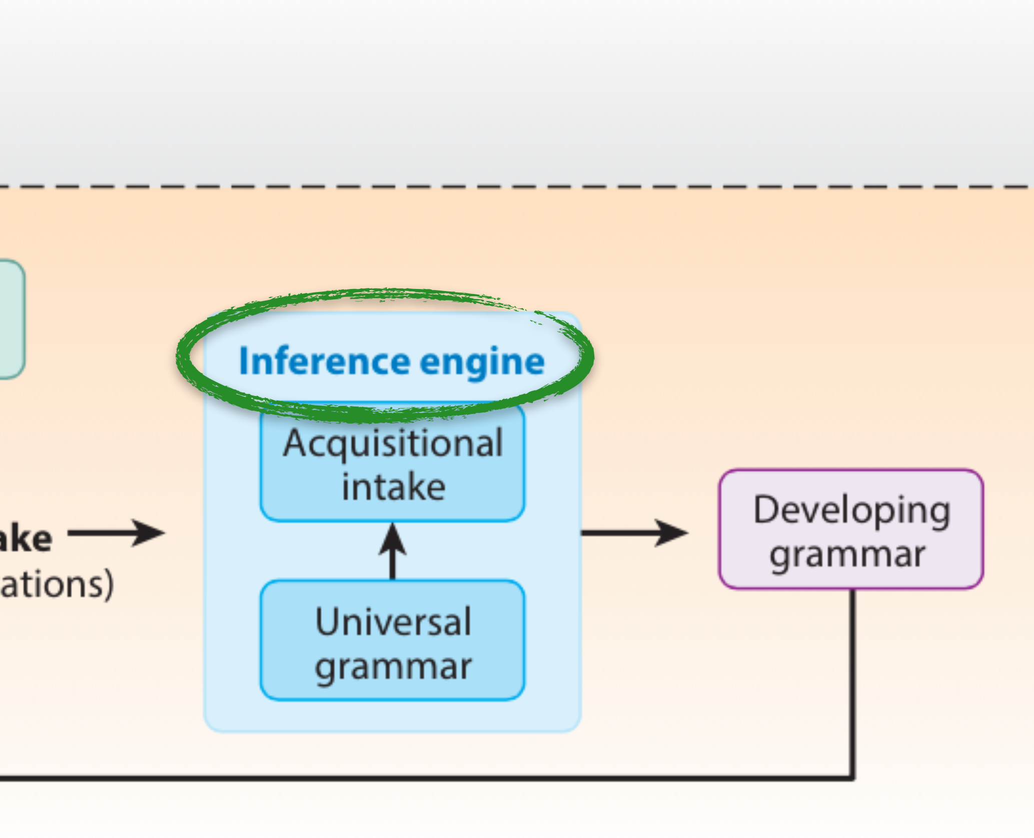
-anim

"it's falling off"

(3x) *NP V PRT*

"it's falling off"

"it's falling off"

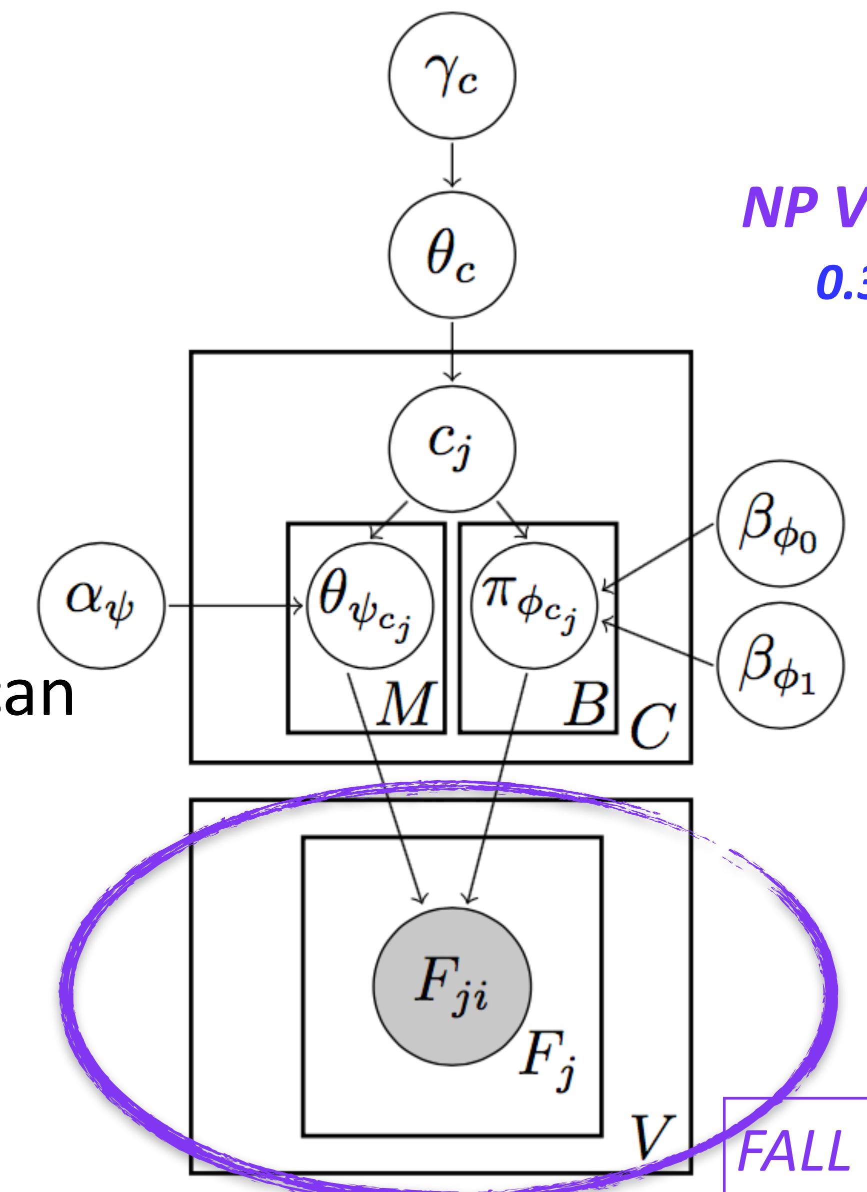


Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs <4yrs <5yrs



Using the observed instances of verb usage, Bayesian inference can be used to determine ...



NP V ...

NP V PRT 0.3

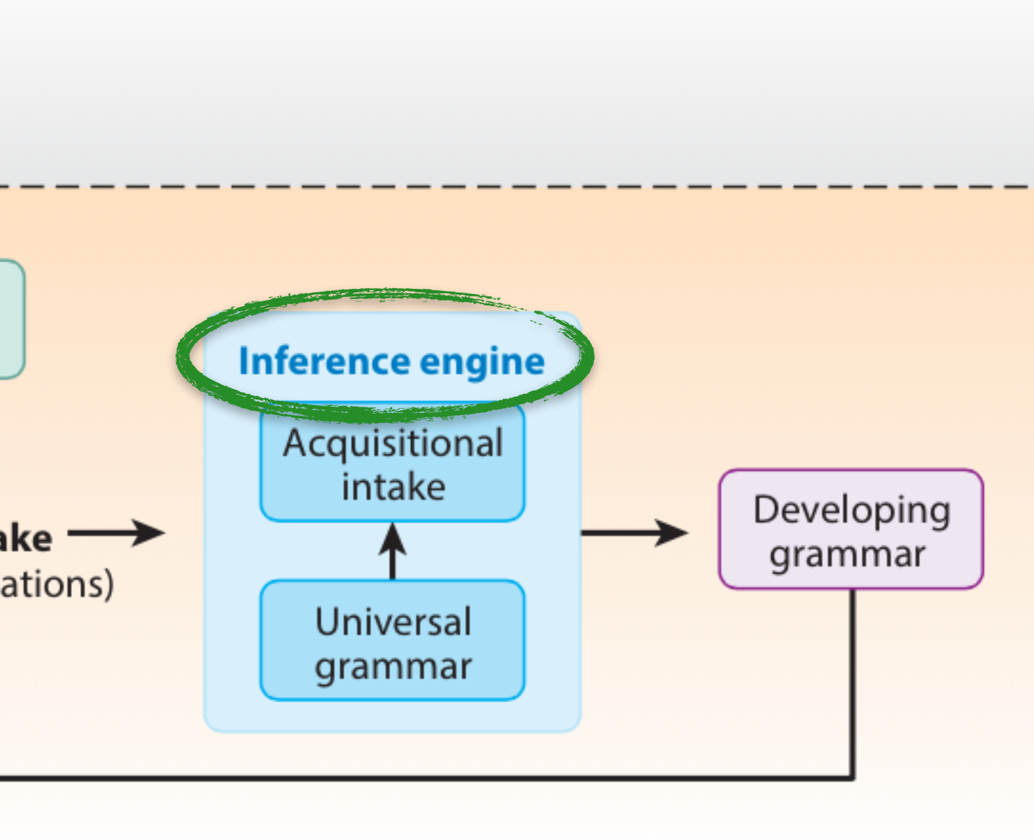
NP V 0.25

NP V S 0

class₇

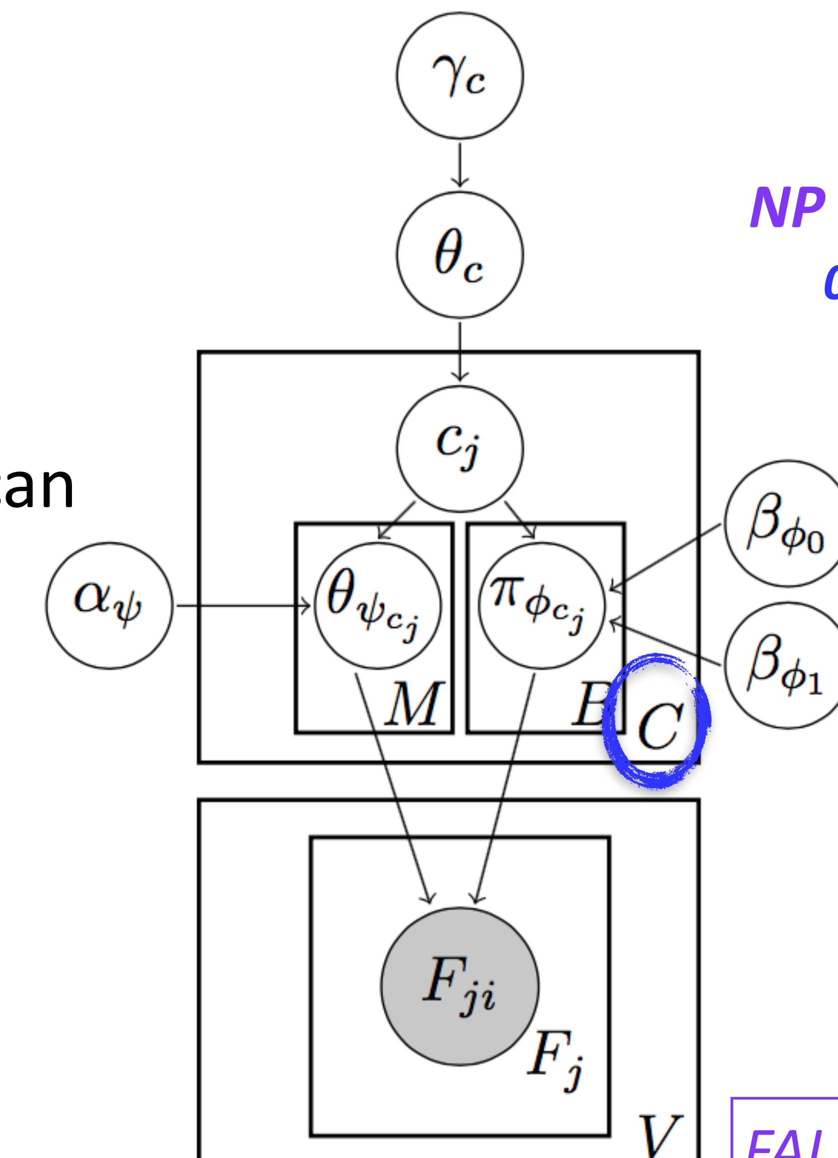
+anim 0.3 Subject -anim 0.7

-anim
"it's falling off"
(3x) NP V PRT
"it's falling off"
"it's falling off"



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs <4yrs <5yrs



NP V 0.25 ...

NP V PRT 0.3

NP V S 0

$class_7$

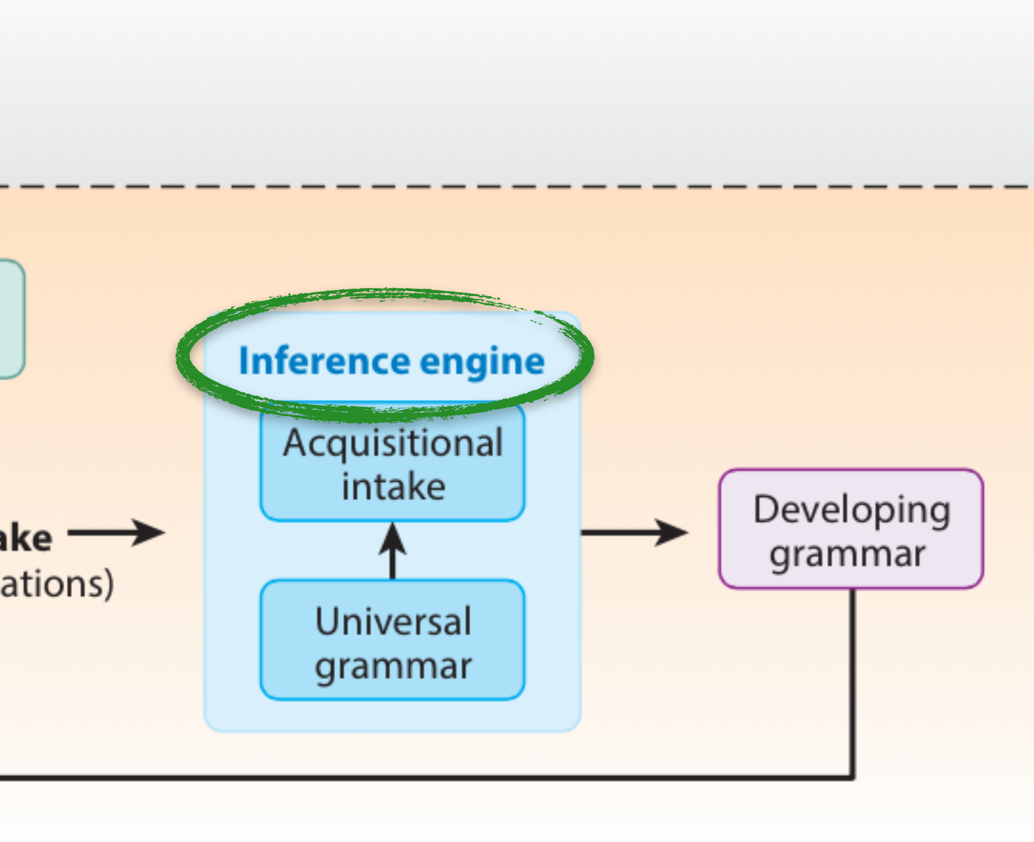
+anim 0.3 Subject -anim 0.7

-anim
"it's falling off"
(3x) NP V PRT
"it's falling off"
"it's falling off"

FALL

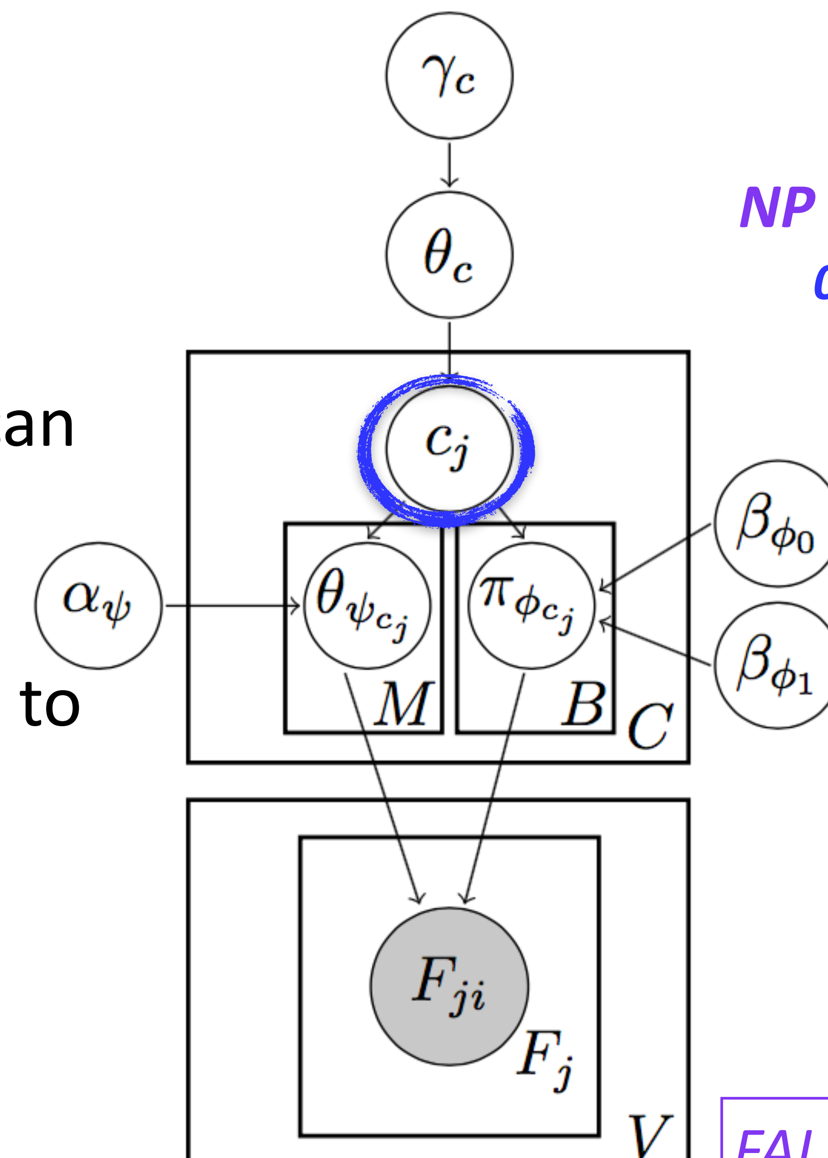
Using the observed instances of verb usage, Bayesian inference can be used to determine

- how many classes there are



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs <4yrs <5yrs



NP V PRT 0.3

NP V 0.25

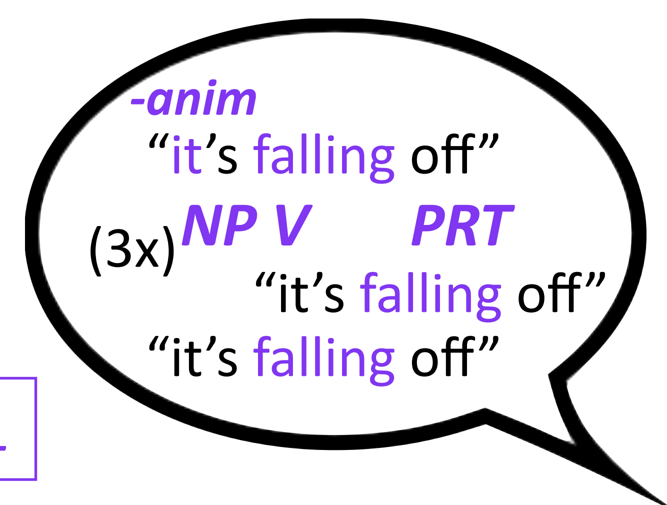
...

NP V S 0

class7

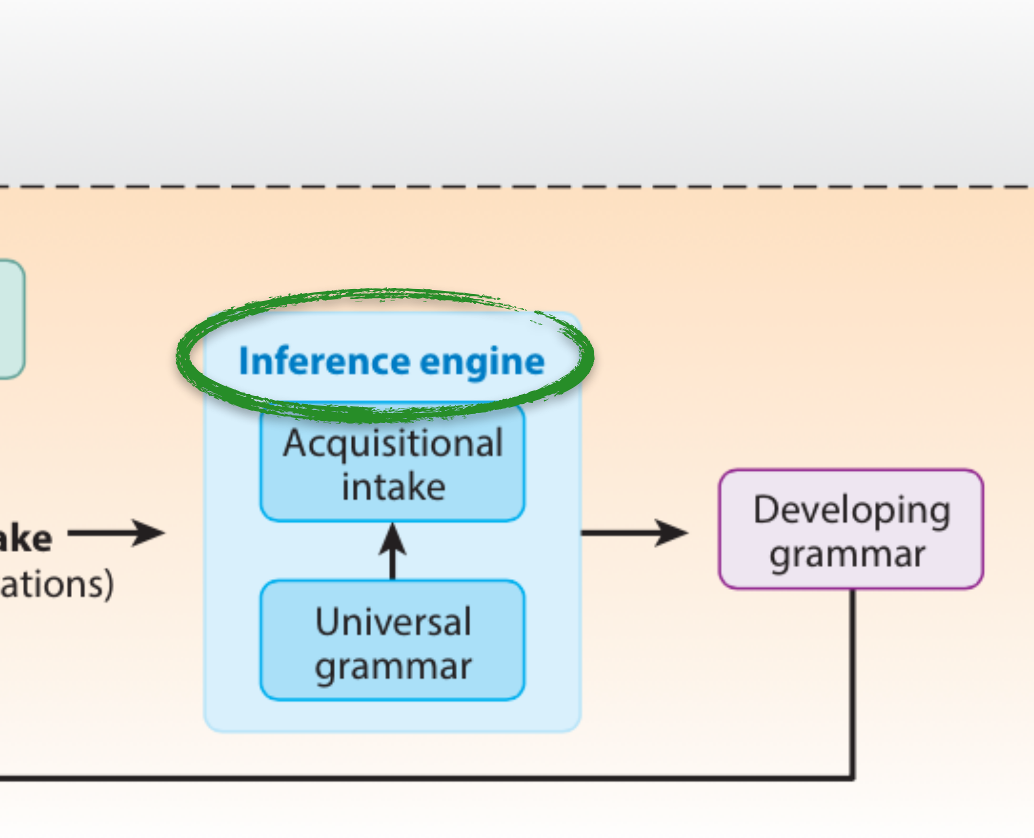
+anim 0.3 Subject -anim 0.7

FALL



Using the observed instances of verb usage, Bayesian inference can be used to determine

- how many classes there are
- which class each verb belongs to

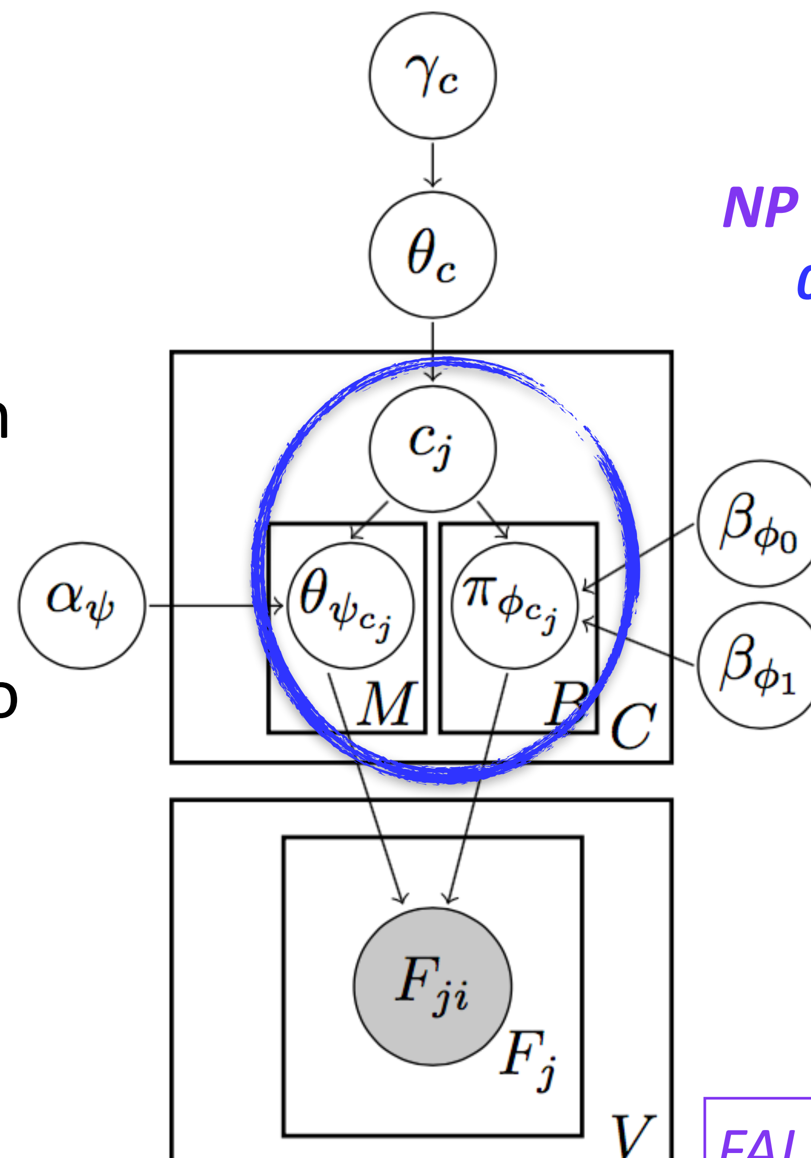


Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

Using the observed instances of verb usage, Bayesian inference can be used to determine

- how many classes there are
- which class each verb belongs to
- what the characteristics are of each class



NP V ***...***

NP V PRT ***0.25*** ***NP V S***

0.3 ***0***

class$_7$

+anim ***Subject*** ***-anim***

0.3 ***0.7***

-anim

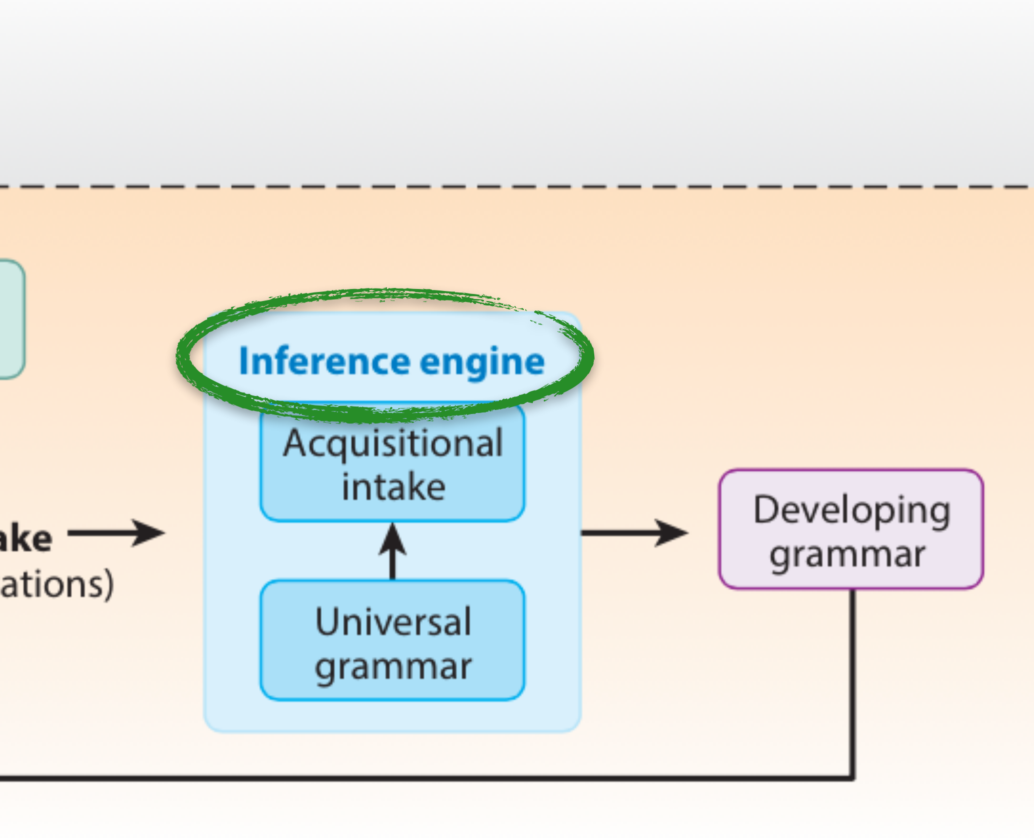
"it's falling off"

(3x) ***NP V PRT***

"it's falling off"

"it's falling off"

FALL



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

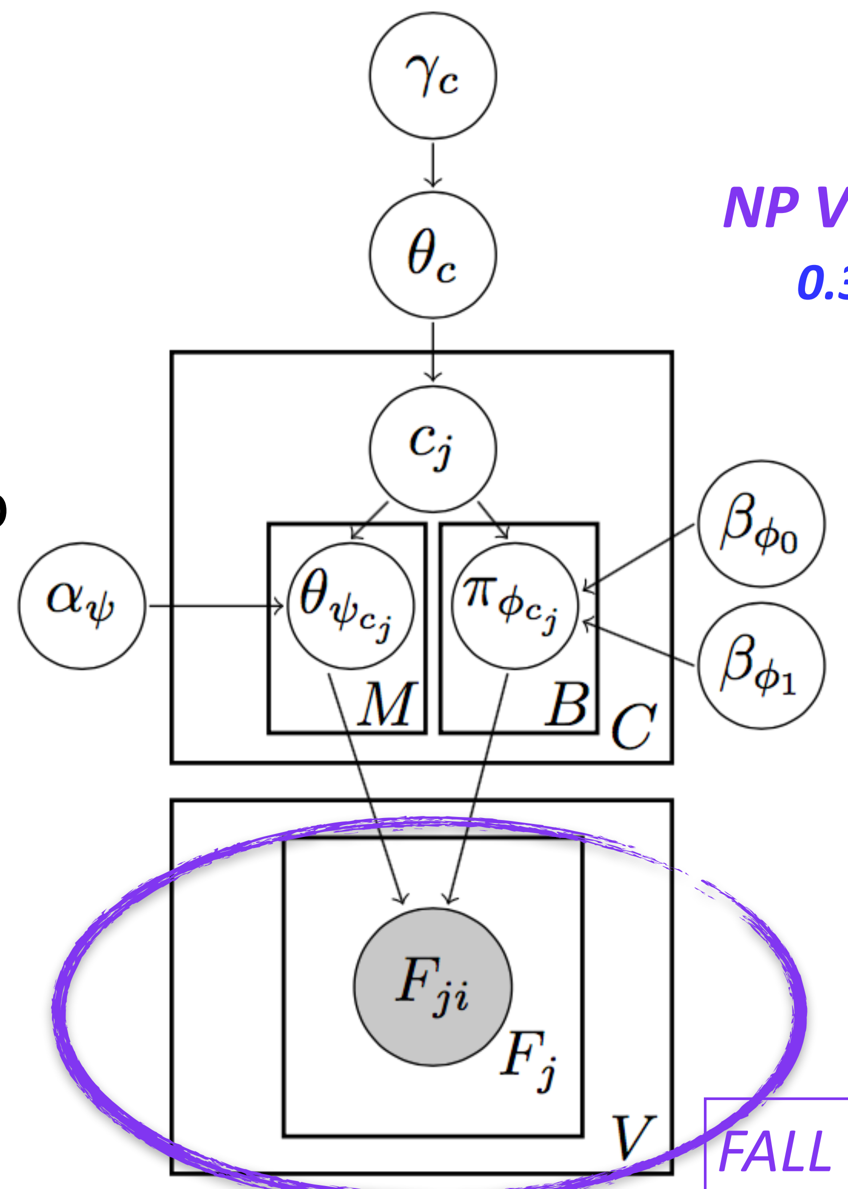
<3yrs **<4yrs** **<5yrs**

Using the observed instances of verb usage, Bayesian inference can be used to determine

- how many classes there are
- which class each verb belongs to
- what the characteristics are of each class

Best answer: maximizes the probability of the observed data.



NP V *...*

NP V PRT *0.25* *NP V S*

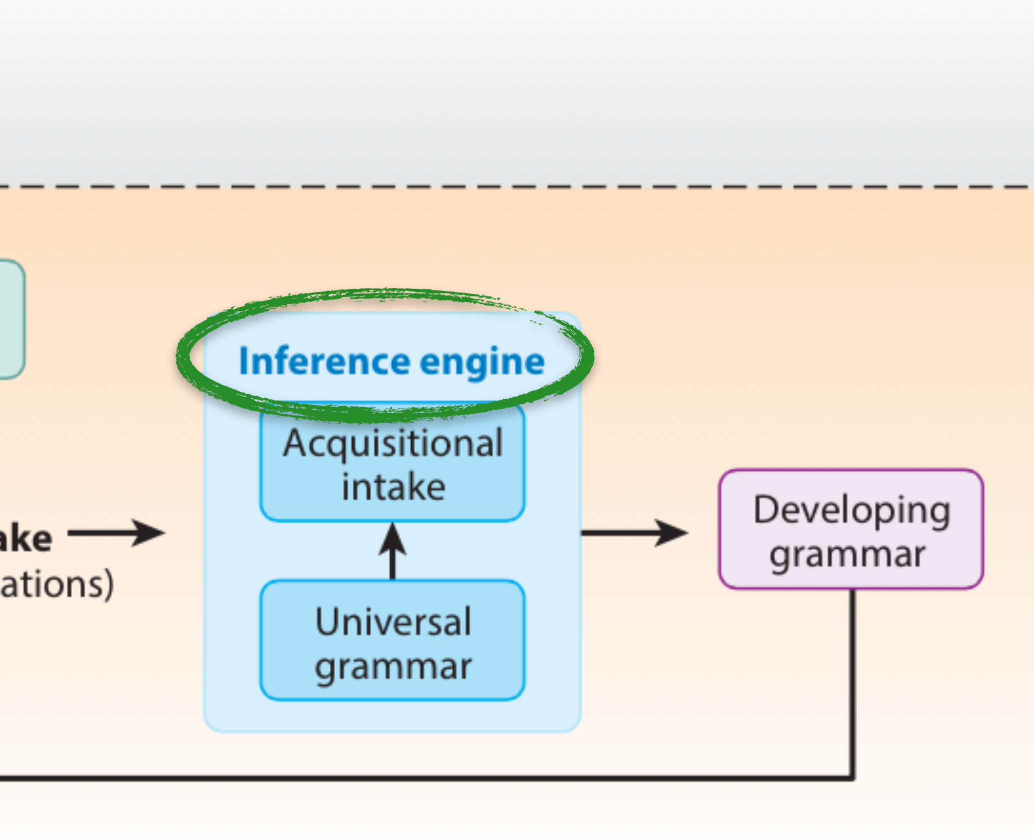
0.3 *0*

class7

+anim *Subject* *-anim*

0.3 *0.7*

-anim
"it's falling off"
(3x) *NP V* *PRT*
"it's falling off"
"it's falling off"



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

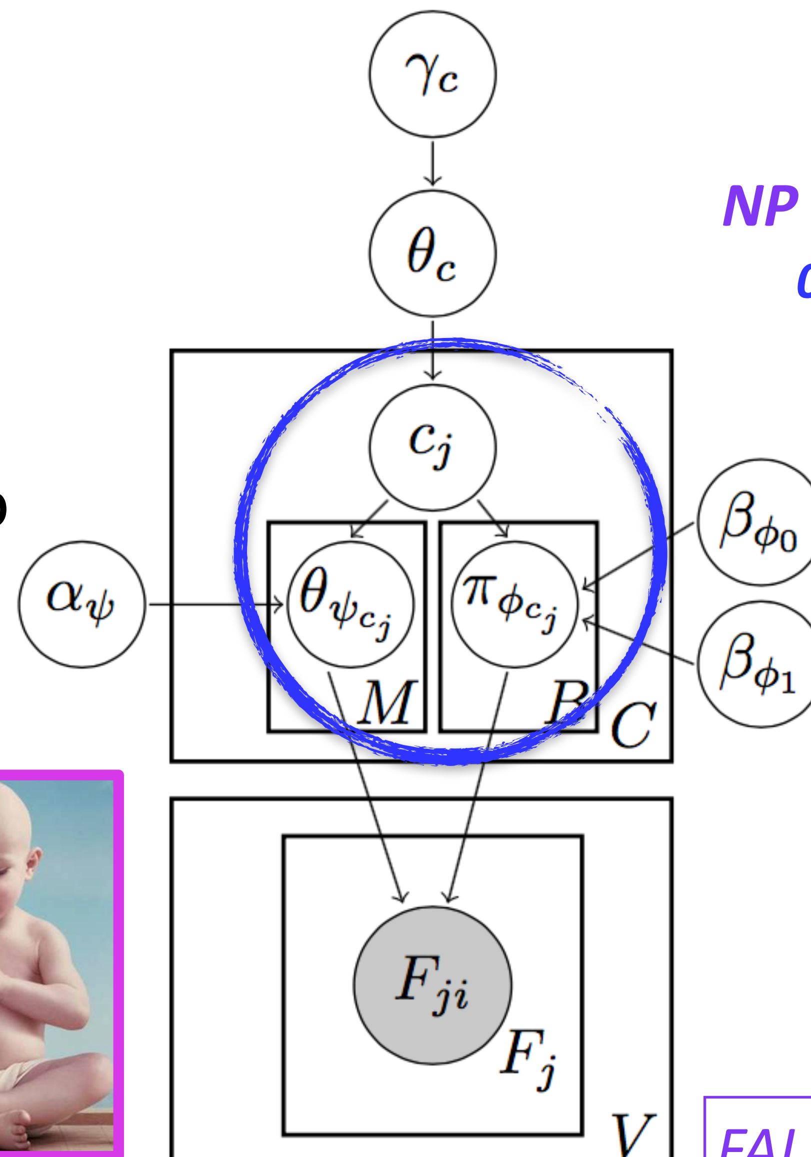


Using the observed instances of verb usage, Bayesian inference can be used to determine

- how many classes there are
- which class each verb belongs to
- what the characteristics are of each class

$$p_{c_j} = P(c_j|c_{-j}, \gamma_c, F_{-j}, \lambda) = p_{cat_j} * p_{binary_{c_j}} * p_{multinomial_{c_j}}$$

+ Gibbs sampling



NP V PRT 0.3

NP V 0.25

...

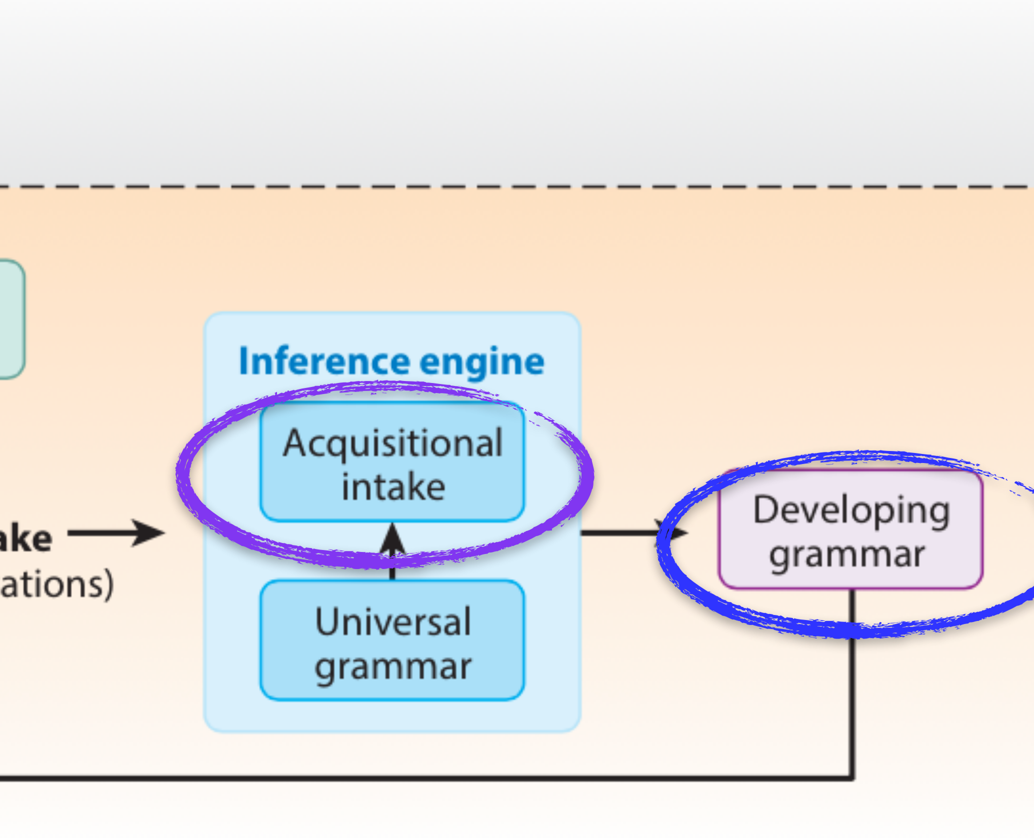
NP V S 0

class7

+anim 0.3 *Subject* *-anim* 0.7

-anim
"it's falling off"
(3x) *NP V* *PRT*
"it's falling off"
"it's falling off"

FALL



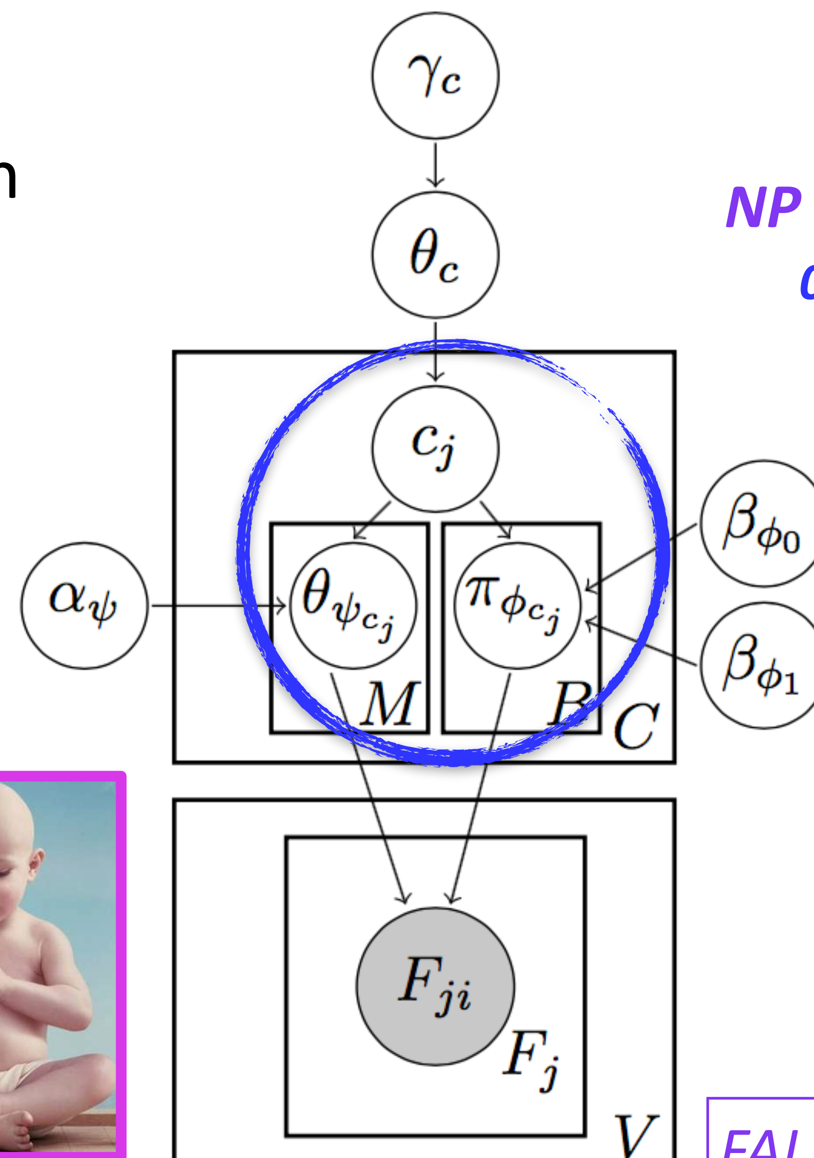
Goal: Model the
developmental trajectory
from 3 to 4 to 5 years old

<3yrs <4yrs <5yrs



Goal: Determine if the information provided in the modeled learner's acquisitional intake is sufficient to identify verb classes this way.

-surfmorph
+surfmorph
UTAH
rUTAH
-expmap
+expmap

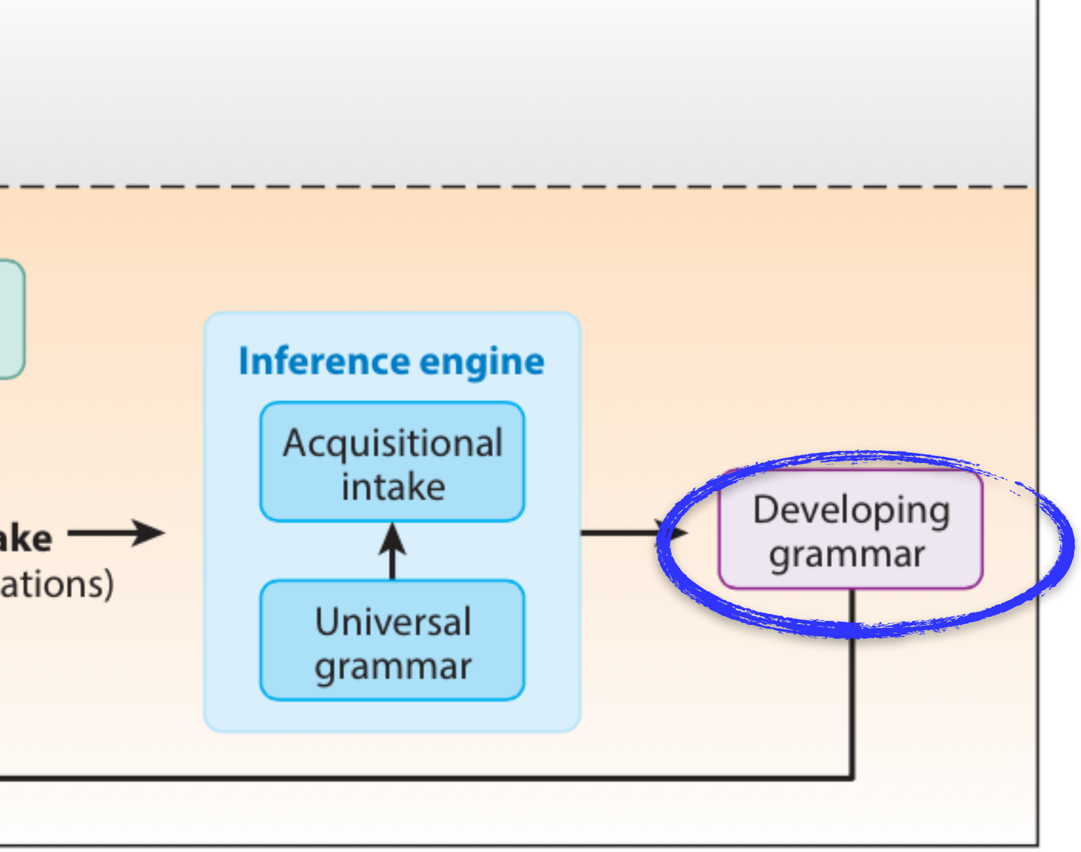


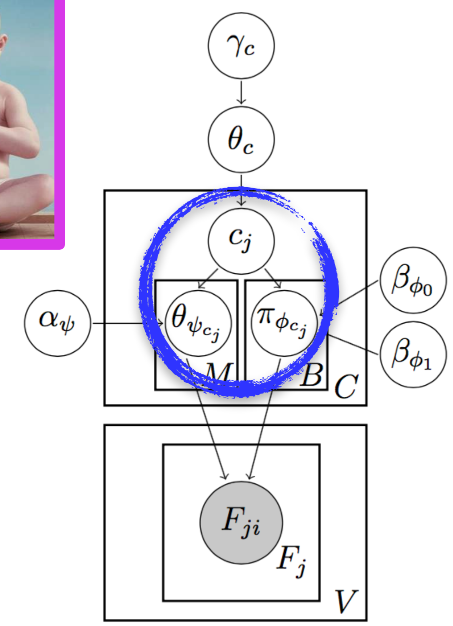
NP V ...
NP V PRT 0.3
0.25
NP V S 0

class7
+anim 0.3
Subject
-anim 0.7

FALL

-anim
"it's falling off"
(3x) NP V PRT
"it's falling off"
"it's falling off"

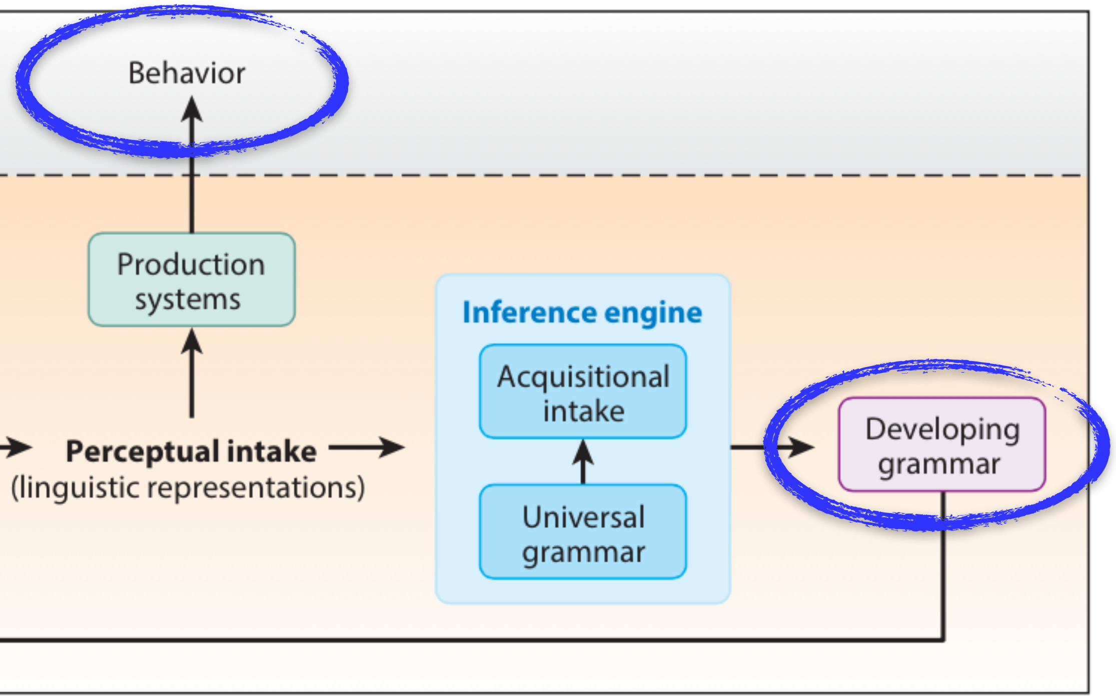


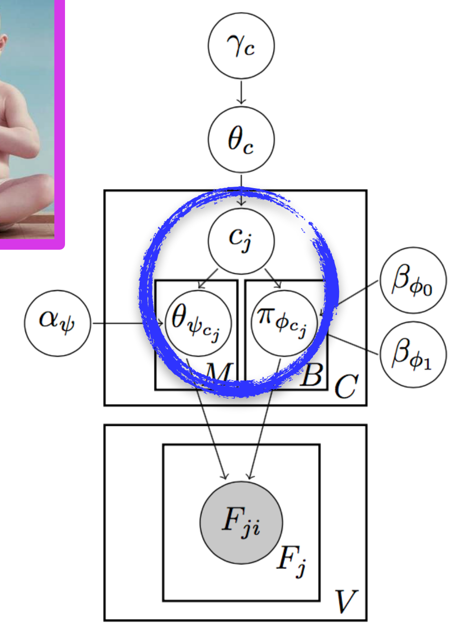


Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

verb classes



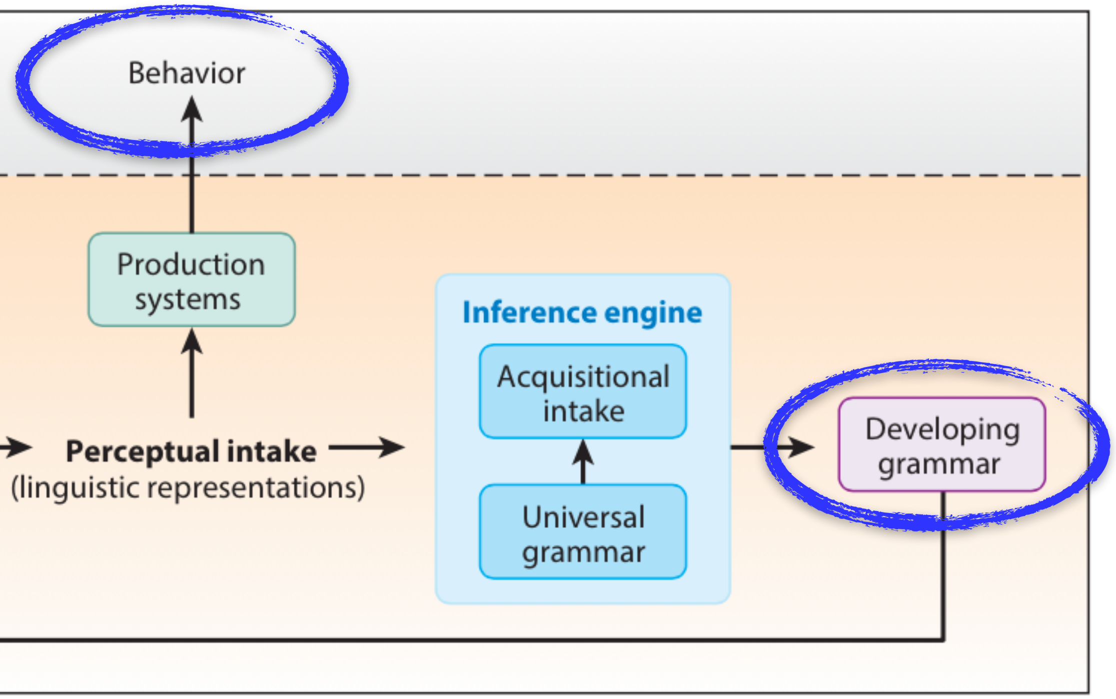


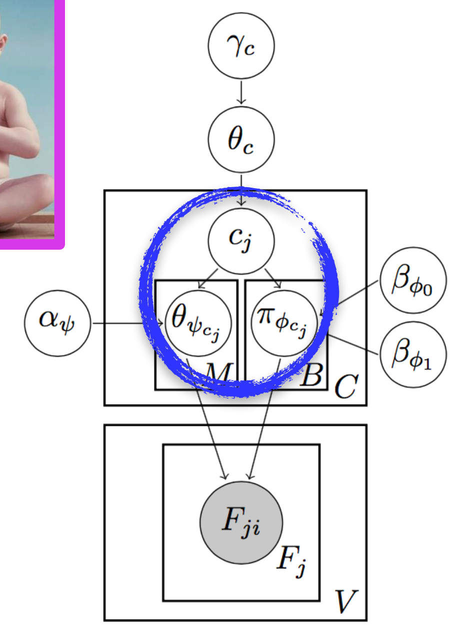
Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

verb classes

Survey of **32** experimental studies on children's production and comprehension of specific verbs





Goal: Model the
developmental trajectory
from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

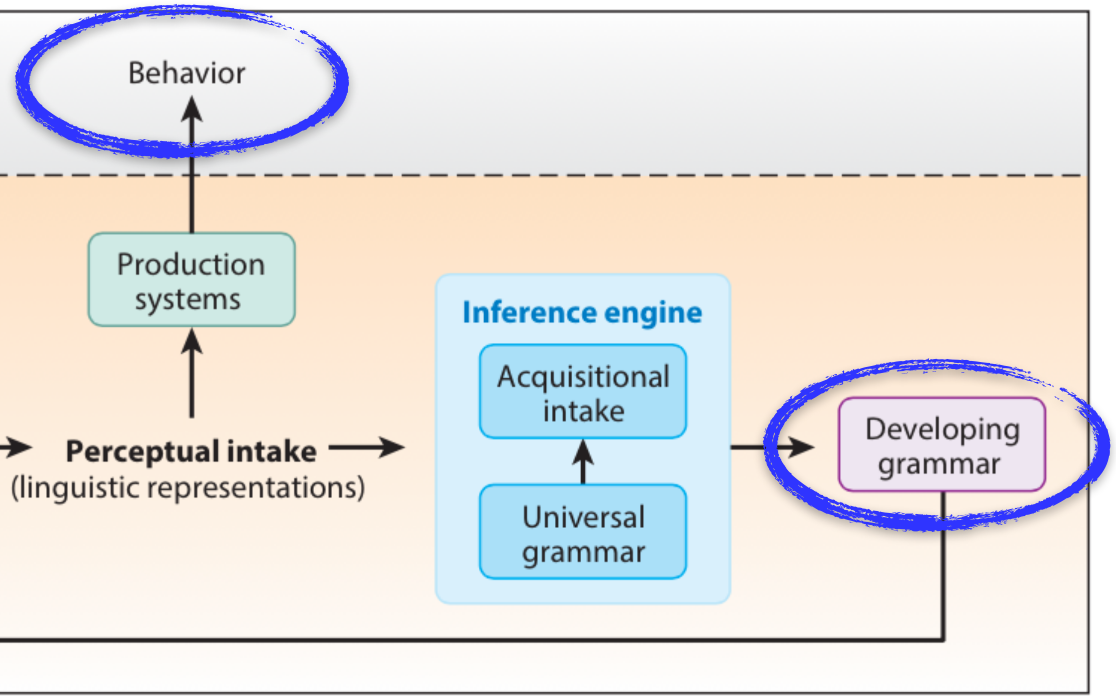


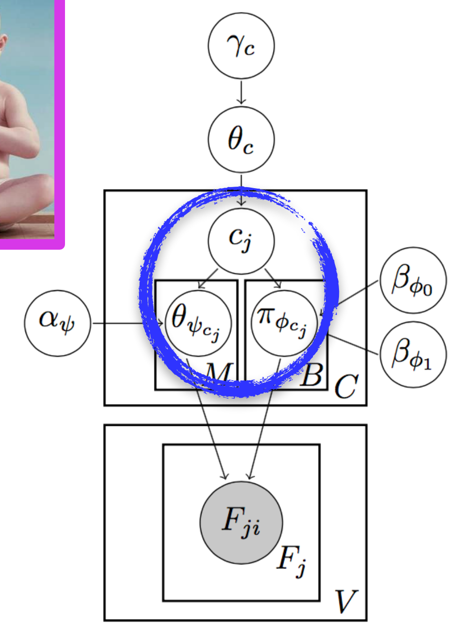
verb classes

Survey of **32** experimental studies on children's production and comprehension of specific verbs

Yields 12 verb behaviors

+/-passive
+unaccusative
+ditransitive
+control-object
+raising-object
+raising-subject
+control-subject
+*that*-comp
+*whether/if*-comp
+subject-experiencer
+object-experiencer
+non-finite *to*-comp

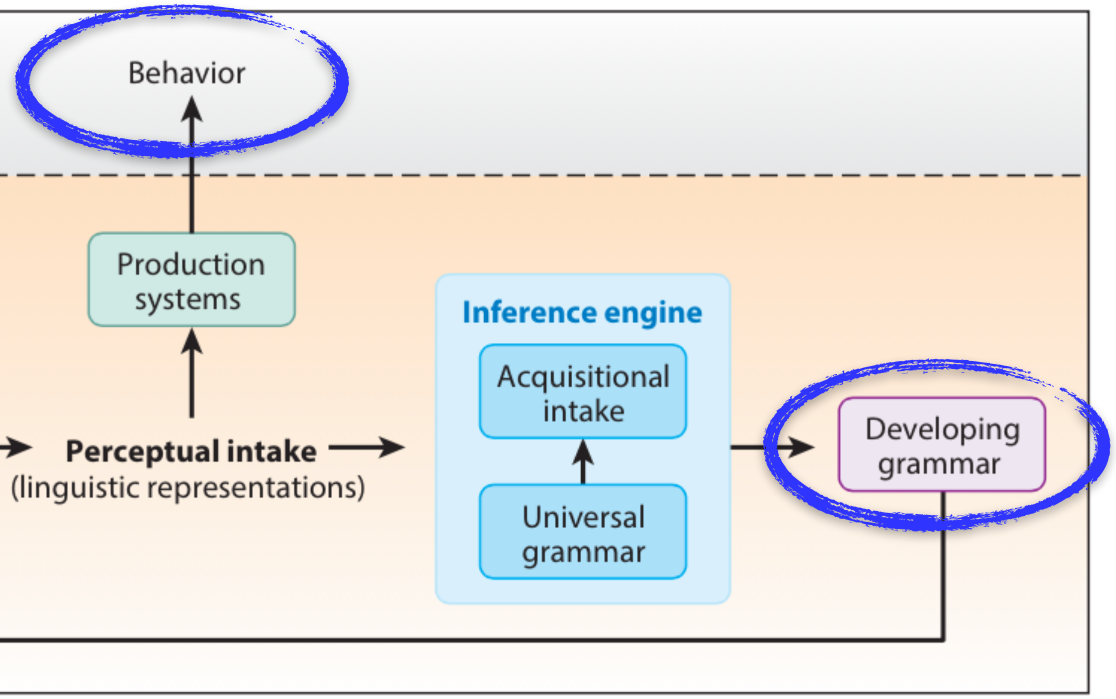


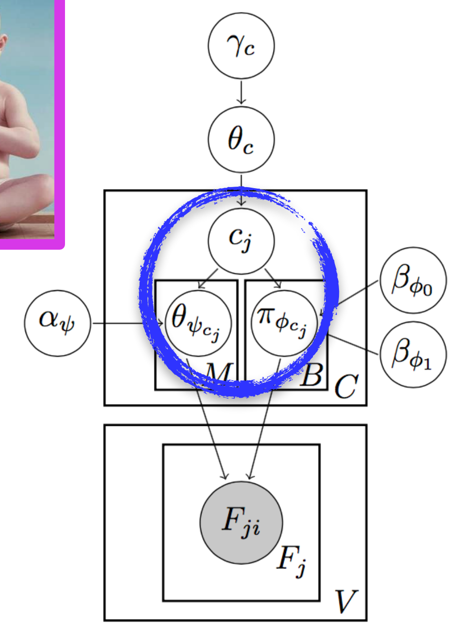


Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

These verb behaviors yield a number of **verb classes** at each age





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

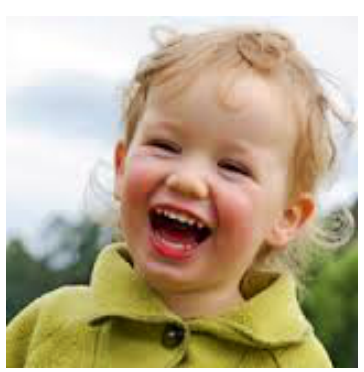
<4yrs

<5yrs

These verb behaviors yield a number of **verb classes** at each age

Example classes

<3yrs



[+passive]: carry, chase, crash, drop, eat, hit, hold, hurt, jump, kick, kiss, knock, lick, punch, push, scratch, shake, turn, wash, watch

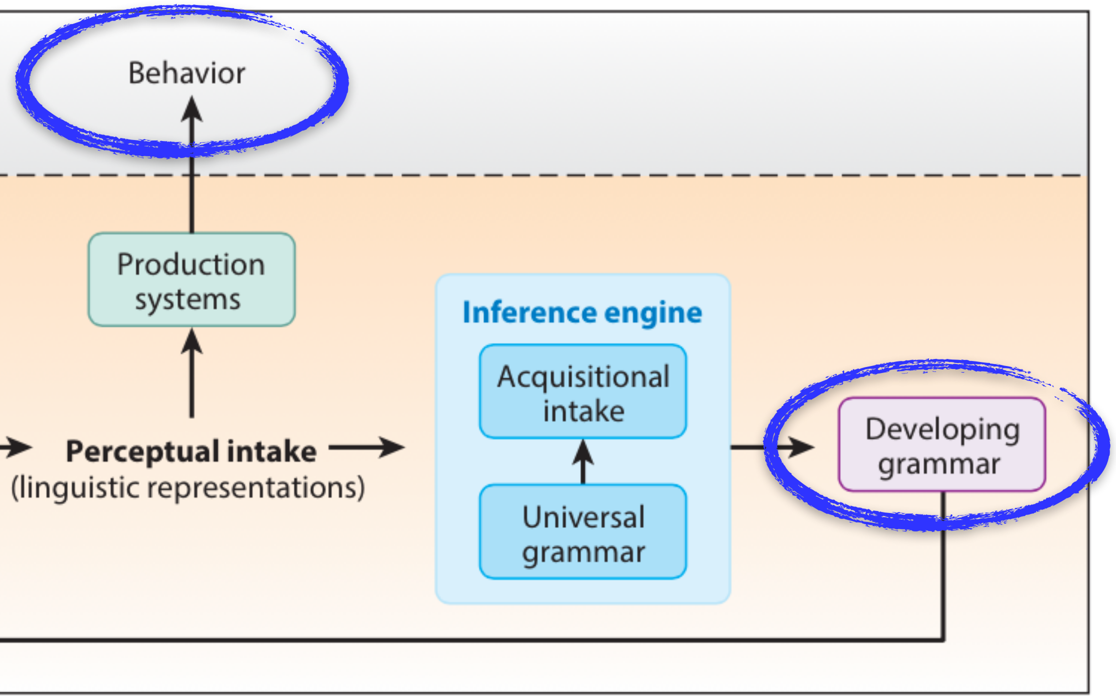
[-passive]: believe, remember

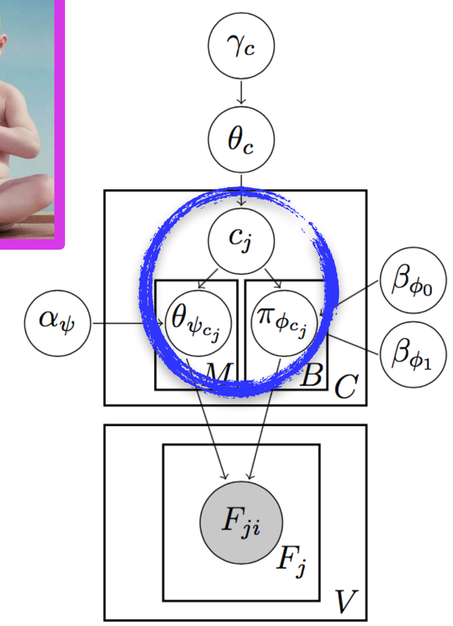
[+non-finite *to*]: ask, have, need, start, suppose, teach, try, use, want

[+*that*-comp]: bet, hope, think, wish

[+passive, +non-finite *to*]: like

[+passive, +*that*-comp]: see





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs

<5yrs

These verb behaviors yield a number of **verb classes** at each age

<4yrs

Example classes

[+passive]: bite, bump, carry, chase, crash, drop, find, hit, hold, hurt, jump, kick, kill, kiss, knock, lick, pull, punch, push, ride, scratch, shake, shoot, turn, wash, watch

[-passive]: believe, remember

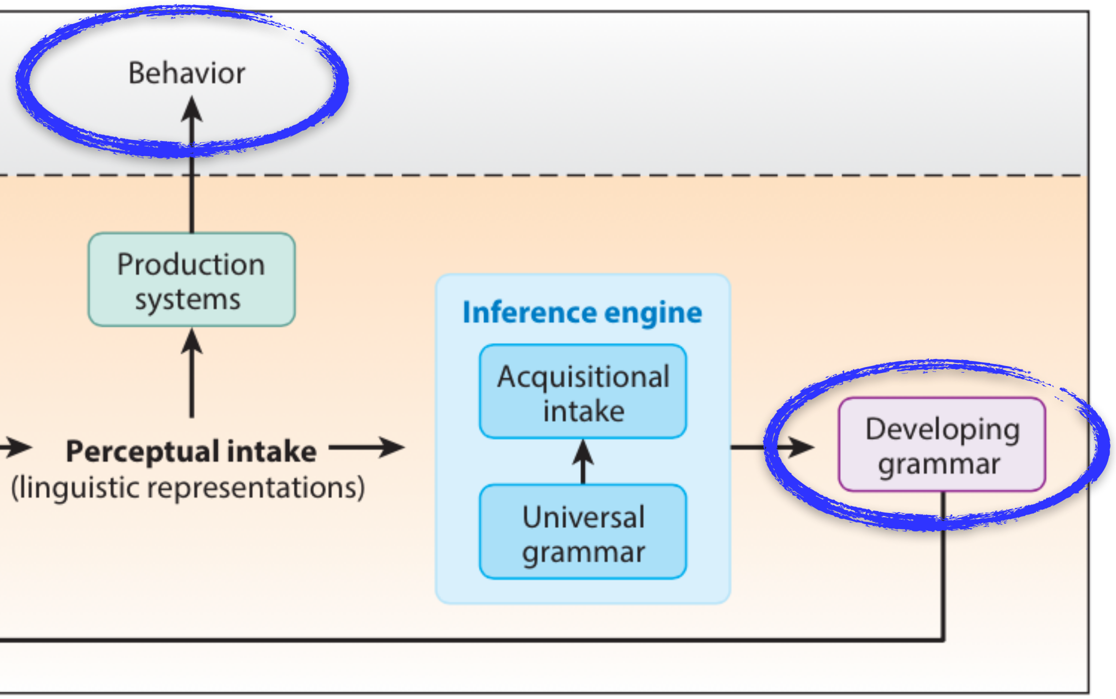
[+*that*-comp]: bet, hope, think, wish

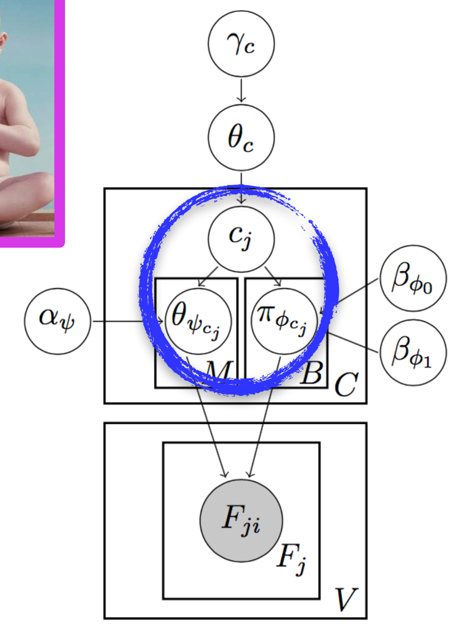
[+non-finite *to,* +raising-obj]: need

[+non-finite *to,* +raising-obj, +control-subj]: want

[+passive, +non-finite *to,* +psych-subj]: like

[+passive, +*that*-comp]: see





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs

<4yrs

These verb behaviors yield a number of **verb classes** at each age

<5yrs

Example classes

[+passive]: bite, bump, carry, chase, crash, drop, find, hit, hold, hurt, jump, kick, kill, kiss, knock, lick pull, push, ride, scratch, shake, shoot, turn, wash, watch

[-passive]: believe, remember

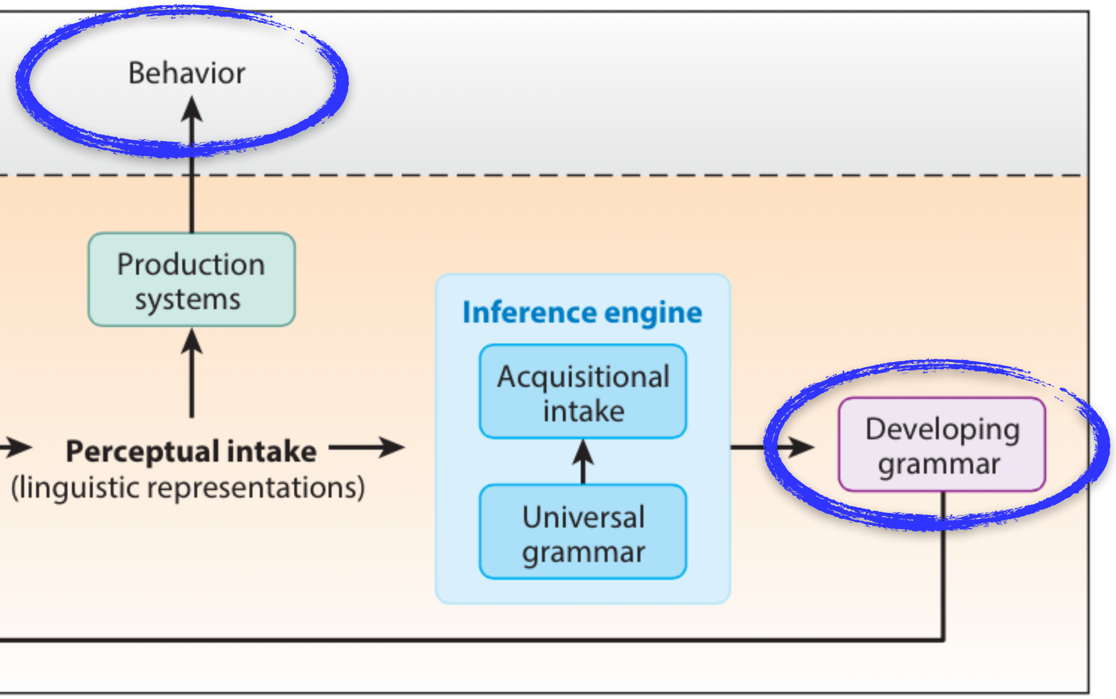
[+*that*-comp]: bet, dream, guess, hope, lie, pretend, think, wish

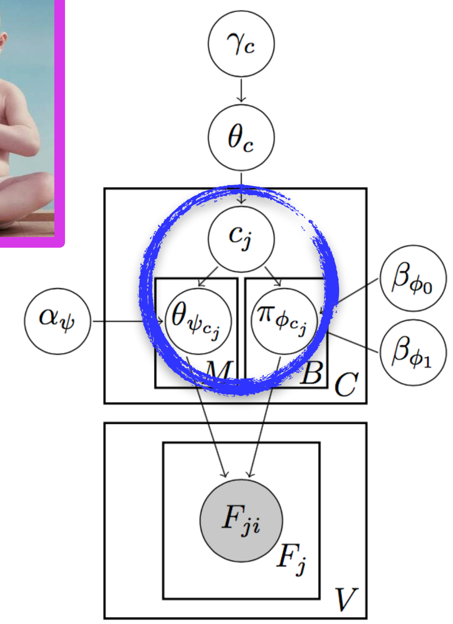
[+non-finite *to,* +raising-obj]: need

[+non-finite *to,* +raising-obj, +control-subj]: want

[+passive, +non-finite *to,* +psych-subj]: like

[+passive, +*that*-comp, +*whether/if*-comp]: see

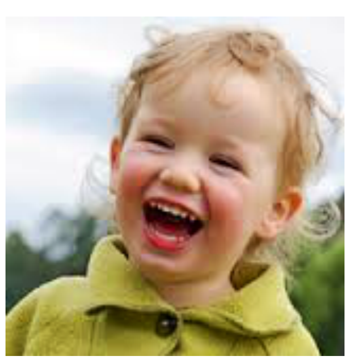




Goal: Model the developmental trajectory from 3 to 4 to 5 years old

These verb behaviors yield a number of **verb classes** at each age

<3yrs



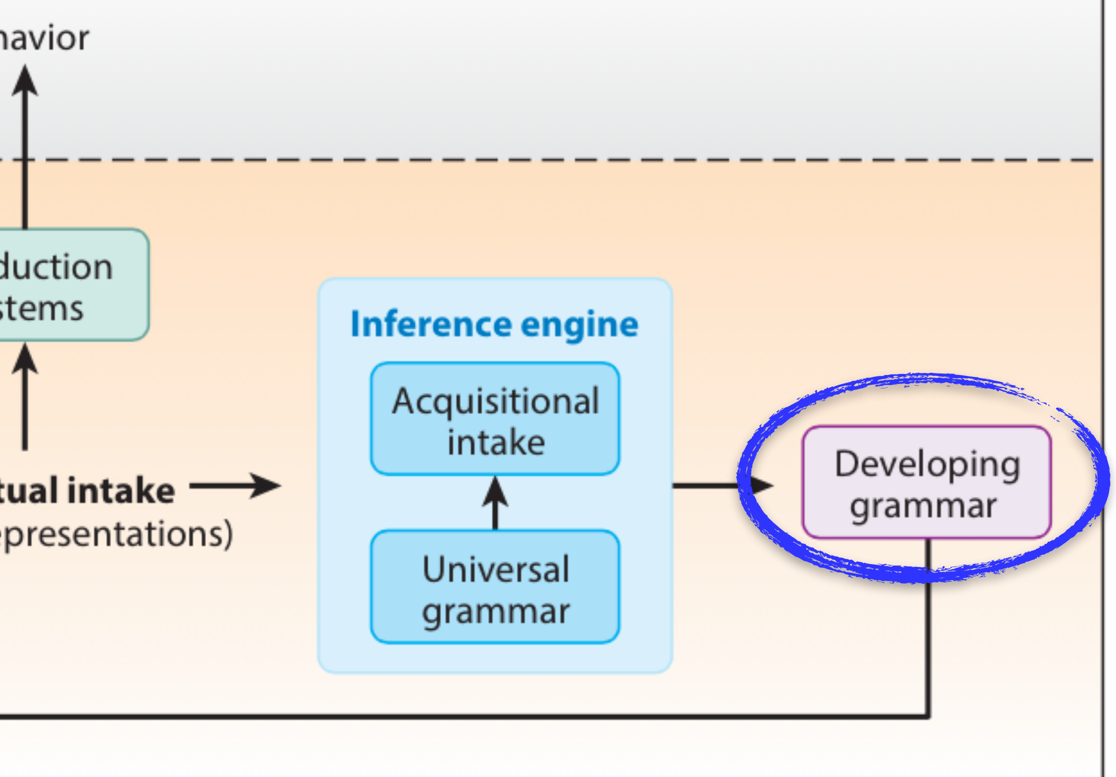
15 classes of 60 verbs total

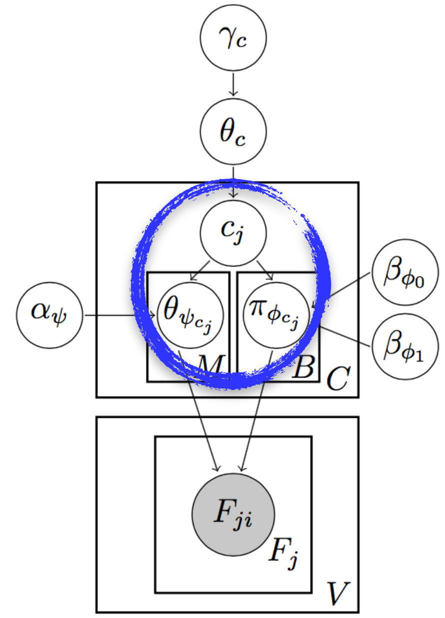
<4yrs

23 classes of 76 verbs total

<5yrs

25 classes of 84 verbs total



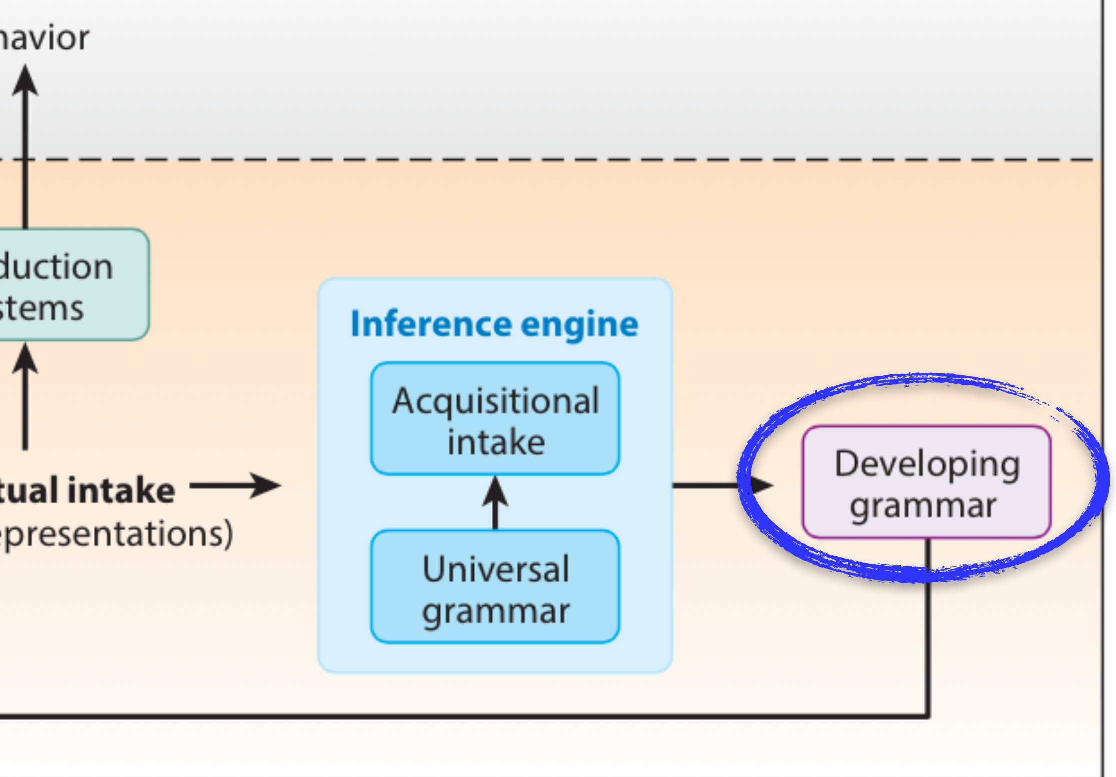


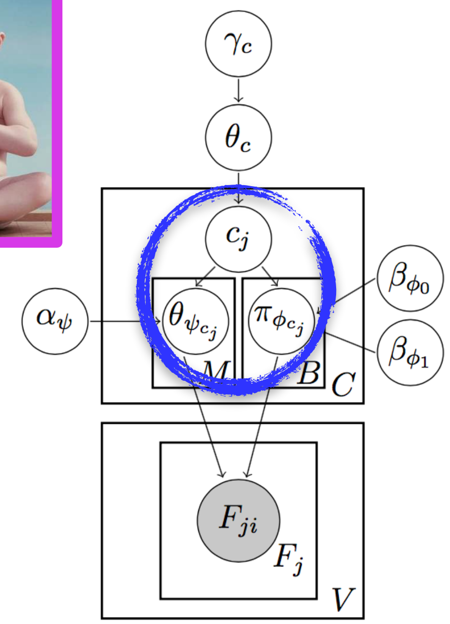
Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs	<4yrs	<5yrs
		
15 classes	23 classes	25 classes

Evaluation:

How well did the modeled learner do at finding these verb classes?





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

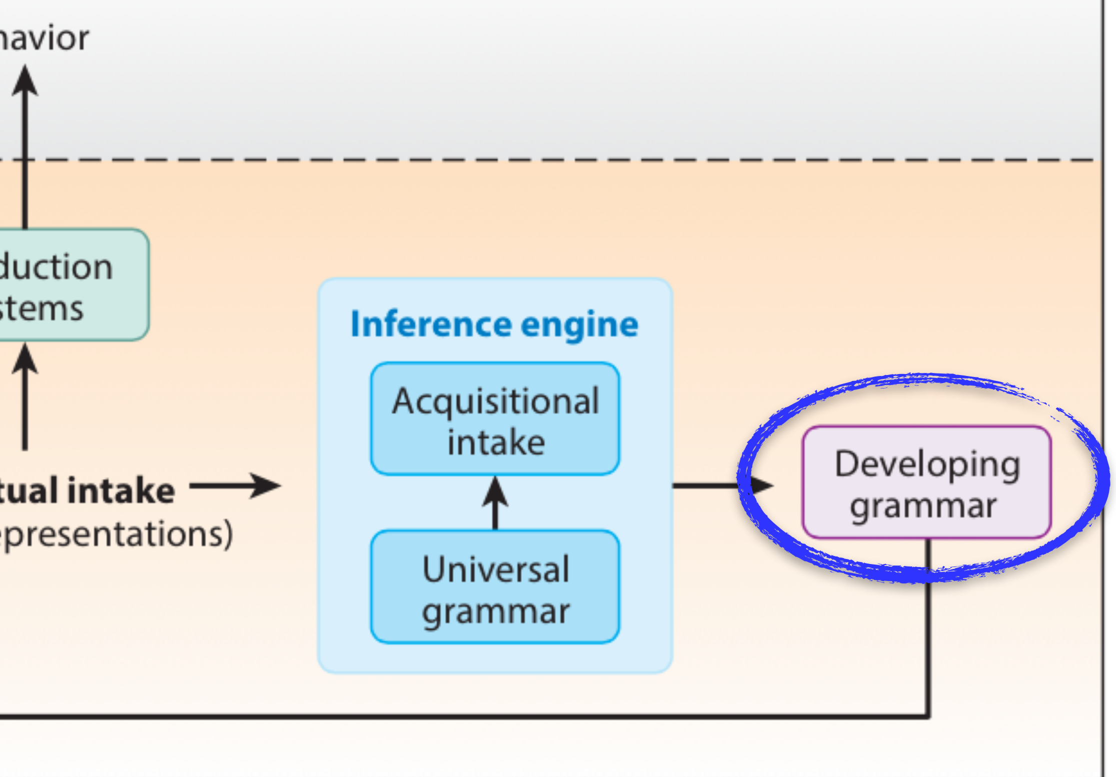
<3yrs	<4yrs	<5yrs
		
15 classes	23 classes	25 classes

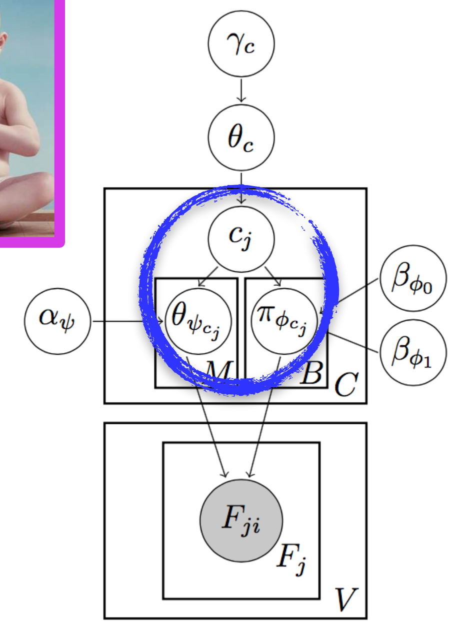
Implementation:
Random Index

0.0 <= RI <= 1.0

Intuition: Get credit for putting things together that belong together and keeping things apart that don’t belong together.





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**



15 classes **23 classes** **25 classes**

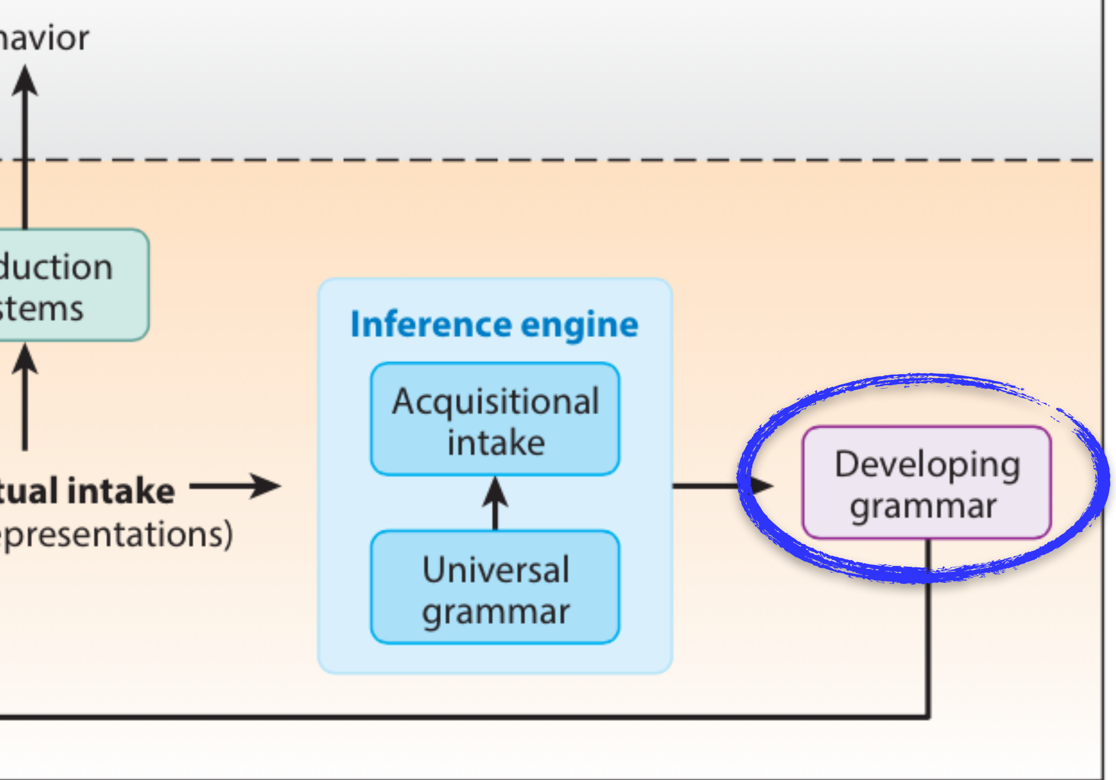
Implementation:
Random Index

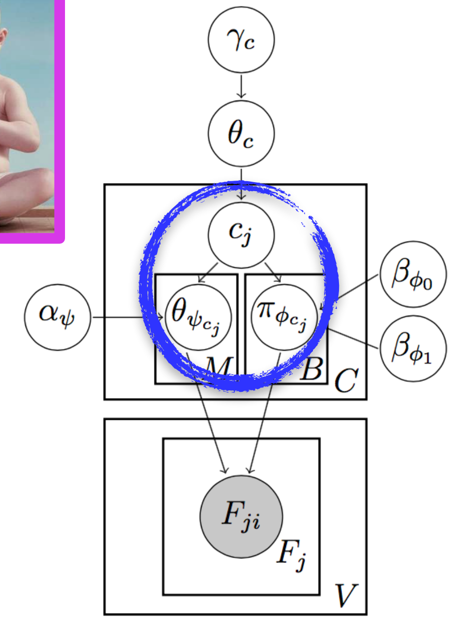

0.0 <= RI <= 1.0

For each pair of verbs in the inferred classes: $verb_i$ $verb_j$

		Inferred Class	
		Same class	Different class
True	Same class	True Positive	False Negative
	Different class	False Positive	True Negative

Intuition: Get credit for putting things together that belong together and keeping things apart that don't belong together.





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs	<4yrs	<5yrs
		
15 classes	23 classes	25 classes

Implementation: Random Index

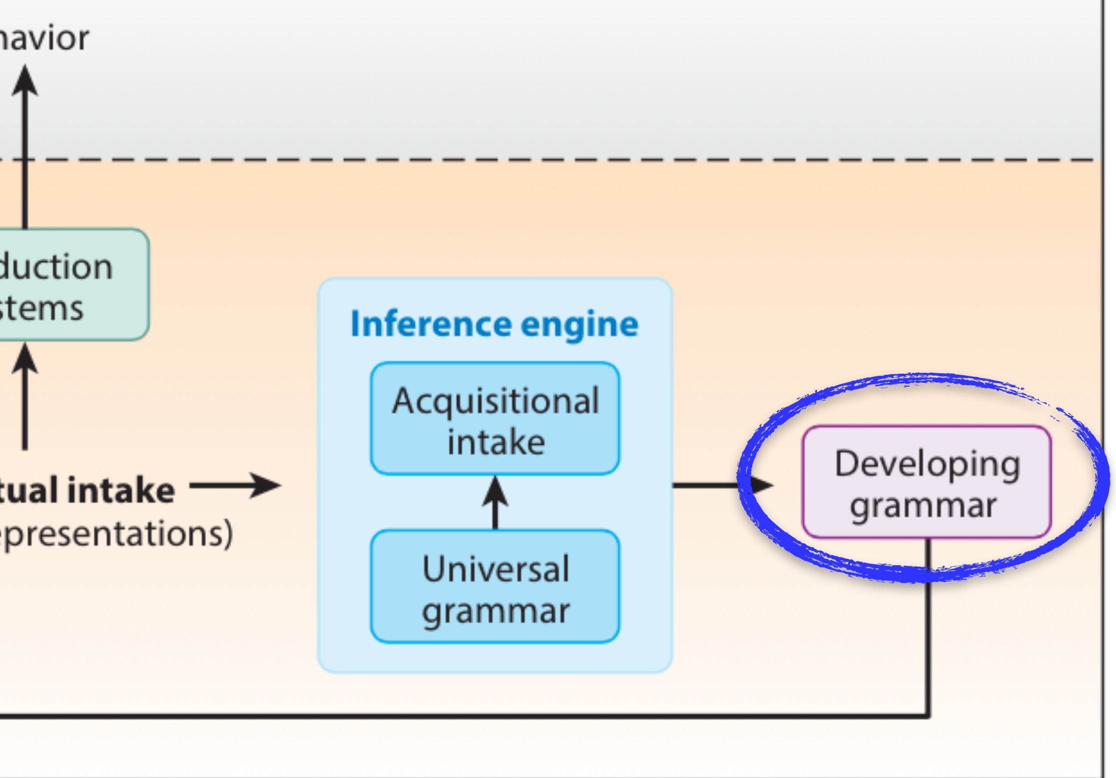
0.0 <= RI <= 1.0

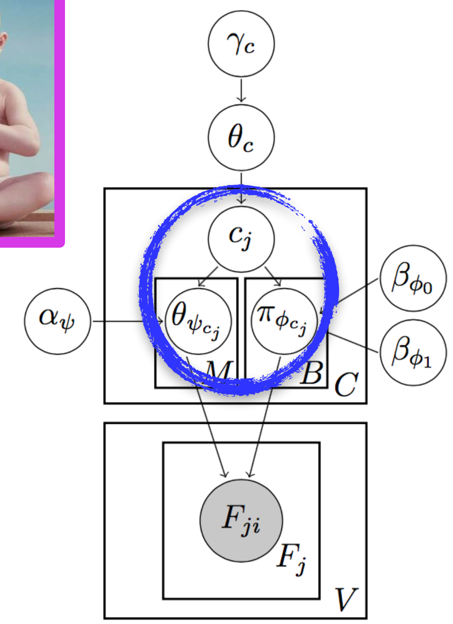
$$\frac{\text{True Positives} + \text{True Negatives}}{\text{True Positives} + \text{True Negatives} + \text{False Positives} + \text{False Negatives}}$$

For each pair of verbs in the inferred classes: verb$_i$ verb$_j$

		Inferred Class	
		Same class	Different class
True	Same class	True Positive	False Negative
	Different class	False Positive	True Negative

Intuition: Get credit for putting things together that belong together and keeping things apart that don't belong together.

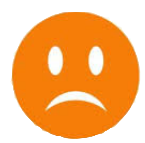




Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs	<4yrs	<5yrs
		
15 classes	23 classes	25 classes

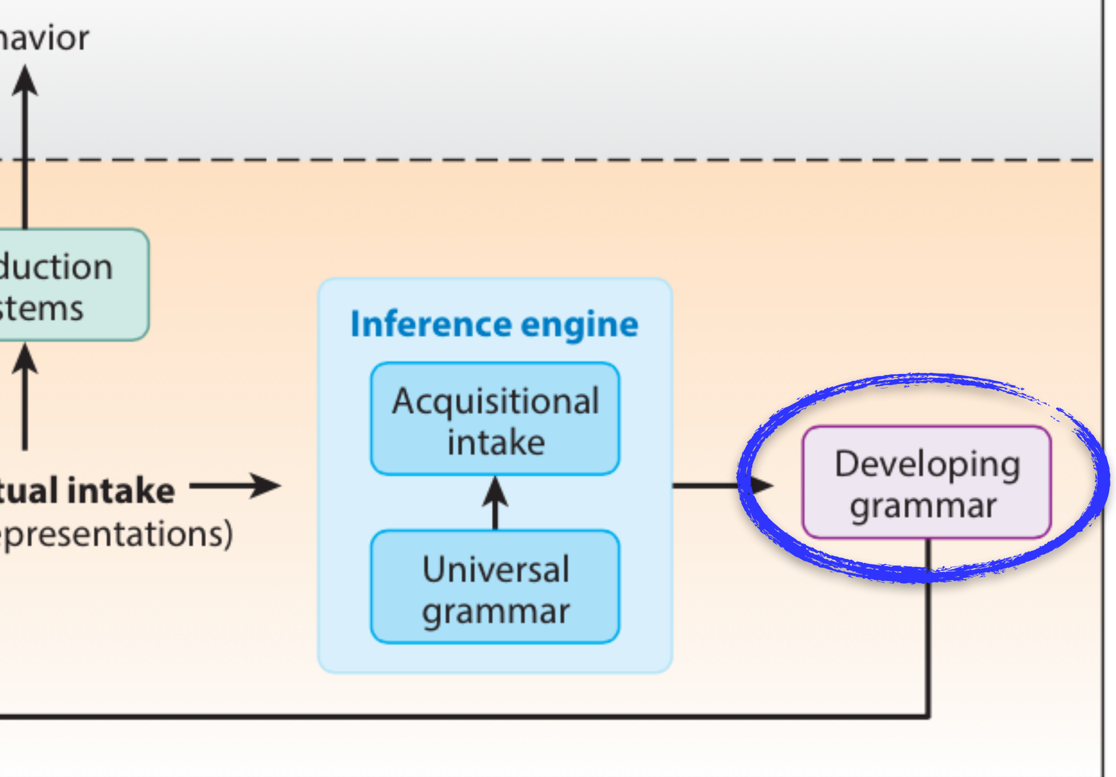
Implementation:
Random Index

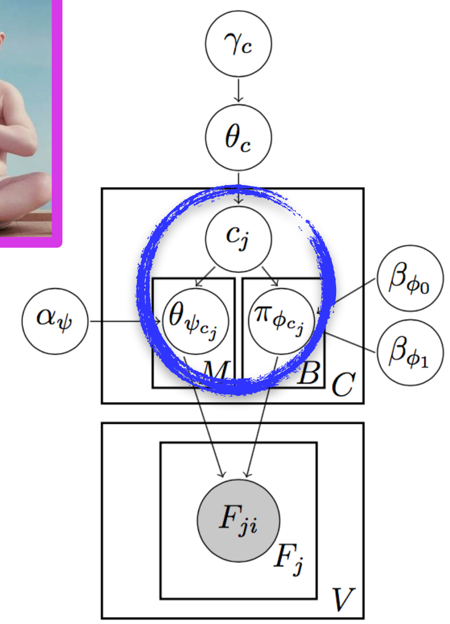
 

0.0 <= RI <= 1.0

Intuition: Get credit for putting things together that belong together and keeping things apart that don't belong together.

But how do we know we're doing better than chance?

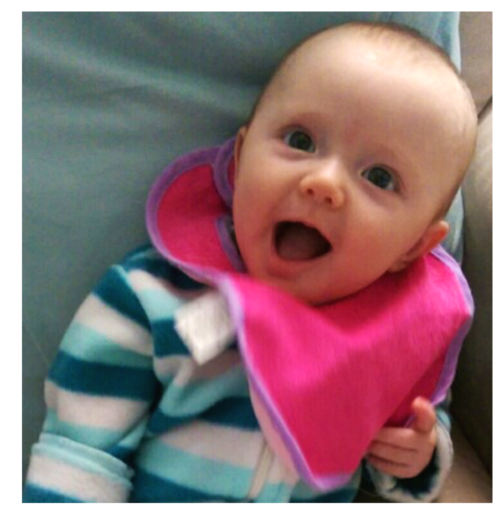




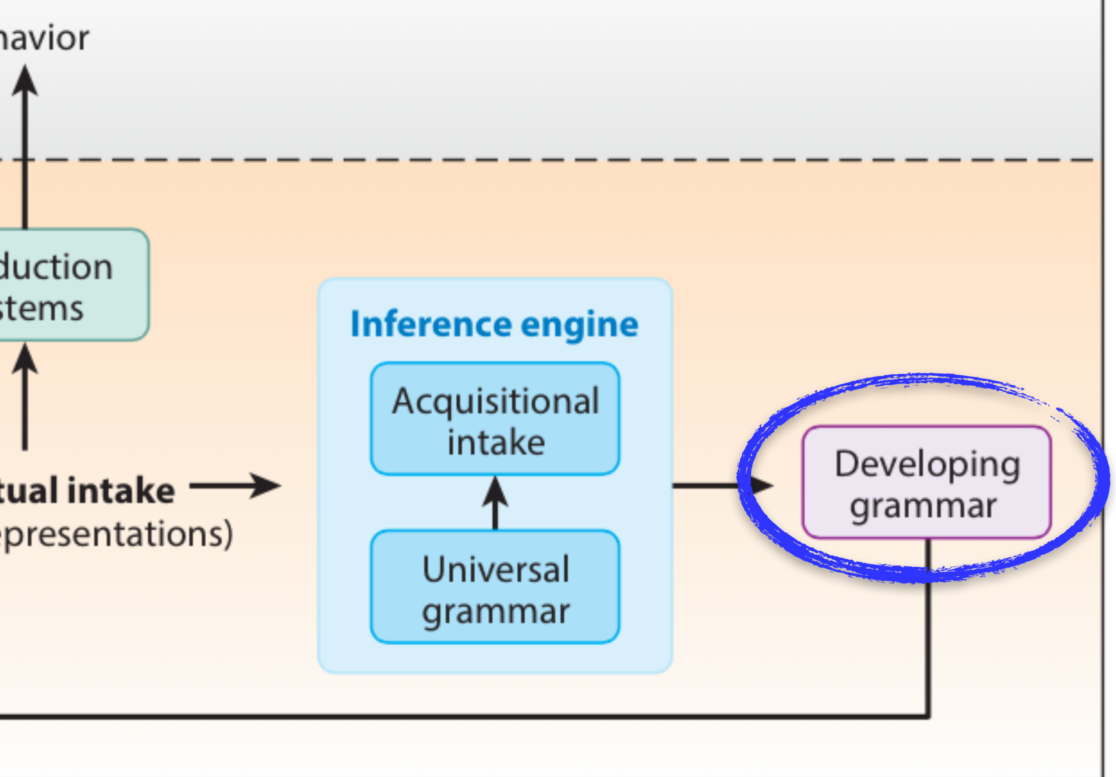
Goal: Model the
developmental trajectory
from 3 to 4 to 5 years old

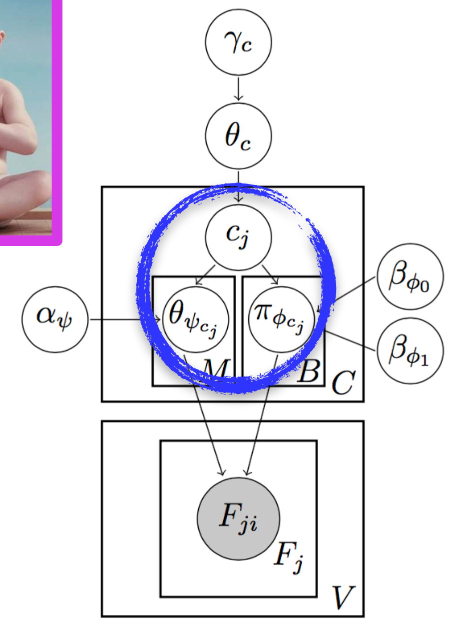
<3yrs	<4yrs	<5yrs
		
15 classes	23 classes	25 classes

Implementation 1:
Bootstrapped confidence intervals
for RI, based on class distribution



- RI > 99% = better than chance
- RI in between = chance performance
- RI < 1% = worse than chance



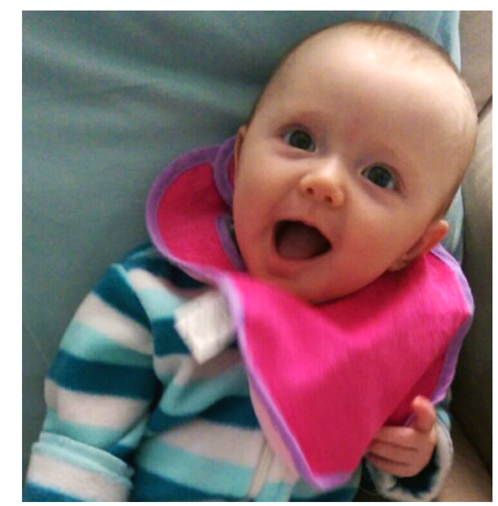


Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs	<4yrs	<5yrs
		
15 classes	23 classes	25 classes

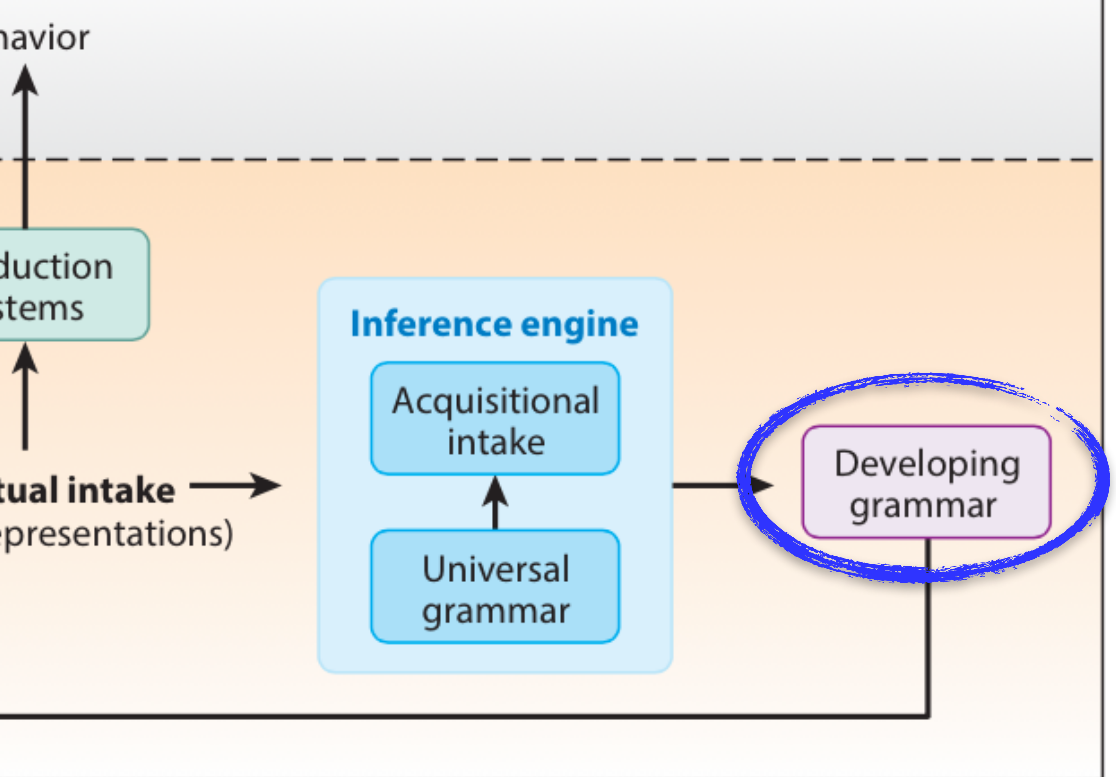
Implementation 2:
Adjusted Random Index

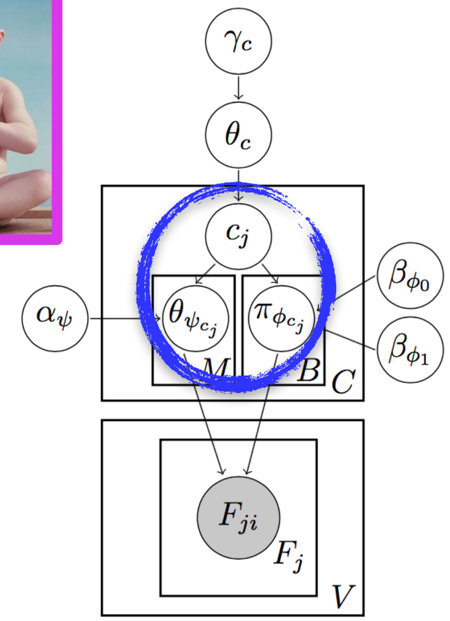
-1.0 <= ARI <= 1.0



Compared against the expected value of the Random Index:

1.0 = perfect classification
>0 = better than chance
0 = chance performance
<0 = worse than chance
-1.0 = perfectly awful classification





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

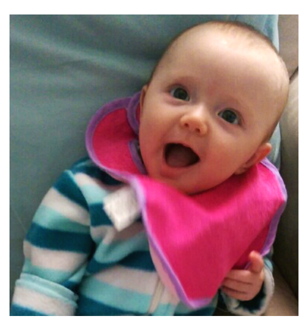
<3yrs **<4yrs** **<5yrs**



15 classes **23 classes** **25 classes**

Implementation 1:
Bootstrapped confidence intervals for RI, based on class distribution

Implementation 2:
Adjusted Random Index (ARI)



Look for agreement between these two measures as signal of significant difference

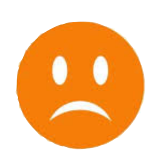
RI > 99% = better than chance

1.0 = perfect classification
>0 = better than chance

RI in between = chance performance

0 = chance performance
<0 = worse than chance

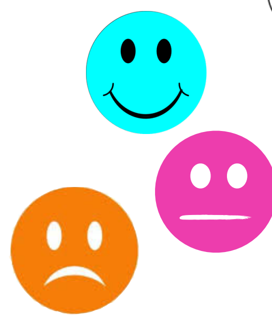
RI < 1% = worse than chance

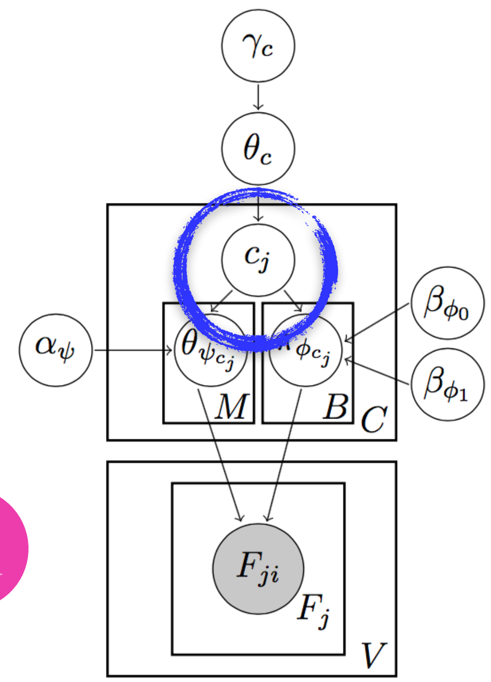


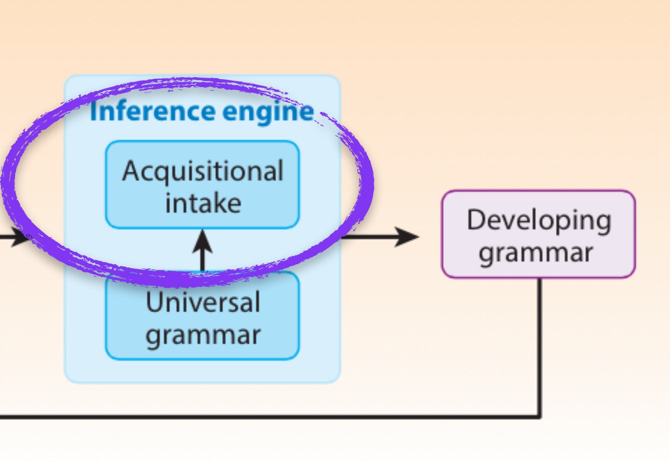
-1.0 = perfectly awful classification

Today's plan

Results & implications







significantly better than chance

3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

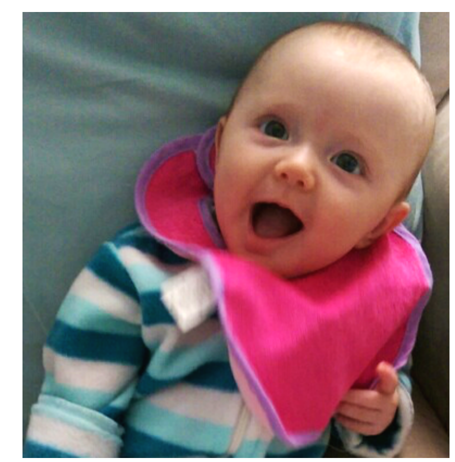
5yrs

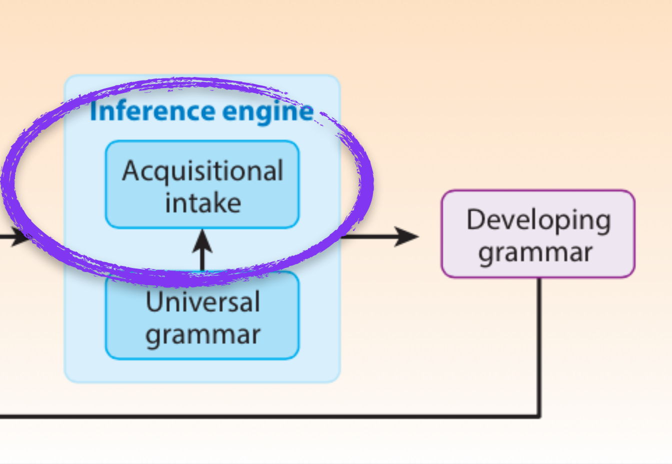
+surfmorph

UTAH rUTAH

+expmap

This is the first articulation of the trajectory of learning assumptions children may have that causes them to group verbs into useful classes the way we observe.





3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH
-expmap

5yrs

+surfmorph

UTAH rUTAH
+expmap

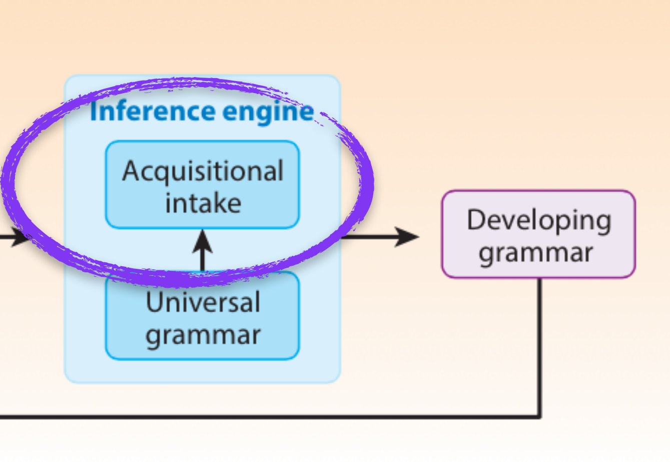
The ice seemed to melt.

NP ___ $S_{nonfinite}$

NP ___**+past** $S_{nonfinite}$

It suggests there are different timelines for

- ignoring vs. heeding surface morphology on verbs …



3yrs

-surfmorph

rUTAH

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

4yrs

+surfmorph

UTAH
-expmap

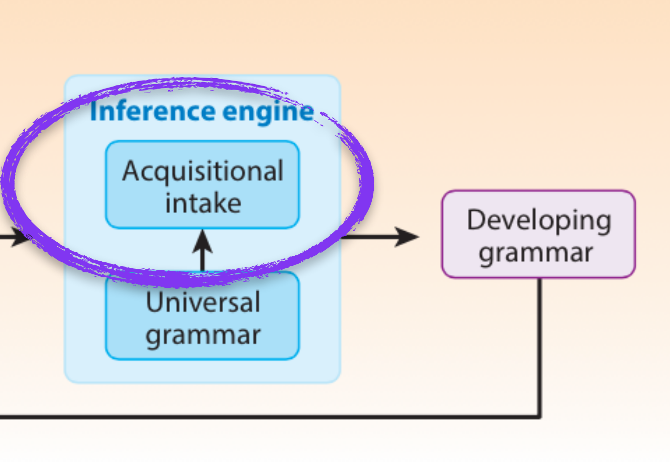
5yrs

+surfmorph

UTAH **rUTAH**
+expmap

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

It suggests there are different timelines for
- ignoring vs. heeding surface morphology on verbs
- **a more fixed vs. more relative intermediate thematic representation…**



3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

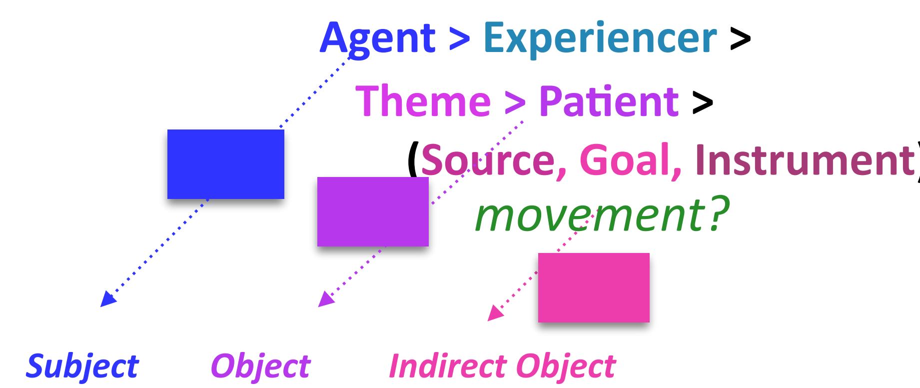
-expmap

5yrs

+surfmorph

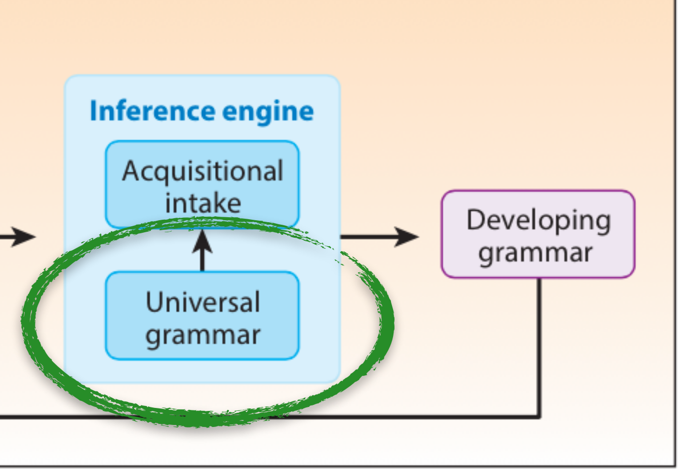
UTAH rUTAH

+expmap



It suggests there are different timelines for

- ignoring vs. heeding surface morphology on verbs
- a more fixed vs. more relative intermediate thematic representation…
- **not expecting vs. expecting a mapping between that intermediate thematic representation and syntactic positions**



3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

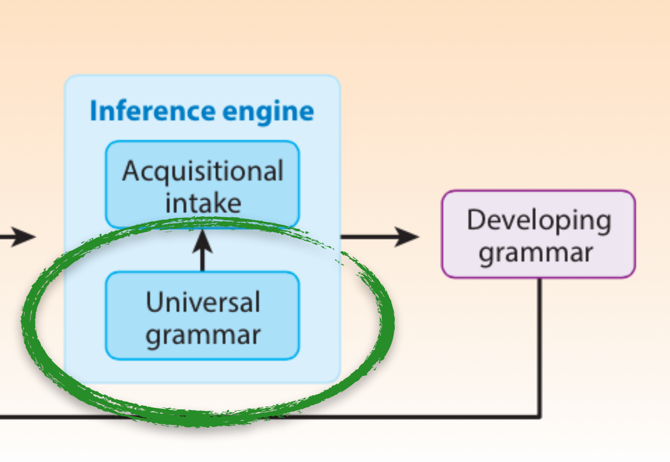
5yrs

+surfmorph

UTAH rUTAH

+expmap

What does this mean for linguistic theory?



3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

5yrs

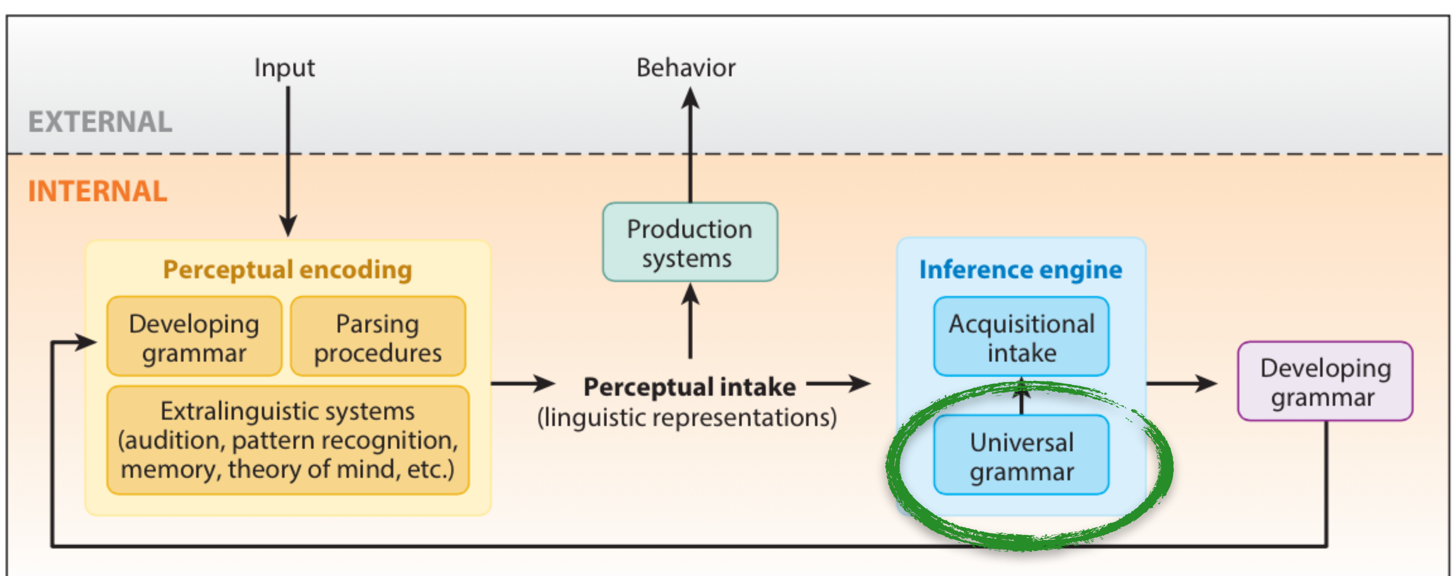
+surfmorph

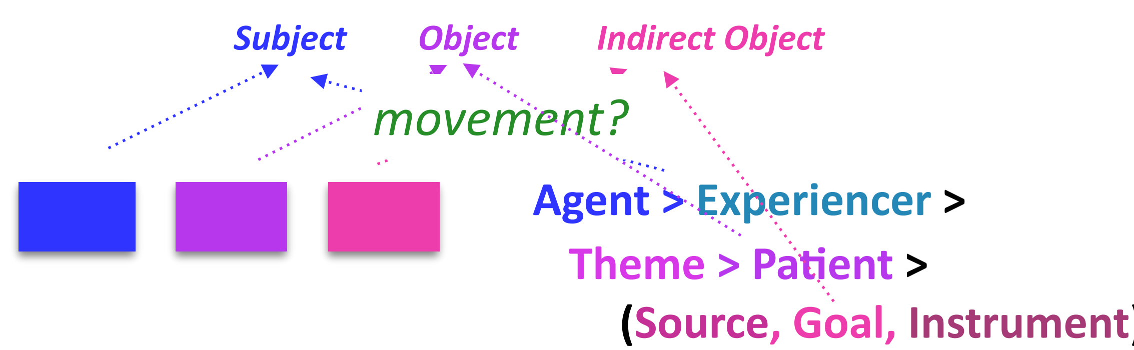
UTAH rUTAH

+expmap

What doesn't need to be built in

An expectation for how to map between intermediate thematic representations and grammatical positions.





What we saw today

Verb classes

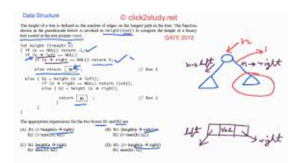
done-to

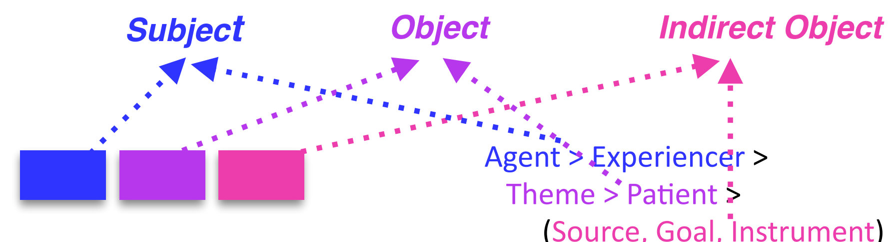
The ice melted.

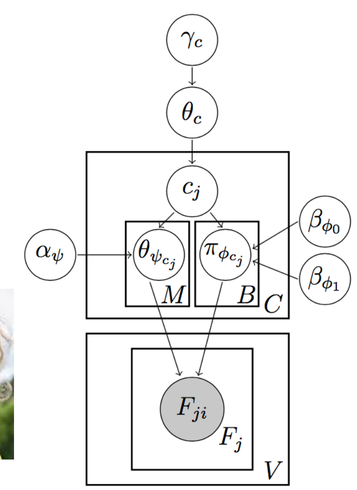
The penguin climbed.

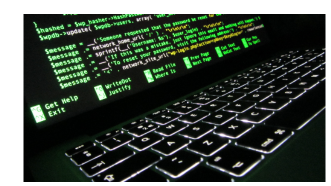
doer

Computational modeling

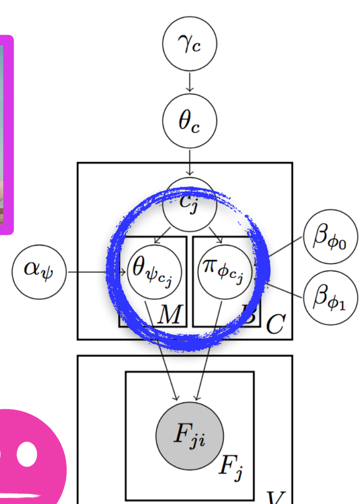


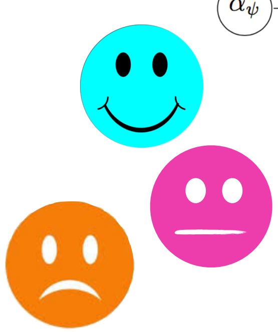


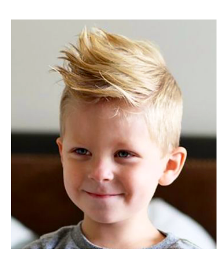




Results & implications







What we saw today

done-to

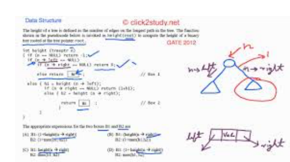
The ice melted.

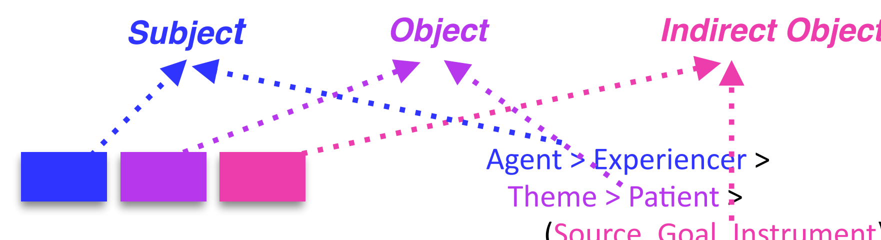
The penguin climbed.

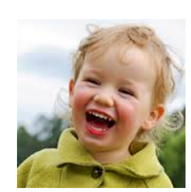
doer

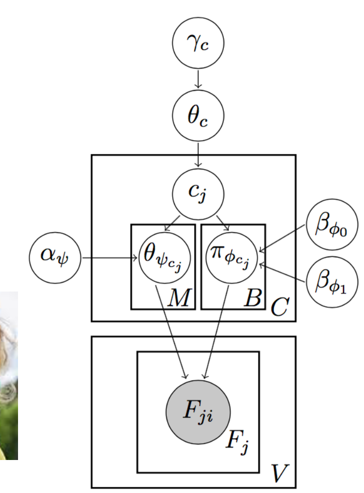
Verb classes: An example of complex linguistic knowledge that children develop, involving several theoretical options for the representations they may be using and how they're integrating conceptual and syntactic information.

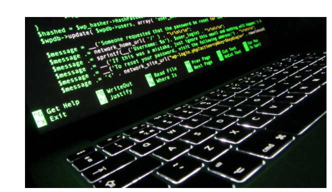
Computational modeling



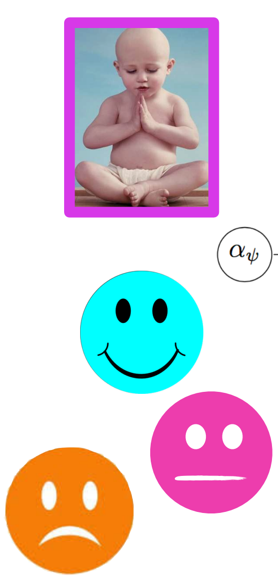


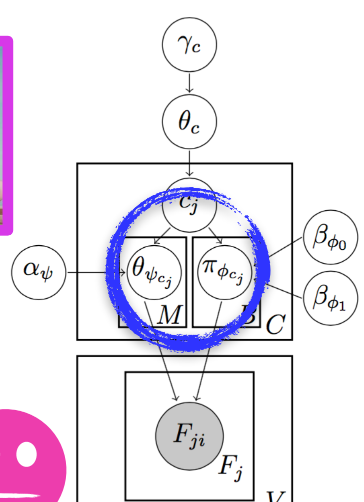


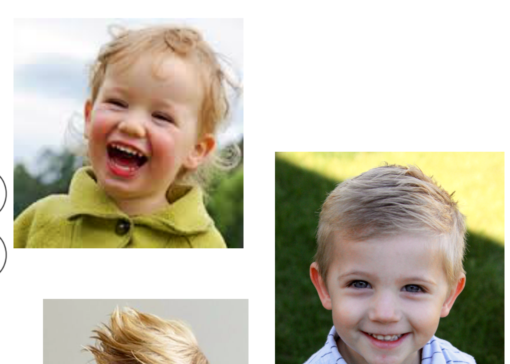


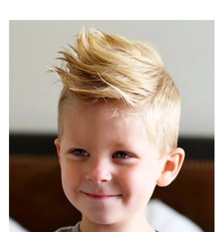


Results & implications









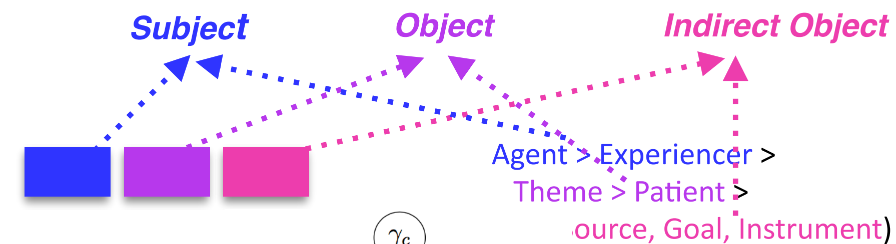
What we saw today

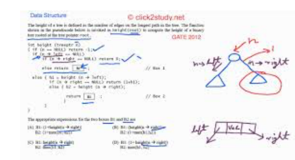
Verb classes: complex linguistic knowledge involving several theoretical options for representations

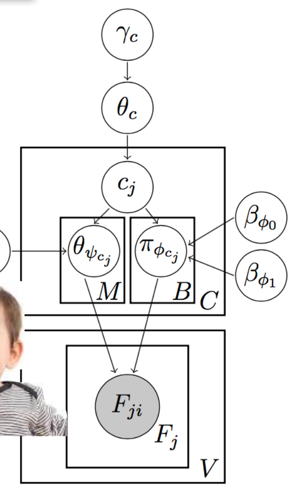
done-to

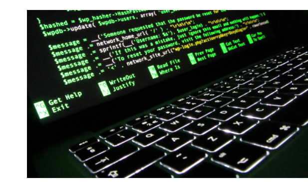
The ice melted.
The penguin climbed.
doer

Computational modeling: A way to explicitly test these theories by implementing them concretely in an empirically grounded model of the acquisition process.

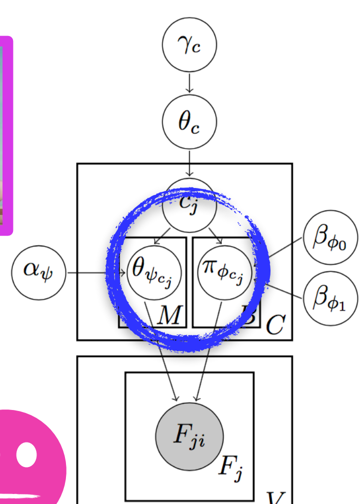


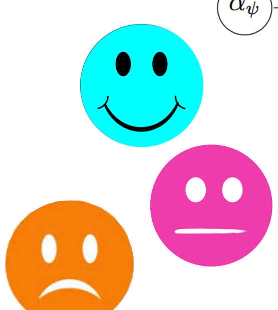


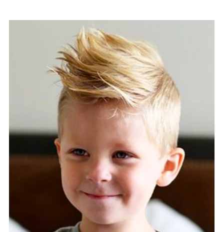




Results & implications







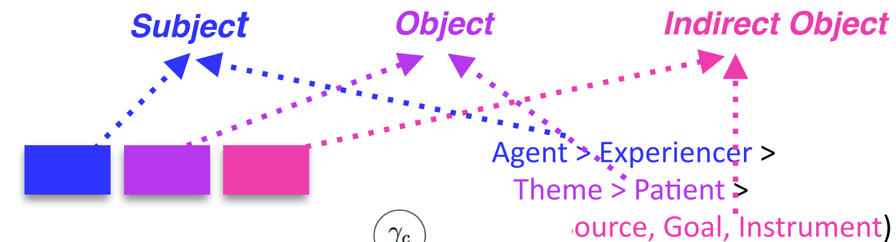
What we saw today

done-to

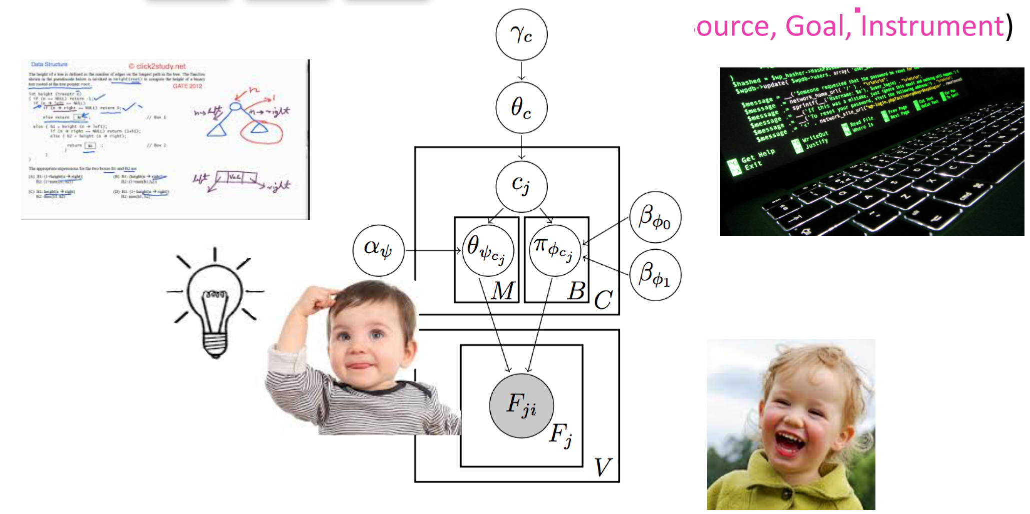
The ice melted.
The penguin climbed.

doer

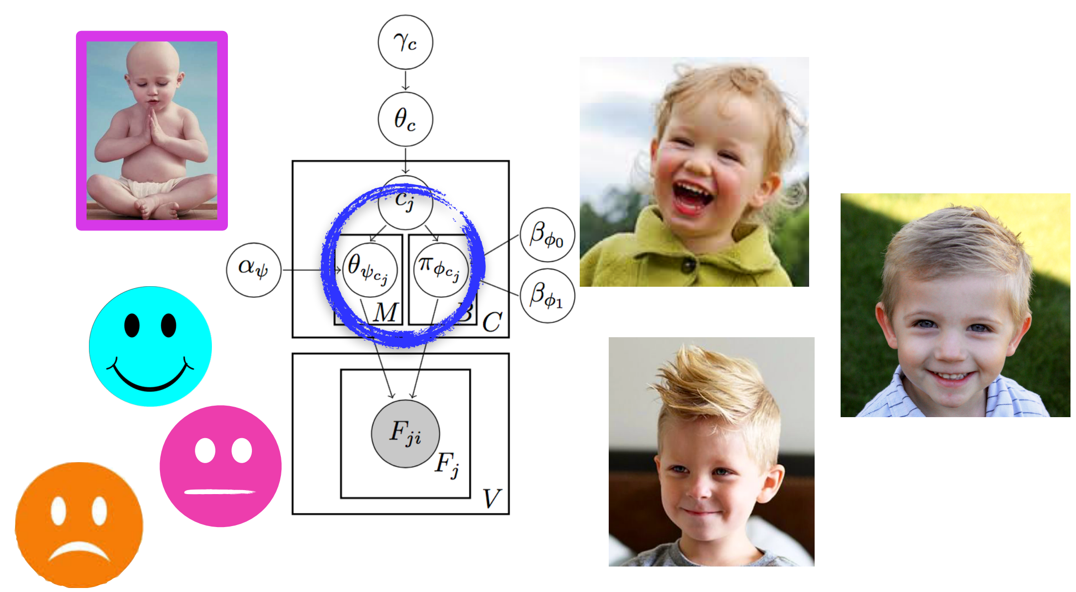
Verb classes: complex linguistic knowledge involving several theoretical options for representations



Computational modeling: explicitly test these theories



Results & implications: Articulating the trajectory of representations and learning assumptions children have at different stages of development



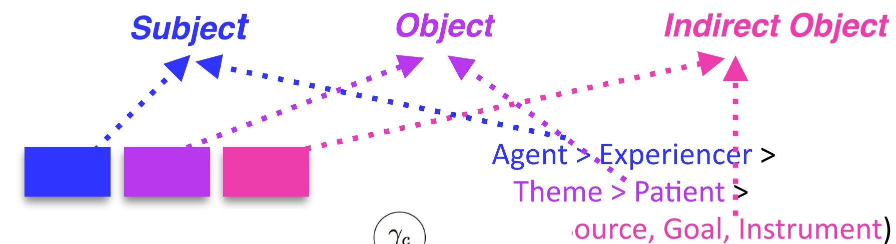
What we saw today

Verb classes: complex linguistic knowledge involving several theoretical options for representations

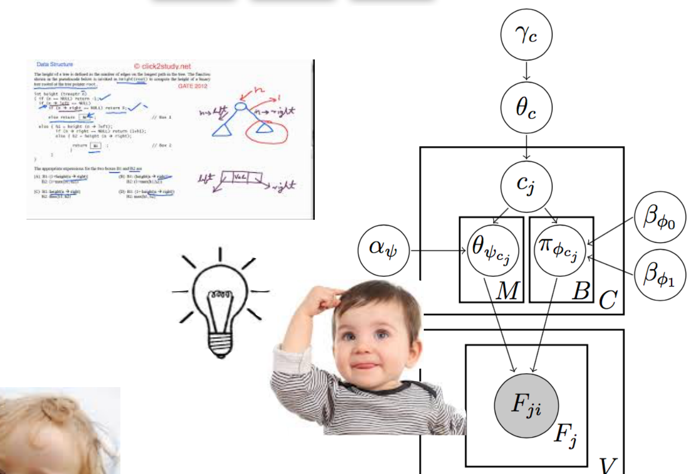
done-to

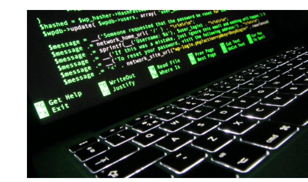
The ice melted.
The penguin climbed.

doer

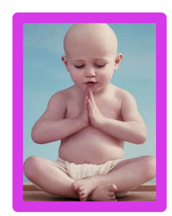


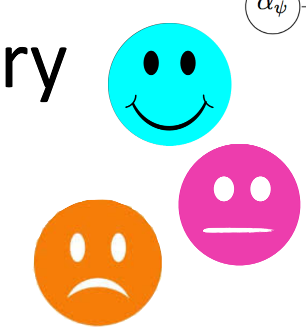
Computational modeling: explicitly test these theories

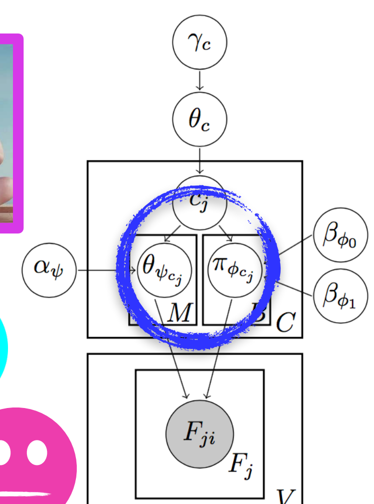


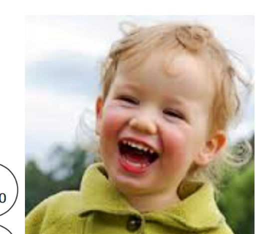


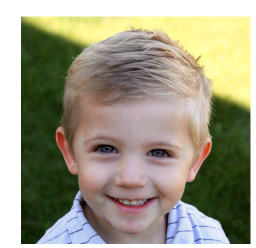
Results & implications: Articulating the representational trajectory over development

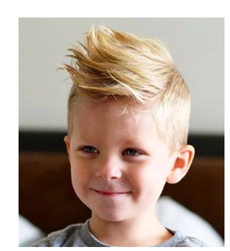












This approach allows us to connect theories of linguistic representation and theories of language acquisition to understand more about both.

Thank you!

Jon Sprouse

UCI Linguistics 2017

SynLinks workshop 2016

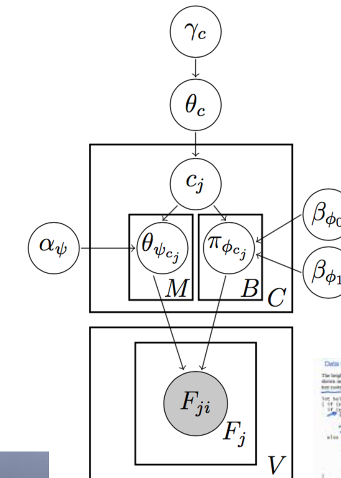
McGill Linguistics 2016

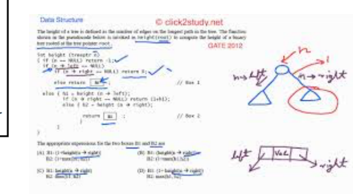
done-to

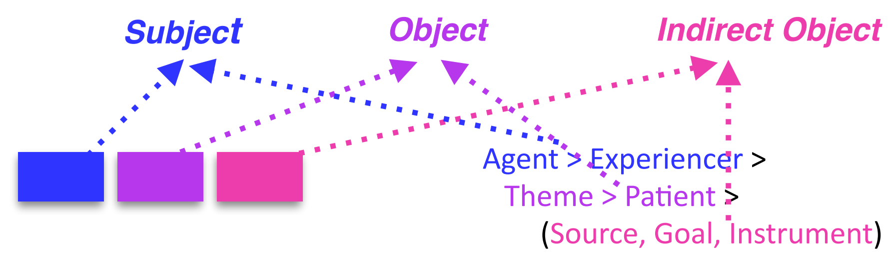
The ice melted.

The penguin climbed.

doer







Computation of Language Laboratory

UC Irvine

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NSF

Special thanks to Abbie Thornton, Alandi Bates, Emily Yang, and BreAnna Silva for CHILDES Treebank corpus annotation.

Language acquisition = Information processing task

Given the available input …

The penguin tried to climb.

The ice seemed to melt.

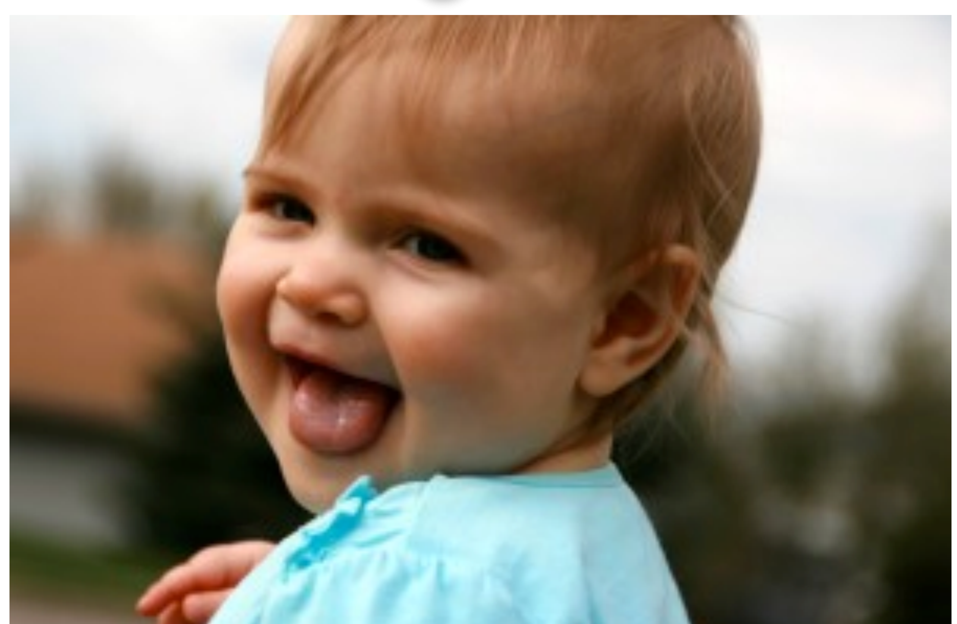
Language acquisition = Information processing task

Given the available input, information processing done by human minds…

processing & generalization

The penguin tried to climb.

The ice seemed to melt.



Language acquisition = Information processing task

Given the available input, information processing done by human minds to build a system of linguistic knowledge …

processing & generalization

appear

subject-raising

seem

want

subject-control

try need

climb

melt

unaccusative

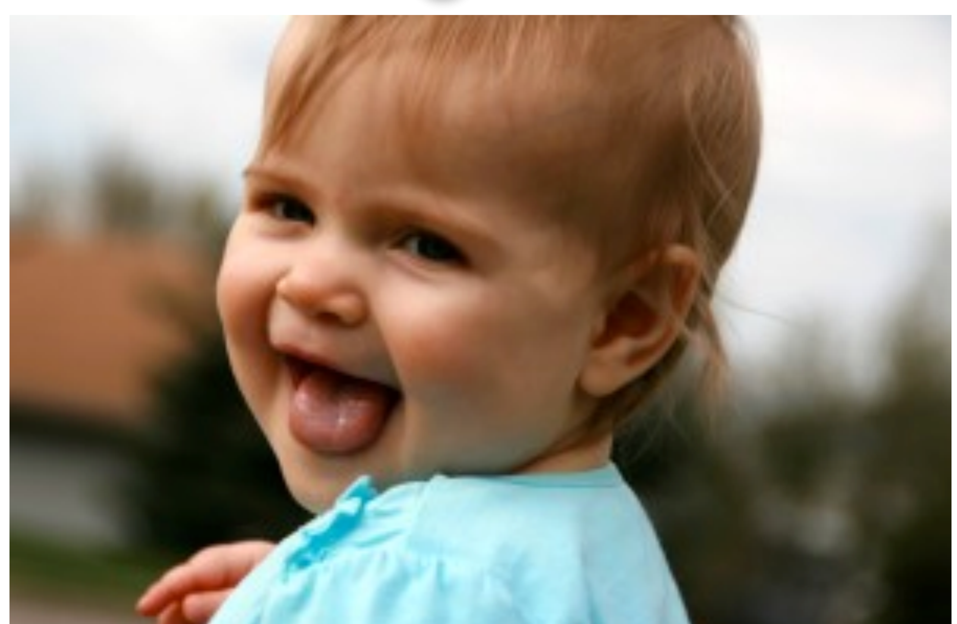
unergative

break fall

laugh dance

The penguin tried to climb.

The ice seemed to melt.



Language acquisition = Information processing task

Given the available input, information processing done by human minds to build a system of linguistic knowledge whose output we observe

appear

subject-raising

seem

want

subject-control

try need

climb

melt

unaccusative

unergative

break fall

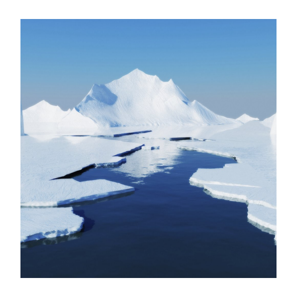
laugh dance

processing & generalization

The penguin tried to climb.

The ice seemed to melt.

The penguin wanted to dance.



It appeared that the ice broke.

Language acquisition = Information processing task

To understand how children solve the acquisition task, we need to make explicit the relevant components of the task.

processing & generalization

appear

subject-raising

seem

want

subject-control

try need

climb

unergative

laugh dance

melt

unaccusative

break fall

The penguin tried to climb.

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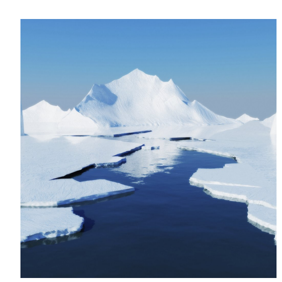

It appeared that the ice broke.

Thematic roles & how to use them

One idea about how children could use thematic role information: (r)UTAH.

The (**r**elativized) **U**niformity of **T**heta **A**ssignment **H**ypothesis

UG knowledge

UTAH: Baker 1988, Baker 1997, Dowty 1991, Fillmore 1968, Grimshaw 1990, Jackendoff 1987, Perlmutter & Postal 1984, Speas 1990

Each thematic role maps to a specific syntactic position (grammatical role).

control

She tried to melt the ice.
doer ***doer*** ***done-to***

**It tried that she melted the ice.*
doer ***done-to***

The penguin seemed to climb the hill.
doer ***done-to***

It seemed that the penguin climbed the hill.
doer ***done-to***

raising

Pearl & Sprouse in progress

Thematic roles & how to use them

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Each thematic role maps to a specific syntactic position (grammatical role).

Agent-like = grammatical subject

Agent
Causer
Experiencer
Possessor

("internal cause" = Rappaport-Hovav 1995)

control

She tried to melt the ice.
doer
doer
done-to

**It tried that she melted the ice.*
doer *done-to*

The penguin seemed to climb the hill.
doer *done-to*

It seemed that the penguin climbed the hill.
doer *done-to*

raising

Pearl & Sprouse in progress

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Each thematic role maps to a specific syntactic position (grammatical role).

Agent-like = grammatical subject

Agent
Causer
Experiencer *(*Baker: only when subject)*
Possessor

("internal cause" = Rappaport-Hovav 1995)

control

She tried to melt the ice.
doer **doer** **done-to**

*It *tried that she melted the ice.*
doer **done-to**

She fears spiders.
Experiencer

Spiders frighten her.
Experiencer

The penguin seemed to climb the hill.
doer **done-to**

It seemed that the penguin climbed the hill.
doer **done-to**

raising

Pearl & Sprouse in progress

Thematic roles & how to use them

One idea about how children could use thematic role information: (r)UTAH.

The (**r**elativized) **U**niformity of **T**heta **A**ssignment **H**ypothesis

UG knowledge

UTAH: Baker 1988, Baker 1997, Dowty 1991, Fillmore 1968, Grimshaw 1990, Jackendoff 1987, Perlmutter & Postal 1984, Speas 1990

Each thematic role maps to a specific syntactic position (grammatical role).

Agent-like = grammatical subject

Patient-like = grammatical object

Patient

Theme

Experiencer

Subject Matter

("external cause")

control

She tried to melt the ice.

doer

doer

done-to

**It tried that she melted the ice.*

doer

done-to

The penguin seemed to climb the hill.

doer

done-to

It seemed that the penguin climbed the hill.

doer

done-to

raising

Pearl & Sprouse in progress

Thematic roles & how to use them

One idea about how children could use thematic role information: (r)UTAH.

The (relativized) Uniformity of Theta Assignment Hypothesis

UG knowledge

UTAH: Baker 1988, Baker 1997, Dowty 1991, Fillmore 1968, Grimshaw 1990, Jackendoff 1987, Perlmutter & Postal 1984, Speas 1990

Each thematic role maps to a specific syntactic position (grammatical role).

Agent-like = grammatical subject

Patient-like = grammatical object

Patient

Theme

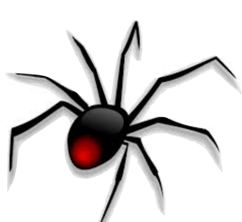
Experiencer *(*Baker: only when not subject)*

Subject Matter

("external cause")

She fears spiders.

Experiencer



Spiders frighten her.

Experiencer

control

She tried to melt the ice.

doer

doer

done-to

**It tried that she melted the ice*

doer

done-to

The penguin seemed to climb the hill.

doer

done-to

It seemed that the penguin climbed the hill.

doer

done-to

raising

Pearl & Sprouse in progress

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One idea about how children could use thematic role information: (r)UTAH.

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UG knowledge

UTAH: Baker 1988, Baker 1997, Dowty 1991, Fillmore 1968, Grimshaw 1990, Jackendoff 1987, Perlmutter & Postal 1984, Speas 1990

Each thematic role maps to a specific syntactic position (grammatical role).

Agent-like = grammatical subject
Patient-like = grammatical object
Goal-like = grammatical indirect object

Location
Source
Goal
Benefactor
Instrument

control

She tried to melt the ice with a blow dryer.
doer ***done-to*** ***done-with***
doer

It tried that she melted the ice with a blow dryer.
doer ***done-to*** ***done-with***

The penguin seemed to climb the hill.
doer ***done-to***

It seemed that the penguin climbed the hill.
doer ***done-to***

raising

Pearl & Sprouse in progress

Thematic roles & how to use them

Syntax **She** melted **the ice** with **a blow dryer**.

Subject ***Object*** ***Indirect Object***

Mapping to Syntax

UG knowledge

The **U**niformity of **T**heta **A**ssignment **H**ypothesis:

Baker 1988, Baker 1997, Dowty 1991, Fillmore 1968, Grimshaw 1990, Jackendoff 1987, Perlmutter & Postal 1984, Speas 1990

UTAH

Intermediate representations

Thematic roles map to one of three categories.

thematic-roles

(likely derived from lower level conceptual info) =
Agent, Experiencer, Patient, Theme, Goal, Source, Instrument…

Thematic roles & how to use them

One idea about how children could use thematic role information: (r)UTAH.

The (**r**)elativized) **U**niformity of **T**heta **A**ssignment **H**ypothesis

UG knowledge

rUTAH: Larson 1988, Larson 1990

Thematic roles are ordered relative to each other, with the highest thematic role mapping to the highest grammatical role (subject > object > indirect object).

control

She tried to melt the ice with a blow dryer.
doer ***doer*** ***done-to*** ***done-with***

**It tried that she melted the ice with a blow dryer.*
doer ***done-to*** ***done-with***

The penguin seemed to climb the hill.
doer ***done-to***

It seemed that the penguin climbed the hill.
doer ***done-to***

raising

Pearl & Sprouse in progress

Thematic roles & how to use them

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UG knowledge

rUTAH: Larson 1988, Larson 1990

Thematic roles are ordered relative to each other, with the highest thematic role mapping to the highest grammatical role (subject > object > indirect object).

Basic intuition:

doer (Agent-like) >

done-to (Patient-like) >

done-for/with (Goal-like)

control

She tried to melt the ice with a blow dryer.
doer ***doer*** ***done-to*** ***done-with***

**It tried that she melted the ice with a blow dryer.*
doer ***done-to*** ***done-with***

The penguin seemed to climb the hill.
doer ***done-to***

It seemed that the penguin climbed the hill.
doer ***done-to***

raising

Pearl & Sprouse in progress

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Basic intuition:

doer (Agent-like) >
done-to (Patient-like) >
done-for/with (Goal-like)

An example implementation:

Agent > Causer > Experiencer > Possessor >
Subject Matter > Causee > Theme > Patient >
(Location, Source, Goal, Benefactor, Instrument)

control

She tried to melt the ice with a blow dryer.
doer *doer* *done-to* *done-with*

**It tried that she melted the ice with a blow dryer.*
doer *done-to* *done-with*

The penguin seemed to climb the hill.
doer *done-to*

It seemed that the penguin climbed the hill.
doer *done-to*

raising

Pearl & Sprouse in progress

Thematic roles & how to use them

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The (**r**elativized) **U**niformity of **T**heta **A**ssignment **H**ypothesis

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Basic intuition:

doer (Agent-like) >

done-to (Patient-like) >

done-for/with (Goal-like)

control

She tried to melt the ice with a blow dryer.
doer ***doer*** ***done-to*** ***done-with***

*It *tried that she melted the ice with a blow dryer.*
doer ***done-to*** ***done-with***

An example implementation:

Agent > Causer > Experiencer > Possessor >

Subject Matter > Causee > Theme > Patient >

(Location, Source, Goal, Benefactor, Instrument)

Note: You don't need to have every role relatively ranked. If some are unranked with respect to each other, the order in which they get mapped to grammatical positions doesn't matter.

The penguin seemed to climb the hill.
doer ***done-to***

It seemed that the penguin climbed the hill.
doer ***done-to***

raising

Pearl & Sprouse in progress

Thematic roles & how to use them

One idea about how children could use thematic role information: (r)UTAH.

The (**r**elativized) **U**niformity of **T**heta **A**ssignment **H**ypothesis

UG knowledge

rUTAH: Larson 1988, Larson 1990
Thematic roles are ordered relative to each other, with the highest thematic role mapping to the highest grammatical role (subject > object > indirect object).

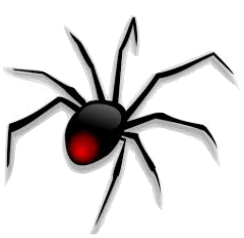
Basic intuition:
doer (Agent-like) >
done-to (Patient-like) >
done-for/with (Goal-like)

An example implementation:
Agent > Causer > Experiencer > Possessor >
Subject Matter > Causee > Theme > Patient >
(Location, Source, Goal, Benefactor, Instrument)

This relative ranking can help deal with certain situations, like those involving Experiencers.

She fears spiders.
Experiencer ***Subject Matter***

Experiencer* > *Subject Matter
Subject ***Object***

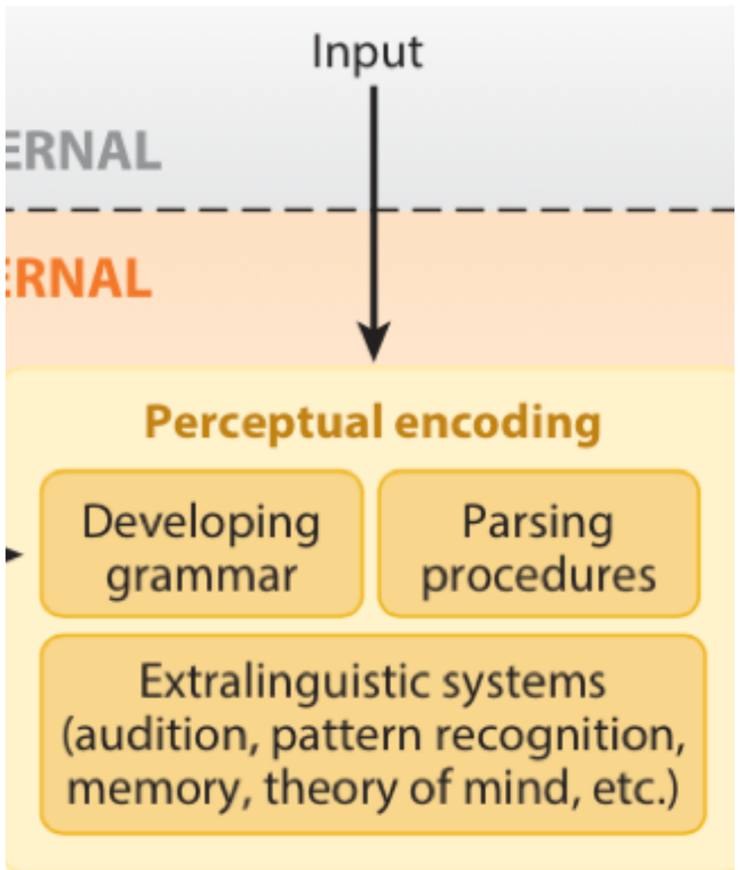


Spiders frighten her.
Causer ***Experiencer***

Causer* > *Experiencer
Subject ***Object***

Pearl & Sprouse in progress

Potential learning strategies



Animacy

+animate
The penguin tried to climb.

-animate
The ice seemed to melt.

Syntactic frame

Choice 1

NP ___ $S_{nonfinite}$ -surfmorph

NP ___**+past** $S_{nonfinite}$ +surfmorph

Thematic roles and how to use them

Choice 2

UTAH

Agent > Experiencer > Theme > Patient > (Source, Goal, Instrument) rUTAH

Choice 3

Subject ***Object*** ***Indirect Object*** -expmap

Subject ***Object*** ***Indirect Object*** +expmap

movement?

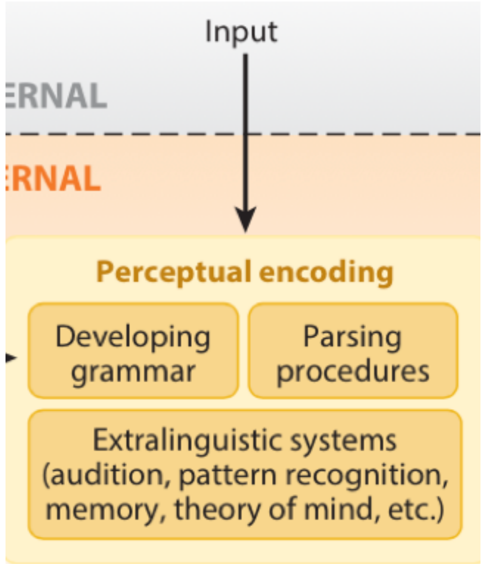
3 binary choices = 8 strategies

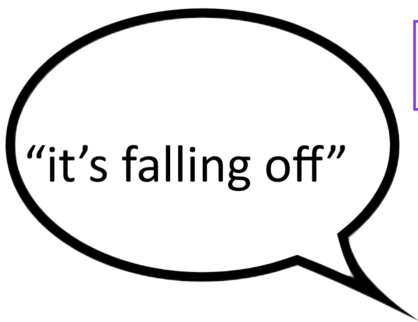
All strategies require learner's initial state to be sufficient to extract this information from the input

Potential acquisitional intakes

3 binary choices = 8 strategies

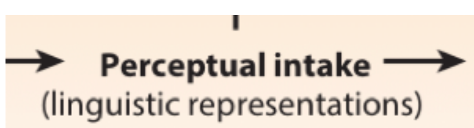
Each strategy has a different impact on the acquisitional intake





Input

(from Brown-Eve corpus in CHILDES Treebank)



Animacy

Syntactic frame

-surfmorph +surfmorph

Thematic roles and how to use them

UTAH rUTAH

Agent > Experiencer >

Theme > Patient >

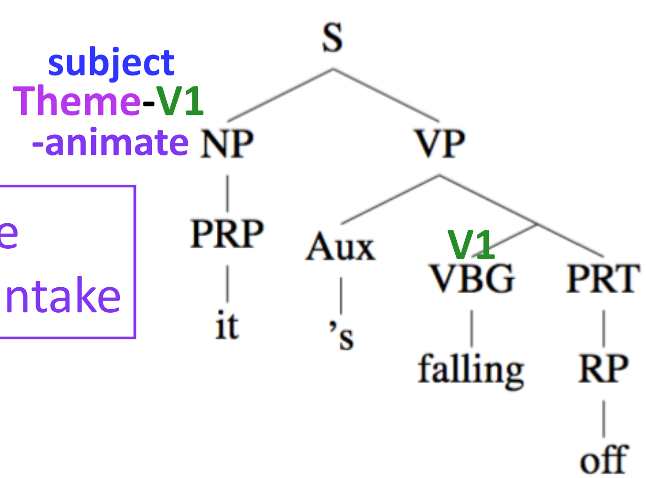
(Source, Goal, Instrument)

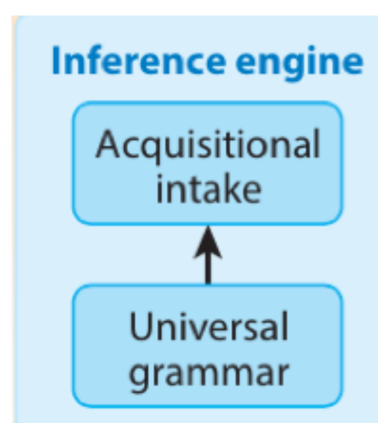
-expmap +expmap

Subject Object Indirect Object *Subject Object Indirect Object*

movement?

Possible perceptual intake

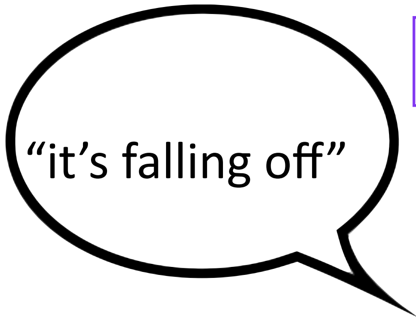




Potential acquisitional intakes

3 binary choices = 8 strategies

Each strategy has a different impact on the acquisitional intake



Input

Animacy

Syntactic frame

-surfmorph +surfmorph

Thematic roles and how to use them

UTAH rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

-expmap

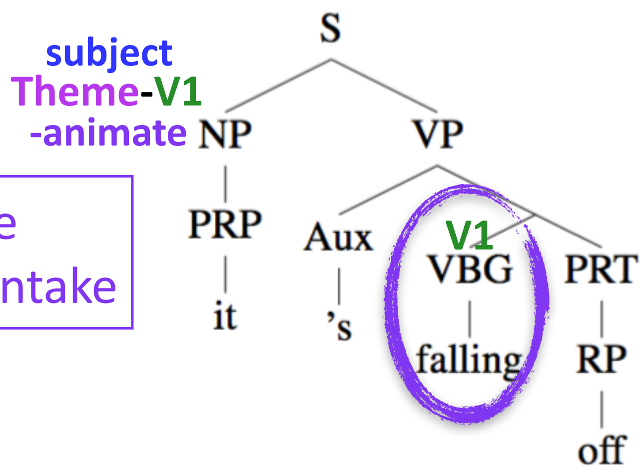
Subject Object Indirect Object

+expmap

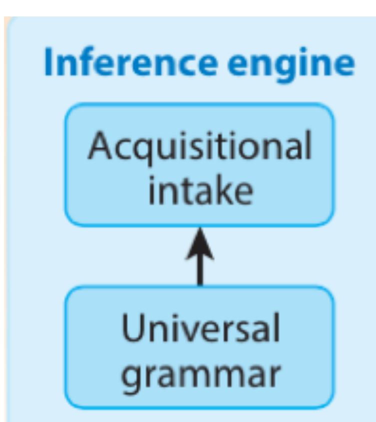
Subject Object Indirect Object

movement?

Possible perceptual intake



FALL



Potential acquisitional intakes

3 binary choices = 8 strategies

Each strategy has a different impact on the acquisitional intake

“it’s falling off”

Input

Animacy

Syntactic frame

-surfmorph +surfmorph

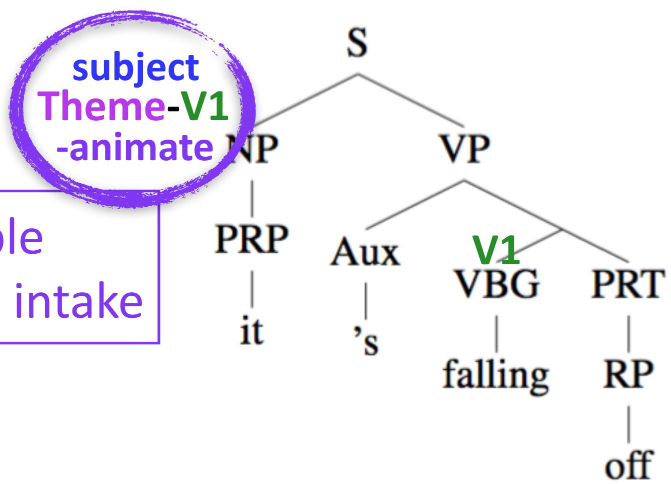
Thematic roles and how to use them

UTAH rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)



Possible perceptual intake

-expmap +expmap

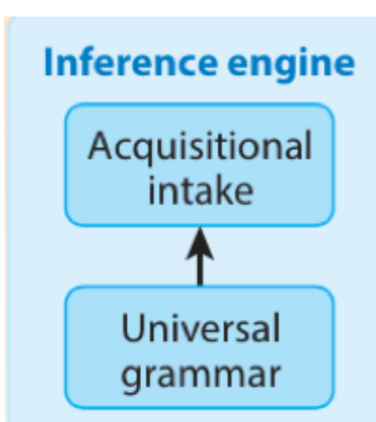
Subject Object Indirect Object

Subject Object Indirect Object

movement?

FALL

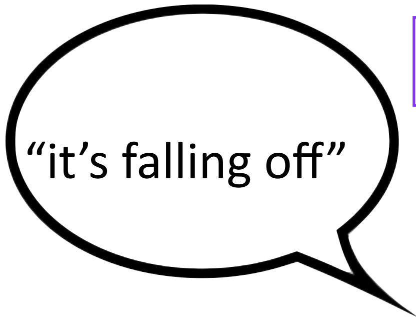
-animate subject: 1



Potential acquisitional intakes

3 binary choices = 8 strategies

Each strategy has a different impact on the acquisitional intake



Input

Animacy

Syntactic frame

+surfmorph

Thematic roles and how to use them

rUTAH

Agent > Experiencer >

Theme > Patient >

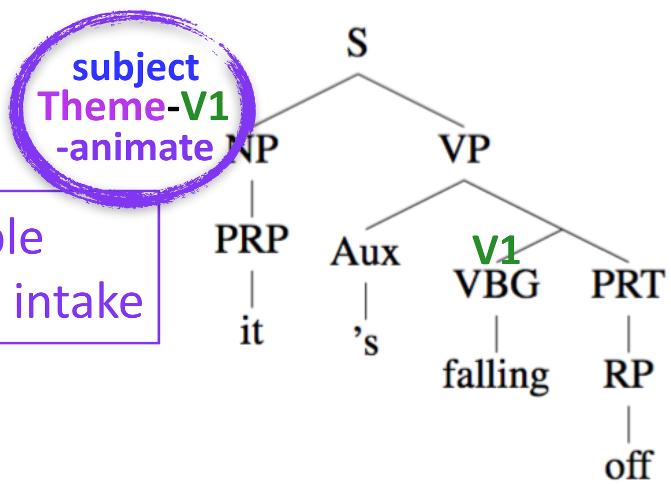
(Source, Goal, Instrument)

+expmap

Subject Object Indirect Object

Subject Object Indirect Object

movement?



Possible perceptual intake

FALL

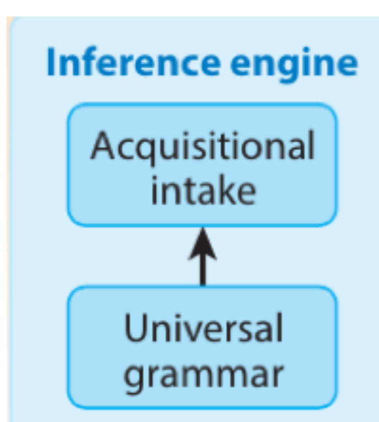
-animate subject: 1

Done-to as subject: 1

UTAH

-expmap

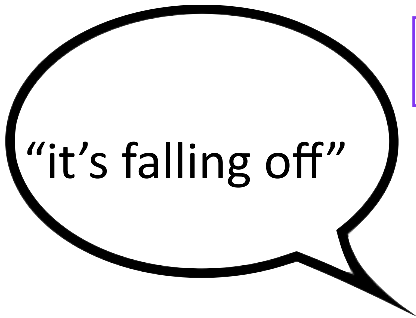
-surfmorph



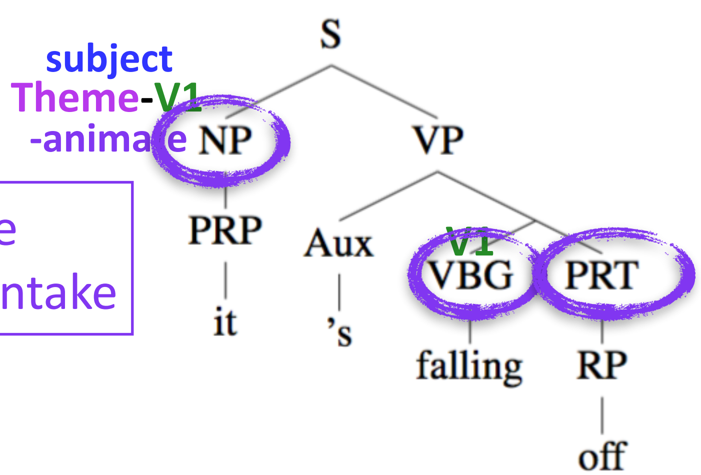
Potential acquisitional intakes

3 binary choices = 8 strategies

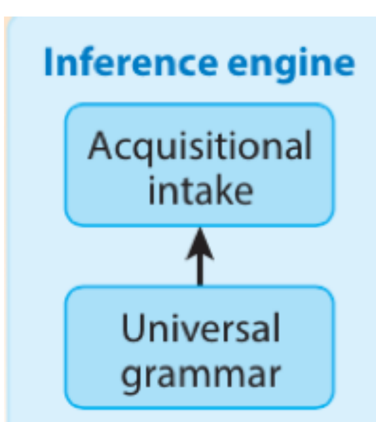
Each strategy has a different impact on the acquisitional intake



Input



Possible perceptual intake



Animacy

Syntactic frame

+surfmorph

Thematic roles and how to use them

rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

+expmap

Subject Object Indirect Object

Subject Object Indirect Object

movement?

FALL

-animate subject: 1

Done-to as subject: 1

NP V PRT

UTAH

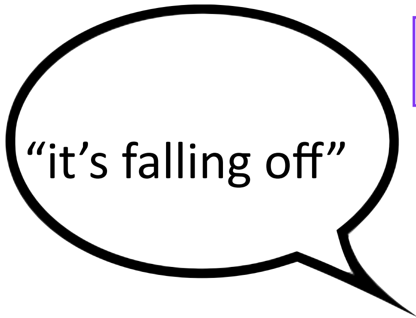
-expmap

-surfmorph

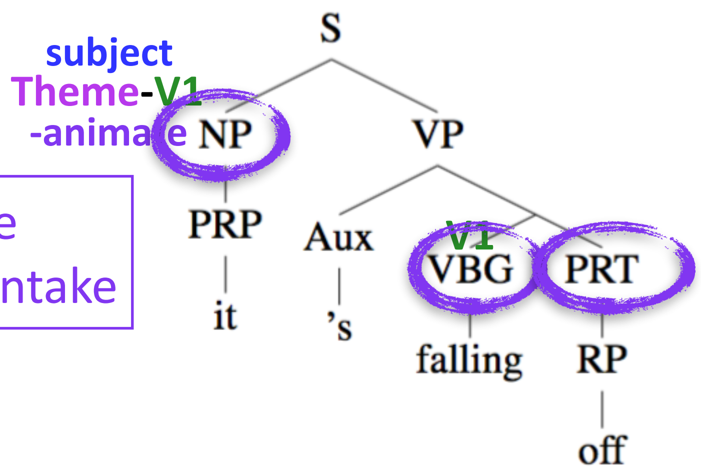
Potential acquisitional intakes

3 binary choices = 8 strategies

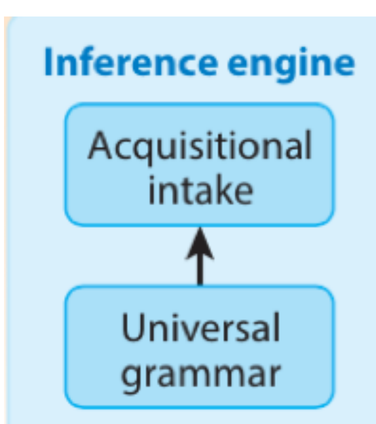
Each strategy has a different impact on the acquisitional intake



Input



Possible perceptual intake



Animacy

Syntactic frame

-surfmorph

Thematic roles and how to use them

rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

+expmap

Subject Object Indirect Object

Subject Object Indirect Object

movement?

FALL

-animate subject: 1

Done-to as subject: 1

UTAH

-expmap

NP V_{+prog} PRT

+surfmorph

Potential acquisitional intakes

3 binary choices = 8 strategies

Each strategy has a different impact on the acquisitional intake

“it’s falling off”

Input

Animacy

Syntactic frame

-surfmorph

Thematic roles and how to use them

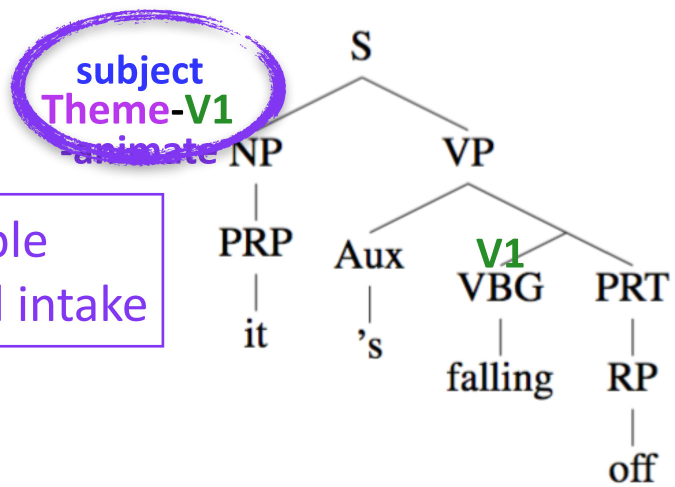
rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

Possible perceptual intake



-expmap

Subject Object Indirect Object

Subject Object Indirect Object

movement?

FALL

-animate subject: 1

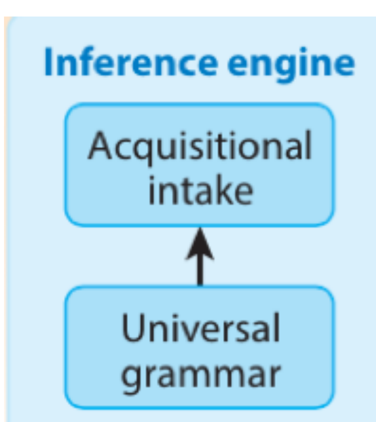
+movement: 1

NP V_{+prog} PRT

UTAH

+expmap

+surfmorph



Theme is expected to map to object, not subject. Indicator of movement.

Potential acquisitional intakes

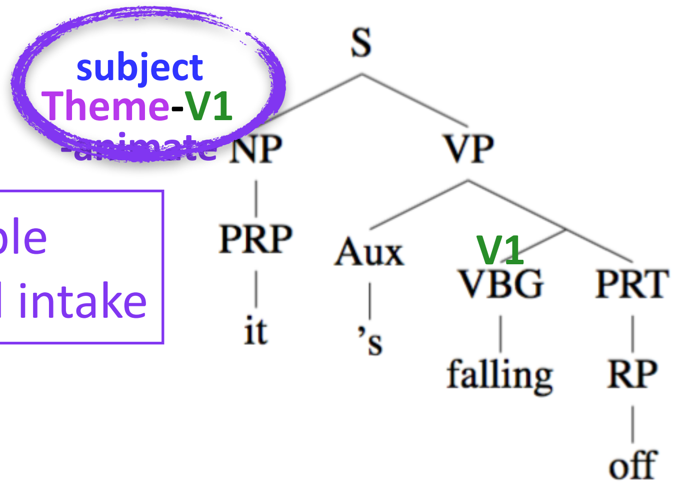
3 binary choices = 8 strategies

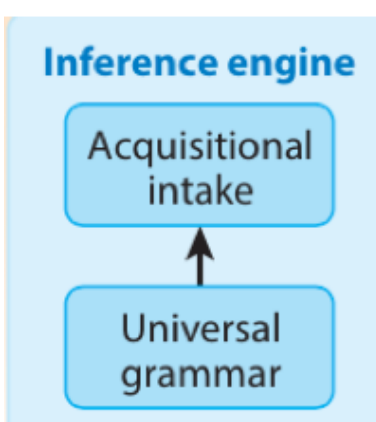
Each strategy has a different impact on the acquisitional intake

“it’s falling off”

Input

Possible perceptual intake





Theme is only role so is default highest. Expected mapping is to highest syntactic position (subject).

Animacy

Syntactic frame

-surfmorph

Thematic roles and how to use them

UTAH

-expmap

Subject Object Indirect Object

Subject Object Indirect Object

movement?

FALL

-animate subject: 1

+movement: 0

NP V_{+prog} PRT

rUTAH

Agent > Experiencer >

Theme > Patient >

(Source, Goal, Instrument)

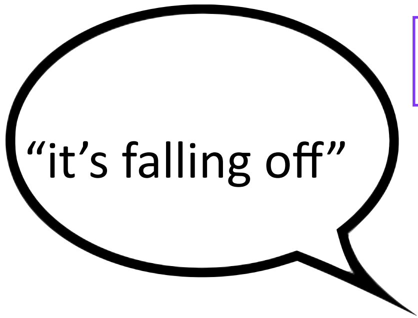
+expmap

+surfmorph

Potential acquisitional intakes

3 binary choices = 8 strategies

Each strategy has a different impact on the acquisitional intake



Input

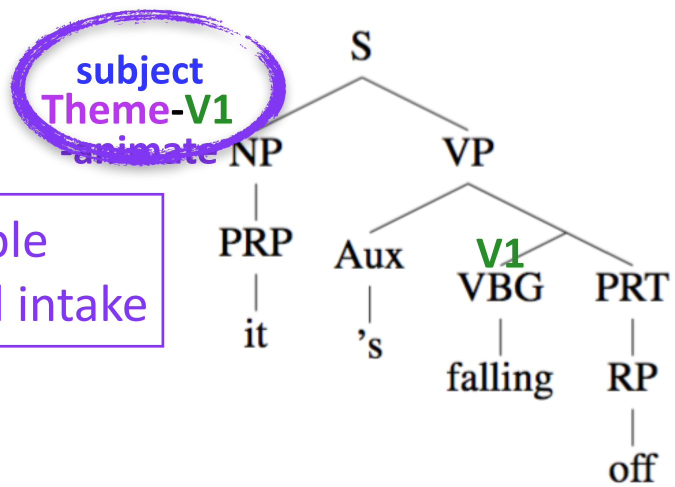
Animacy

Syntactic frame

-surfmorph

Thematic roles and how to use them

UTAH



Possible perceptual intake

Subject *Object* *Indirect Object*

+expmap

Subject *Object* *Indirect Object*

movement?

FALL

-animate subject: 1

rUTAH

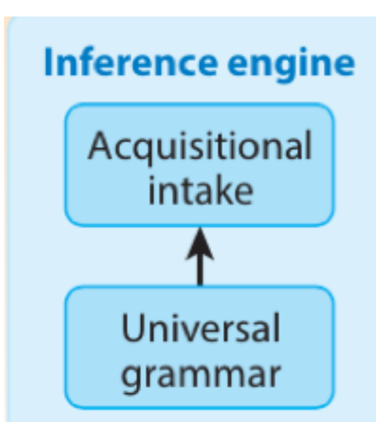
Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

Highest role as subject: 1

-expmap

NP V_{+prog} PRT

+surfmorph

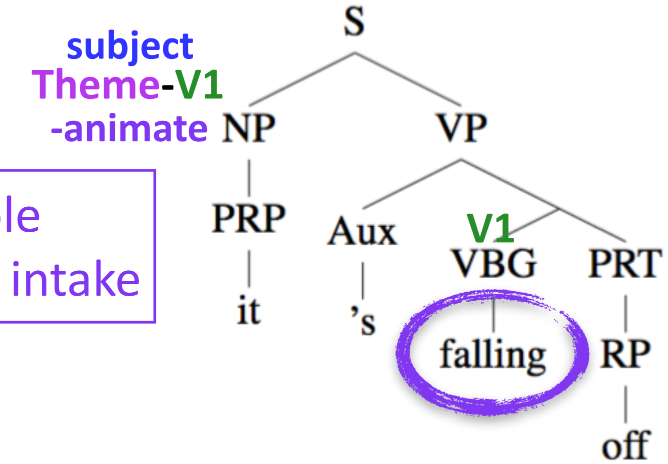


8 modeled learners and their acquisitional intakes

“it’s falling off”

Input

Possible perceptual intake



FALL

8 modeled learners and their acquisitional intakes

"it's falling off"

Input

Possible perceptual intake

subject
Theme-V1
-animate

S
NP VP
PRP Aux V1 VBG PRT
it 's falling RP
off

FALL

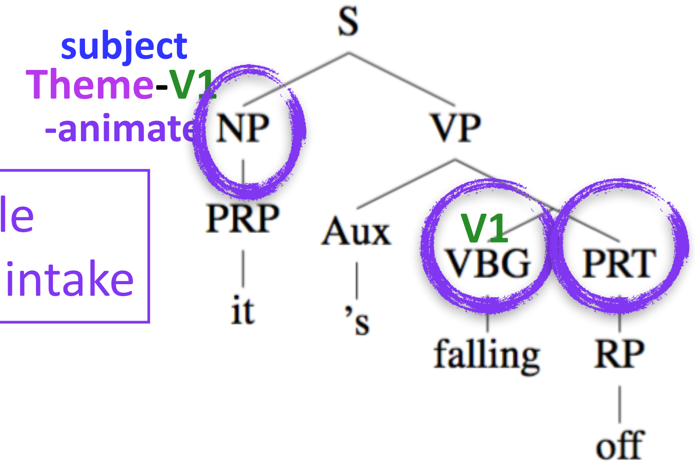
Animacy -animate subject: 1 **All 8 learners**

8 modeled learners and their acquisitional intakes

"it's falling off"

Input

Possible perceptual intake



FALL

Animacy | -animate subject: 1 | All 8 learners

Syntactic frame

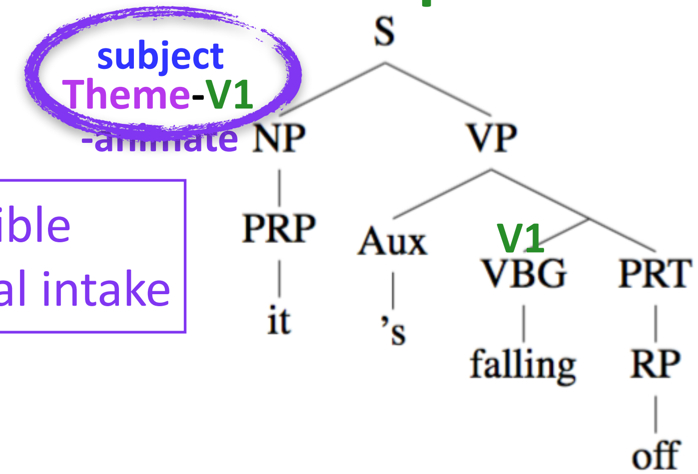
-surfmorph	+surfmorph
4 learners	**4 learners**
NP V PRT	NP V_{+prog} PRT

8 modeled learners and their acquisitional intakes

"it's falling off"

Input

Possible perceptual intake



FALL

Animacy | -animate subject: 1 | All 8 learners

Syntactic frame

-surfmorph

4 learners

NP V PRT

+surfmorph

4 learners

NP V_{+prog} PRT

Intermediate representation

UTAH
Done-to as *subject*
2 learners

rUTAH
Highest as *subject*
2 learners

UTAH
Done-to as *subject*
2 learners

rUTAH
Highest as *subject*
2 learners

8 modeled learners and their acquisitional intakes

"it's falling off"

Input

Possible perceptual intake

subject
Theme-V1
-animate NP

S
NP
PRP
it
VP
Aux
's
V1
VBG
falling
PRT
RP
off

FALL

Animacy | -animate subject: 1 | All 8 learners

Syntactic frame

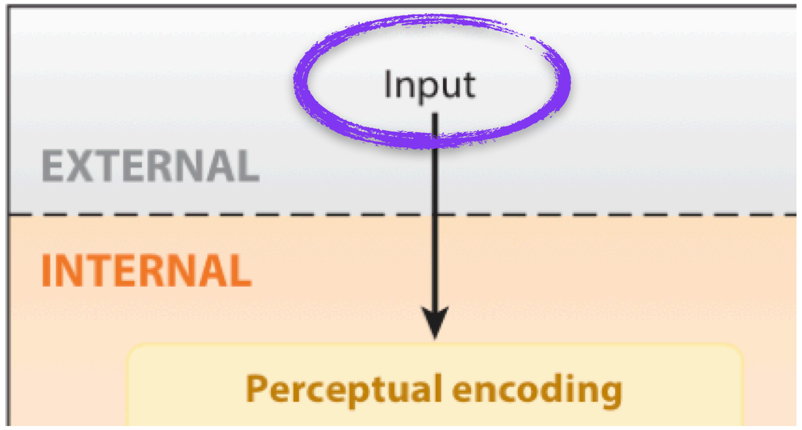
-surfmorph	+surfmorph
4 learners	4 learners
NP V PRT	NP V_{+prog} PRT

Intermediate representation

UTAH	rUTAH	UTAH	rUTAH
Done-to as subject	*Highest as subject*	*Done-to as subject*	*Highest as subject*
2 learners	2 learners	2 learners	2 learners

Mapping to syntax

+expmap	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*
+mvmt: 1	Done-to as subject: 1	+mvmt: 0	Highest as subject: 1	+mvmt: 1	Done-to as subject: 1	+mvmt: 0	Highest as subject: 1
1 learner	**1 learner**	**1 learner**	**1 learner**	**1 learner**	**1 learner**	**1 learner**	**1 learner**



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

Input

CHILDES Treebank

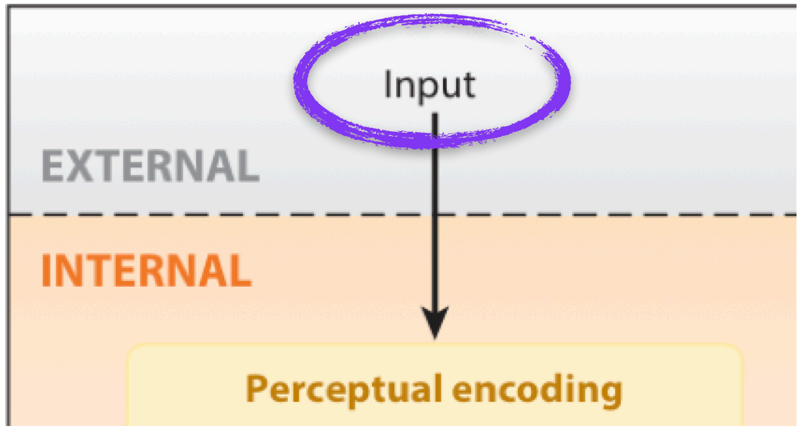
<3 years old

Brown-Eve corpus (Brown 1973) and the Valian corpus (Valian 1991), with syntactic & thematic annotations provided by the CHILDES Treebank (Pearl & Sprouse 2013).

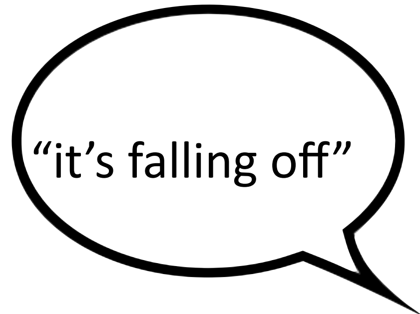
Speech directed at 22 children between 18 and 32 months.

~40,000 utterances (~197,000 word tokens, 555 verbs)

Focus on the 239 verbs occurring 5 or more times.



Goal: Model the developmental trajectory from 3 to 4 to 5 years old



Input

CHILDES Treebank

<3yrs

18 and 32 months
~40,000 utterances
239 verbs

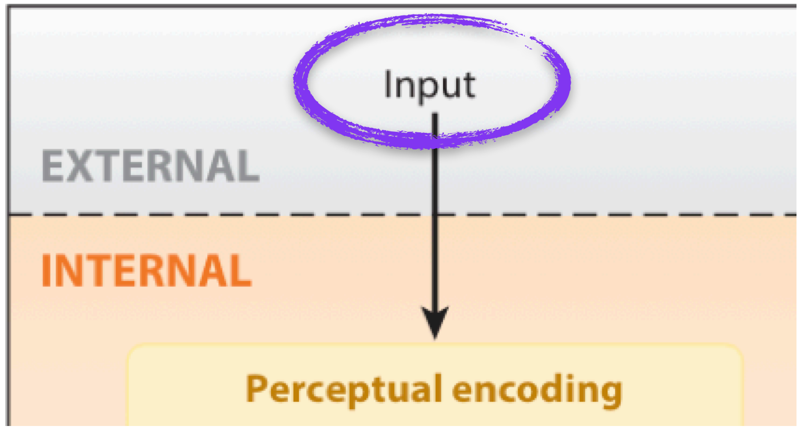
<4 years old

<3yrs + Brown-Adam subsection (Brown 1973), with syntactic & thematic annotations provided by the CHILDES Treebank (Pearl & Sprouse 2013).

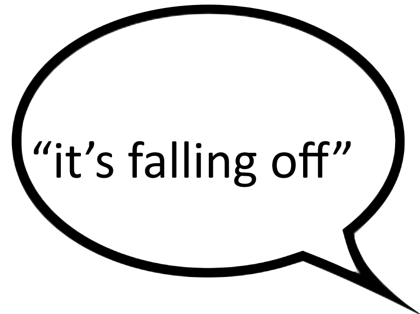
Speech directed at 23 children between 18 and 48 months.

~51,000 utterances (~254,000 word tokens, 617 verbs)

Focus on the 267 verbs occurring 5 or more times.



Goal: Model the developmental trajectory from 3 to 4 to 5 years old



Input

CHILDES Treebank

<3yrs

18 and 32 months
~40,000 utterances
239 verbs

<4yrs

18 and 48 months
~51,000 utterances
267 verbs

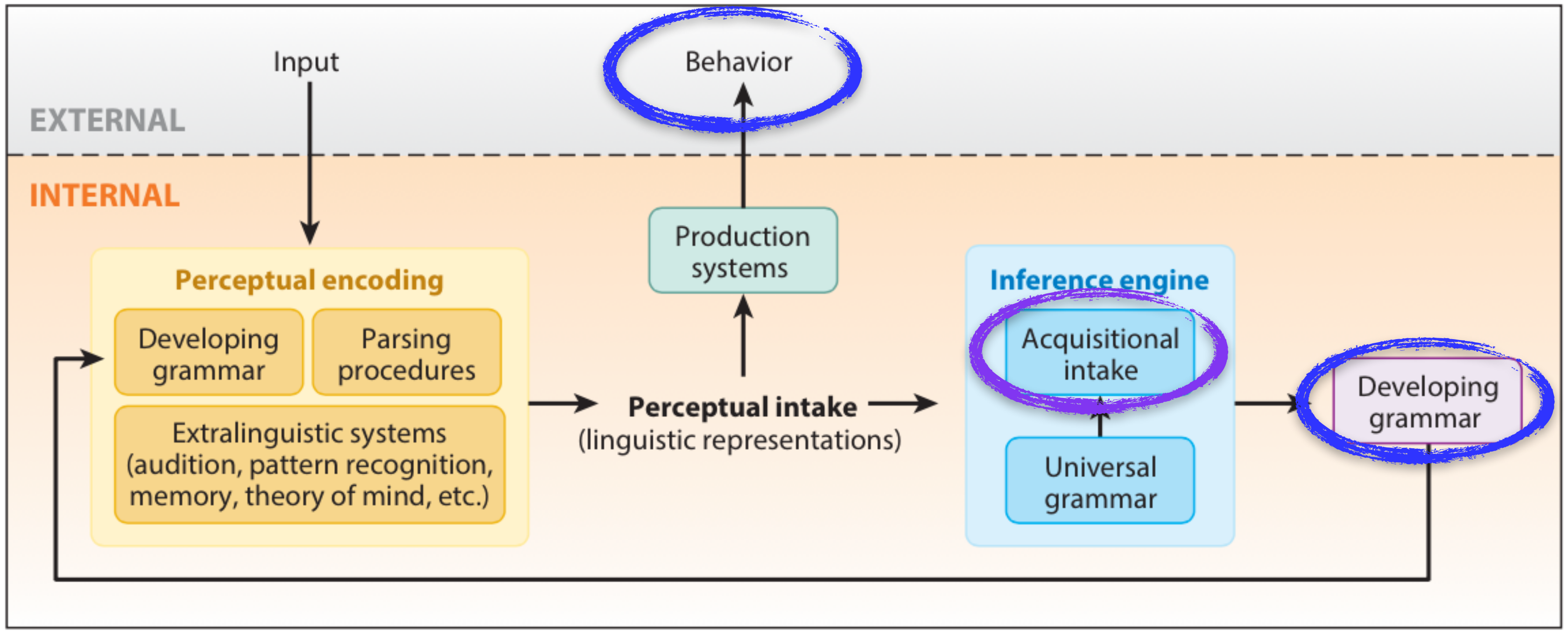
<5 years old

<4yrs + Brown-Adam subsection (Brown 1973), with syntactic & thematic annotations provided by the CHILDES Treebank (Pearl & Sprouse 2013).

Speech directed at 23 children between 18 and 58 months.

~56,500 utterances (~285,000 word tokens, 651 verbs)

Focus on the 284 verbs occurring 5 or more times.



Goal: Model the developmental trajectory from 3 to 4 to 5 years old

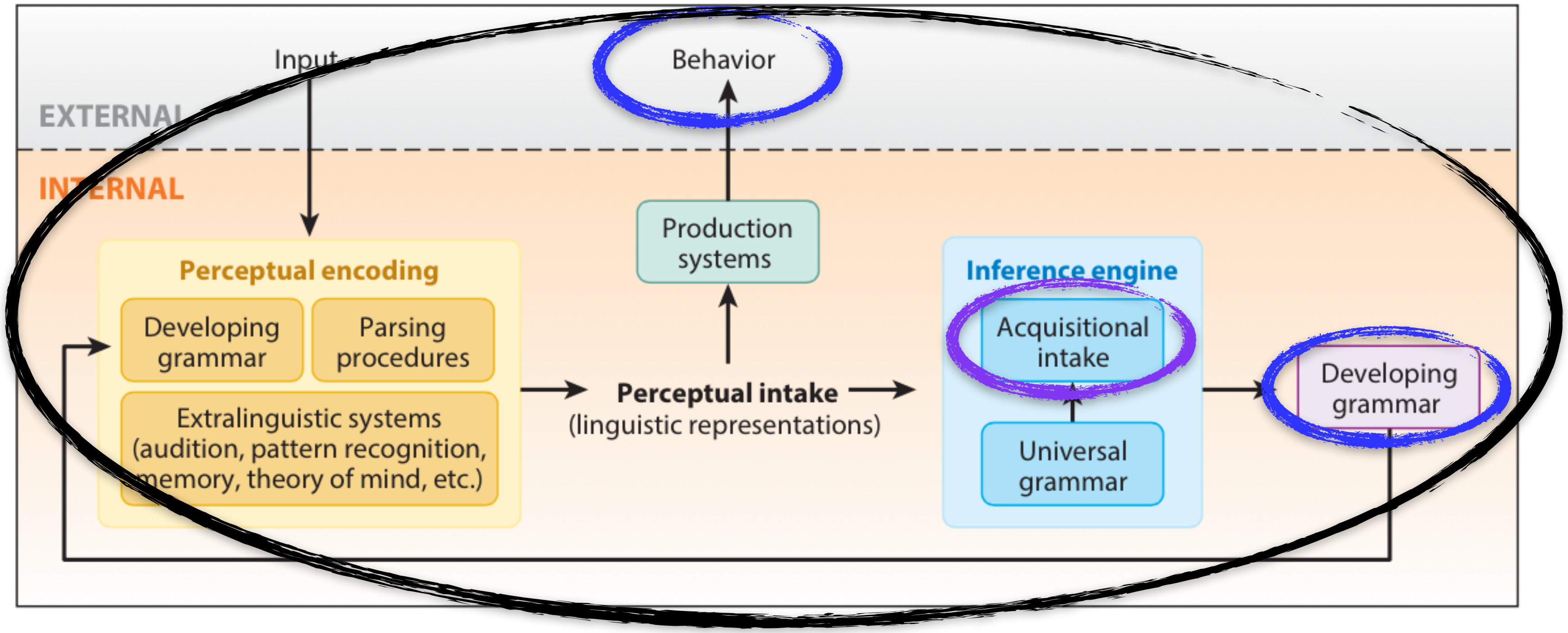
<3yrs **<4yrs** **<5yrs**



Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

This is the goal of learnability approaches (computational-level of analysis: Marr 1982)

Frank et al. 2009, Goldwater et al. 2009, Pearl et al. 2010, Pearl 2011, Legate & Yang 2012, Dillon et al. 2013, Doyle & Levy 2013, Feldman et al. 2013, Orita et al. 2013



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<3yrs **<4yrs** **<5yrs**



Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

Ideal learner model: Also an excellent first step to see if this is the **right conceptualization** of the acquisition task.

-surfmorph

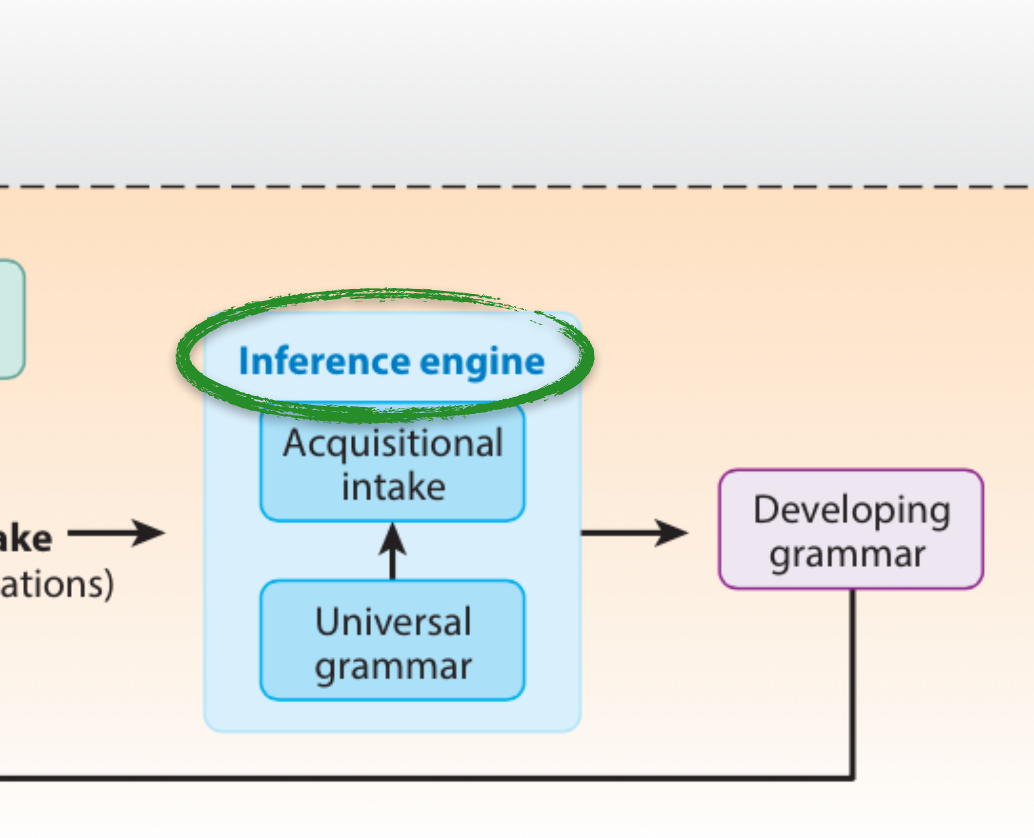
+surfmorph

UTAH

rUTAH

-expmap

+expmap



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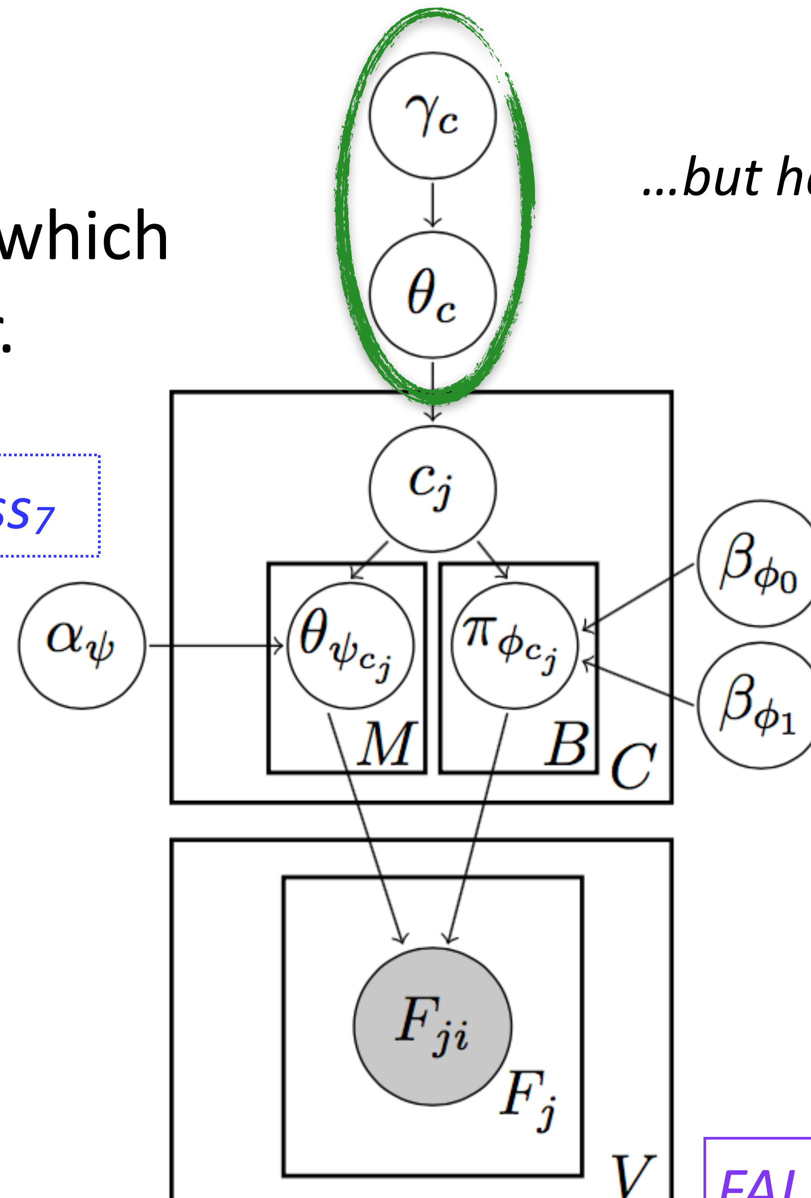
<3yrs <4yrs <5yrs

...*but has a bias for fewer classes.*

Each verb belongs to some class which determines its linguistic behavior.

class₇

Objective: Infer verb class

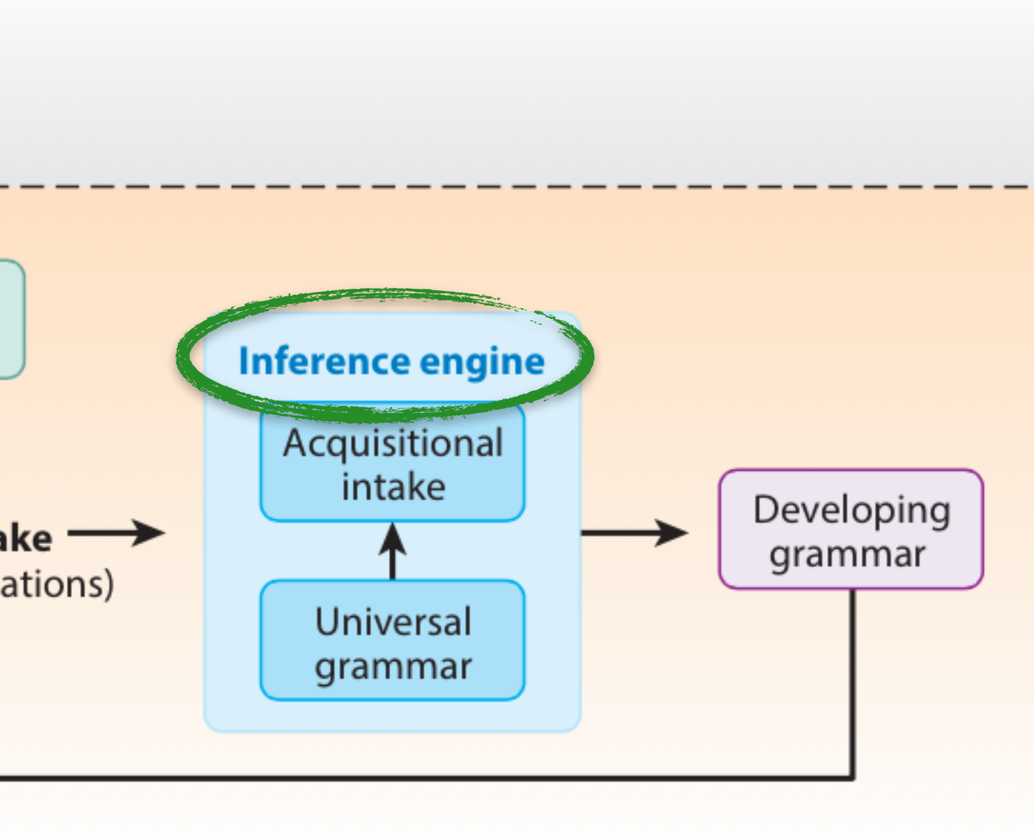


FALL

"it's falling off"

(3x) "it's falling off"

"it's falling off"



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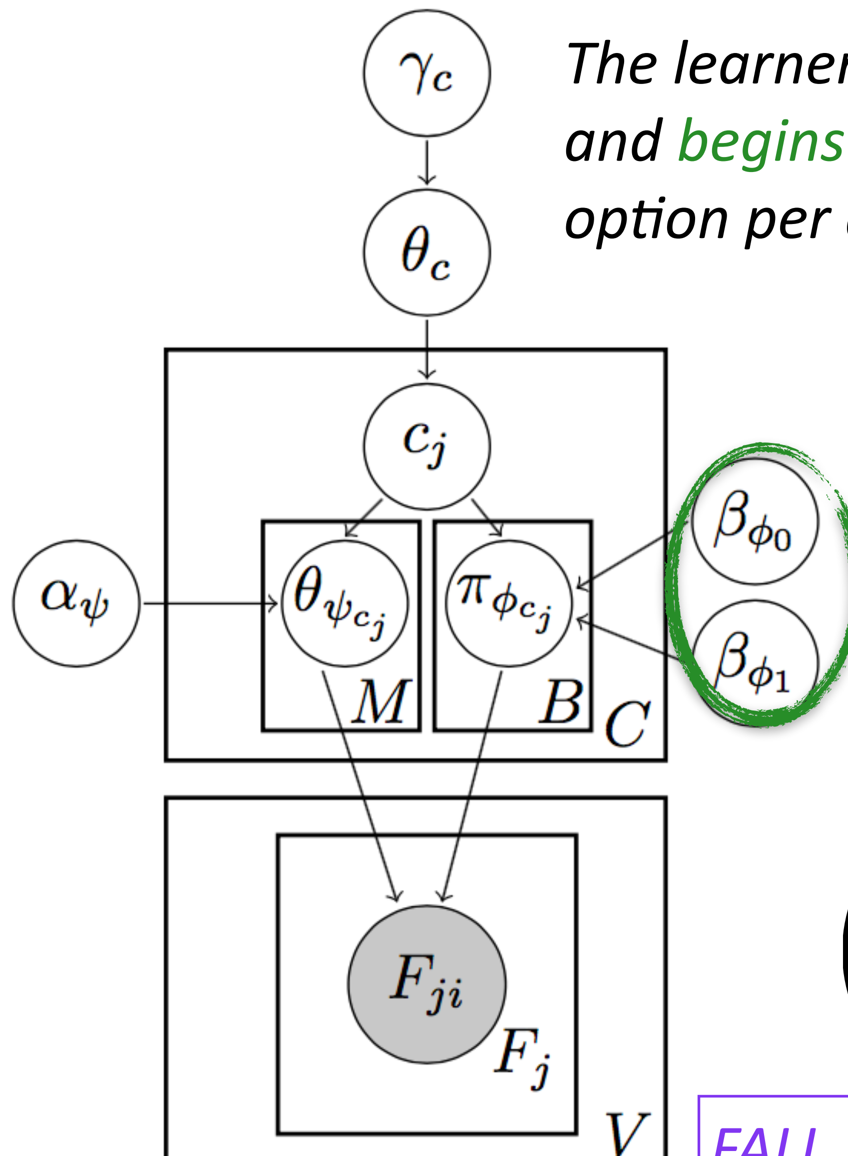


The learner infers these probabilities, and begins with no bias towards either option per class.

Binary choices:

+animate

-animate

Subject ***Object*** ***Indirect Object***

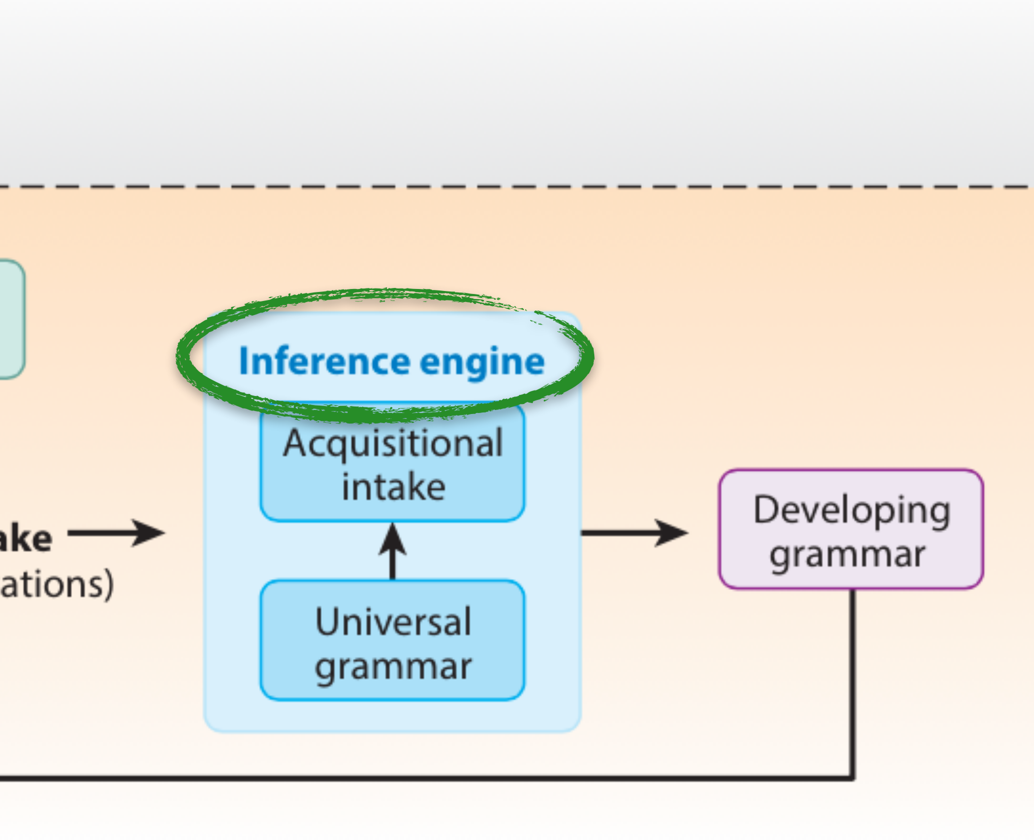
movement?

class₇

+anim	***Subject***	***-anim***
0.3		***0.7***

-anim
"**it**'s falling off"
(3x) "it's falling off"
"it's falling off"

FALL



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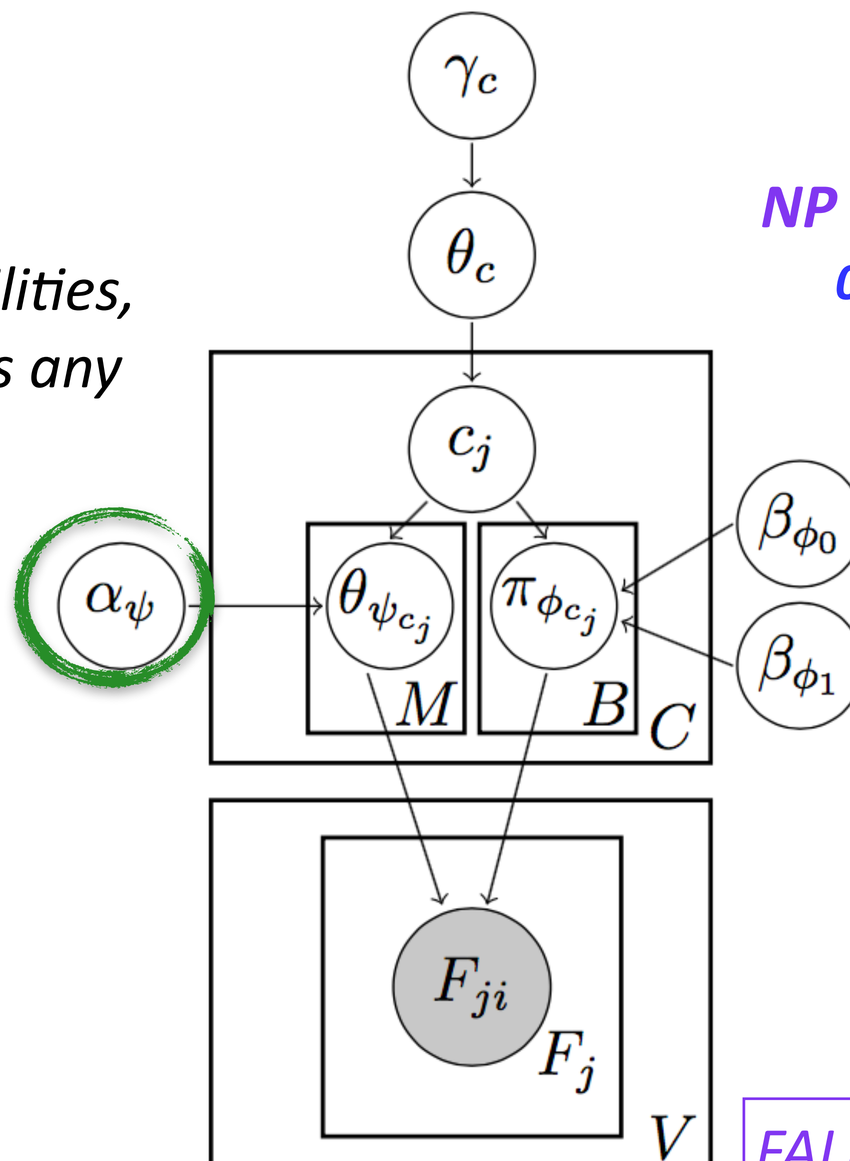


NP V ...

NP V PRT 0.3 | NP V 0.25 | NP V S 0

The learner infers these probabilities, and begins with no bias towards any option per class.

class₇

+anim 0.3 *Subject* *-anim* 0.7

Multinomial choices:

Agent > Experiencer > Theme > Patient > (Source, Goal, Instrument)

NP V PRT

Subject ***Object*** ***Indirect Object***

-anim

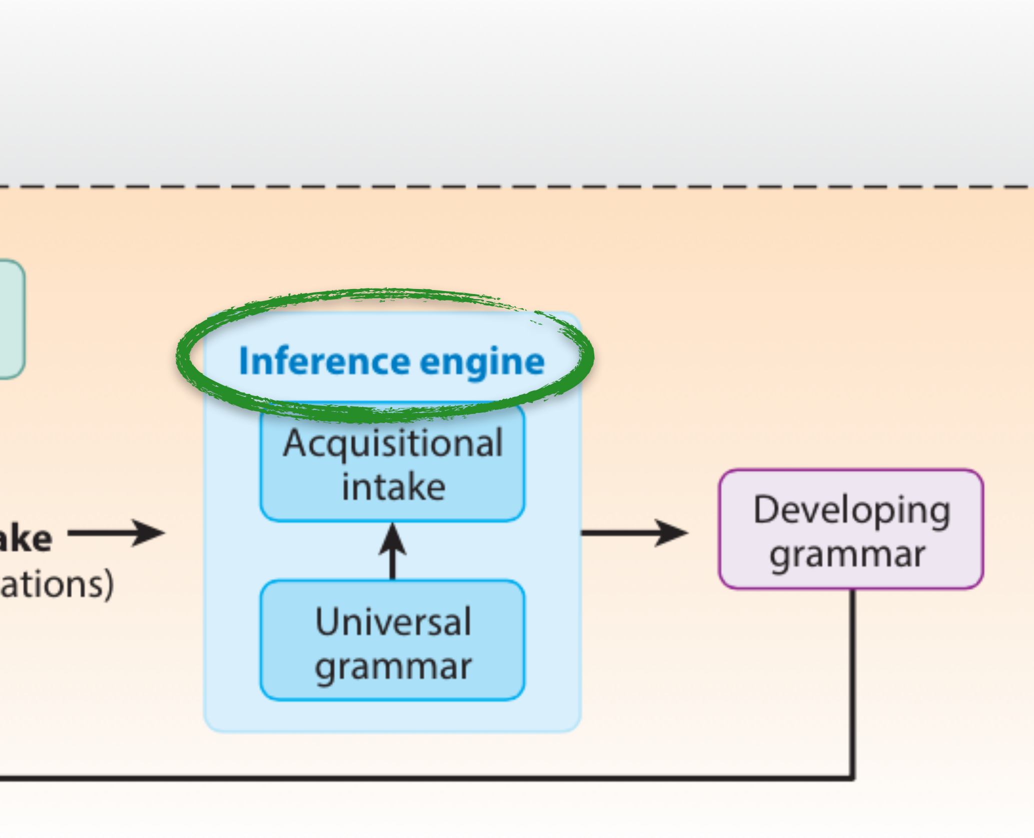
"it's falling off"

(3x) ***NP V PRT***

"it's falling off"

"it's falling off"

FALL



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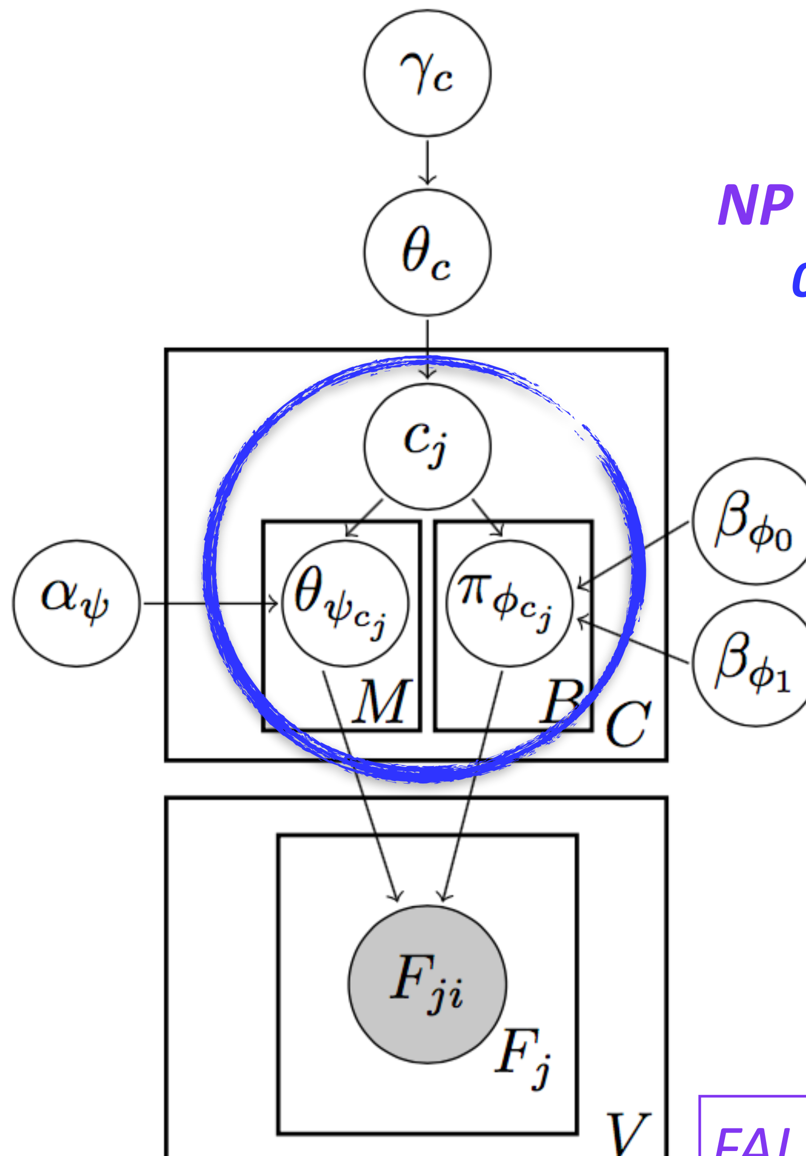


NP V PRT *0.3*

NP V *0.25*

...

NP V S *0*

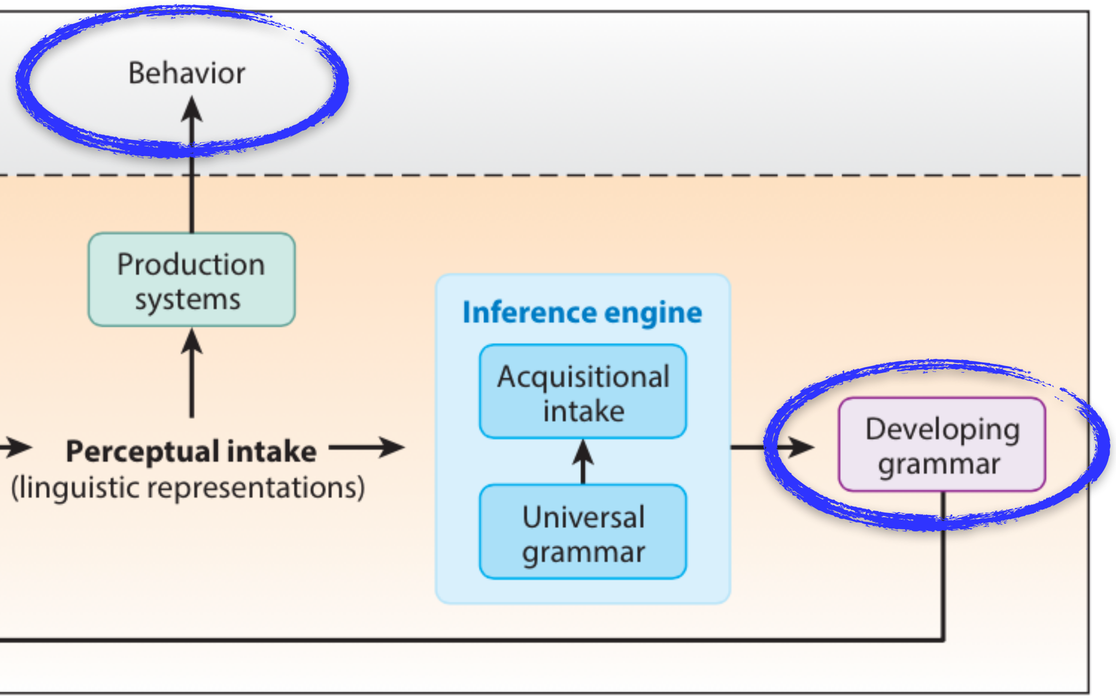
class₇

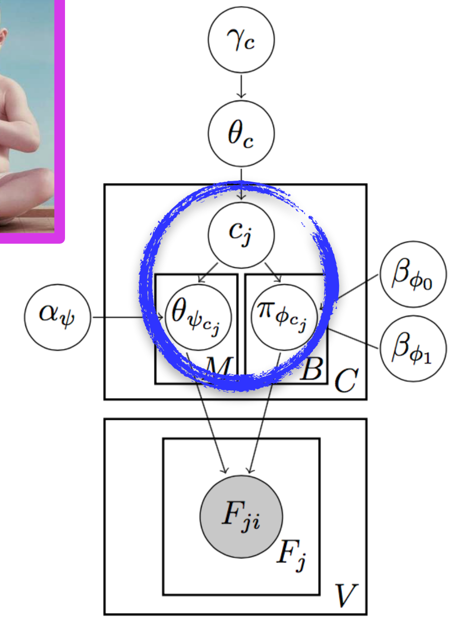
+anim *0.3* *Subject* *-anim* *0.7*

FALL

-anim
"it's falling off"
(3x) *NP V* *PRT*
"it's falling off"
"it's falling off"

Inference: The learner forms different classes because the characteristics are sufficiently different for each class.





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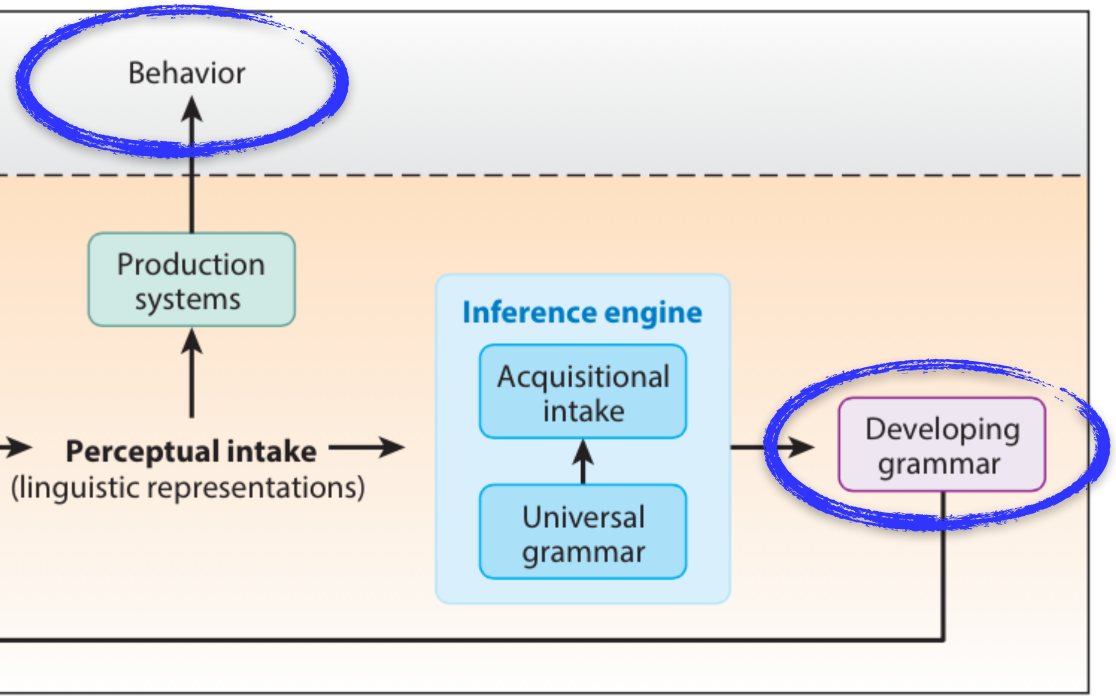
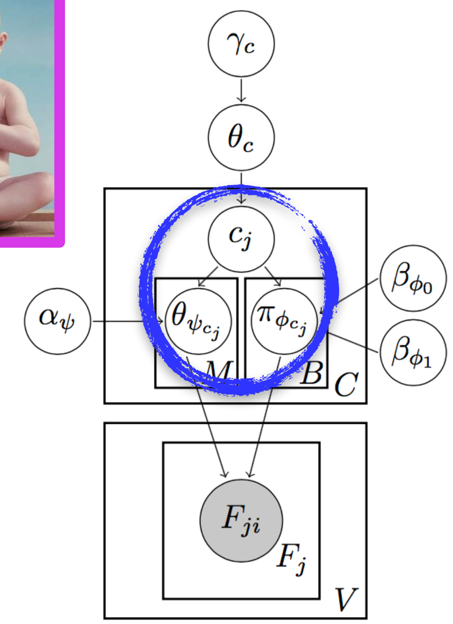
verb classes

Survey of **32** experimental studies on children's production and comprehension of specific verbs

Passives: Maratsos 1974, Maratsos et al. 1985, Gordon & Chafetz 1990, O'Brien et al. 2006, Crain et al. 2009, Messenger et al. 2009, Nguyen et al. 2016

"It was ____-en."
done-to





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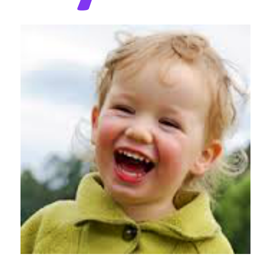
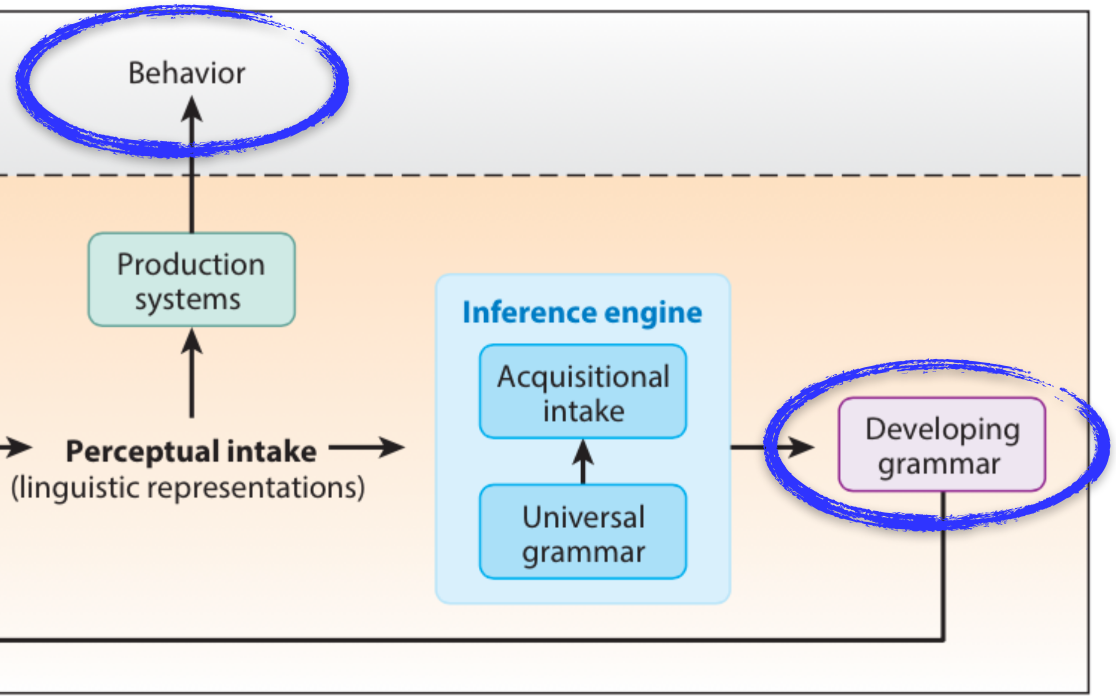
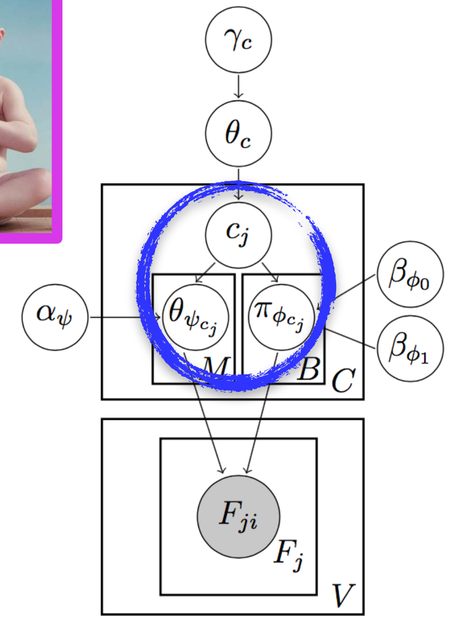
3yrs



+= hit, see, …

-= know, remember, …





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<3yrs

<5yrs

verb classes

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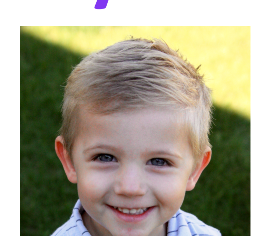
"It was ____-en."

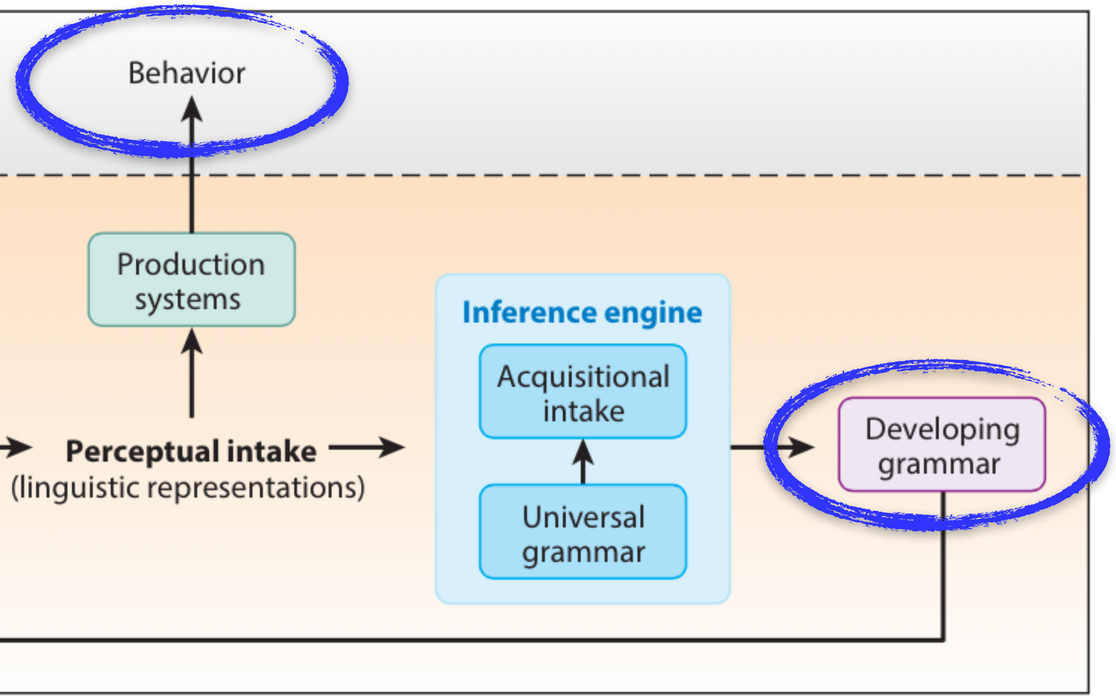
done-to

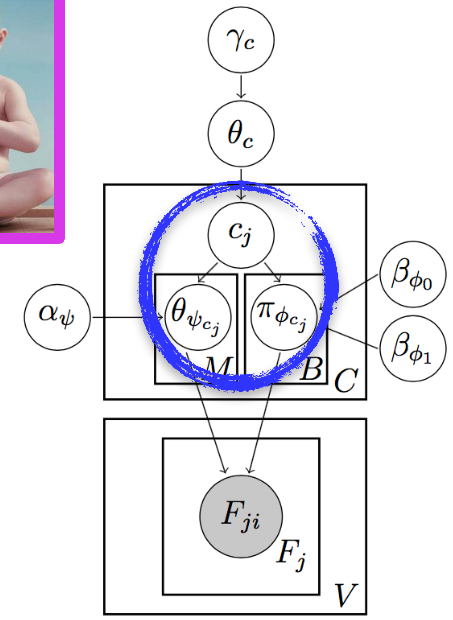
4yrs



+= hit, scare, see, …

-= know, love, remember, …





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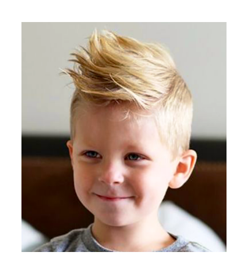
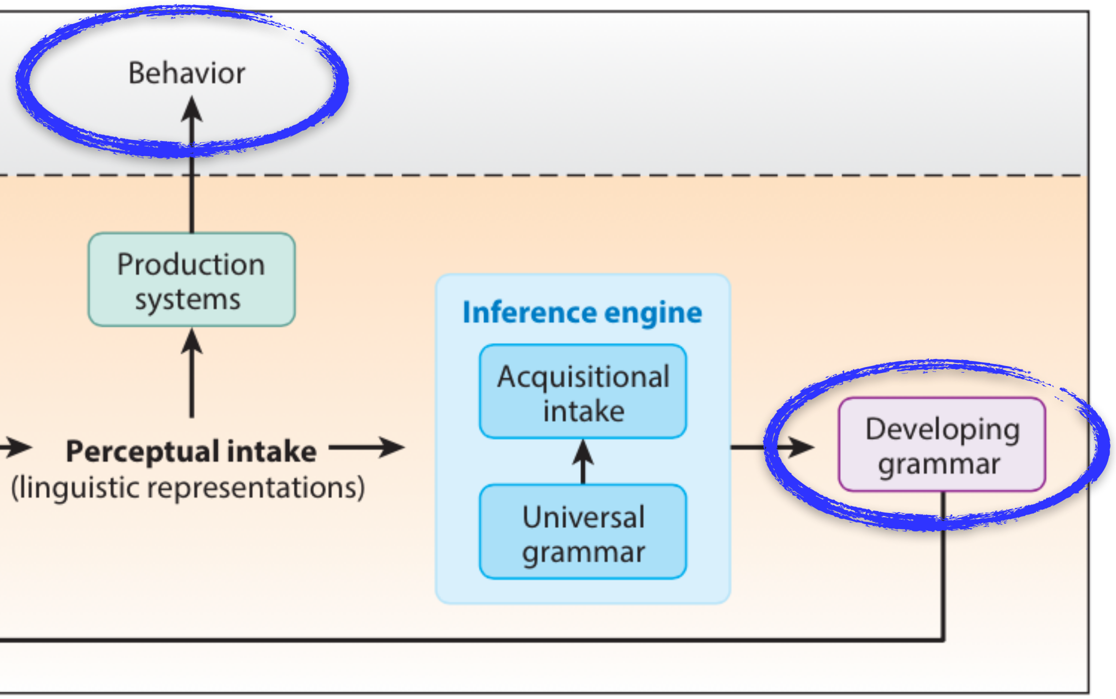
"It was ____-en."
done-to

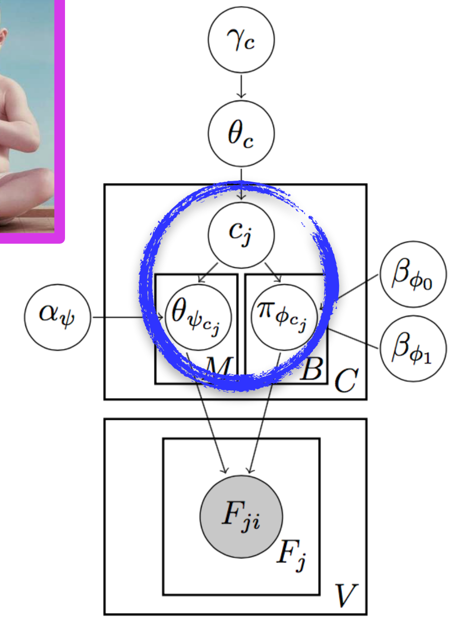
5yrs



+= hit, love, scare, see, …

-= know, remember, …





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verb classes

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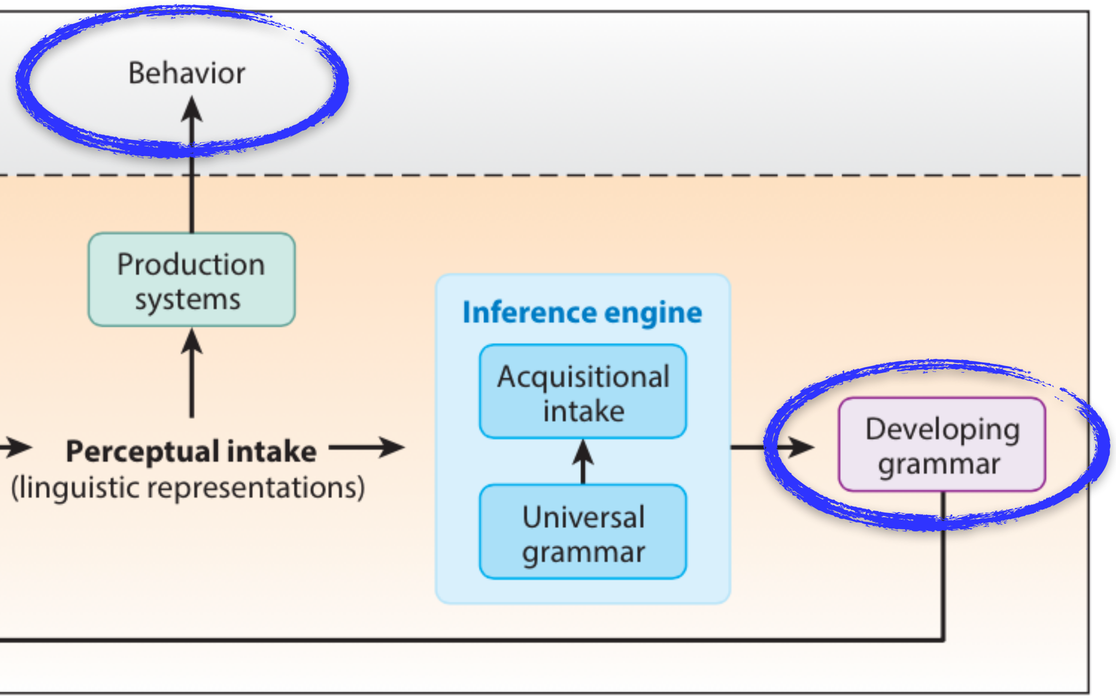
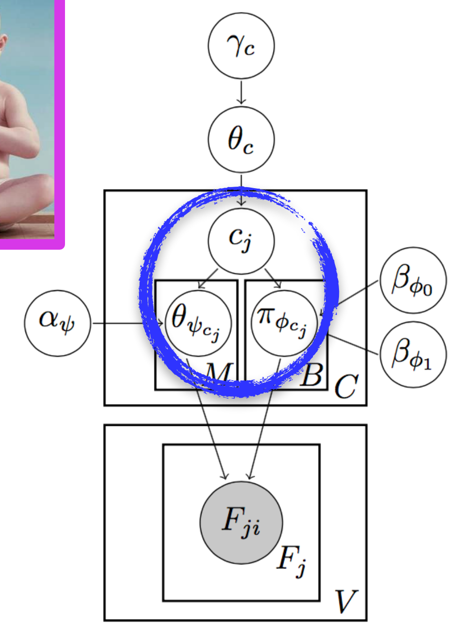
Ditransitives: Gropen et al. 1989, Snedeker & Huang in press, Campbell & Tomasello 2001, Huttenlocher et al. 2004, Conwell & Demuth 2007, Thothathiri & Snedeker 2008

"Jack ___ Lily the thing."





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<5yrs

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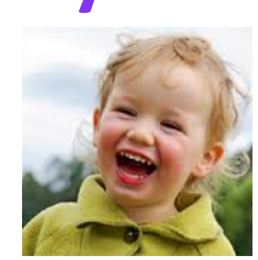
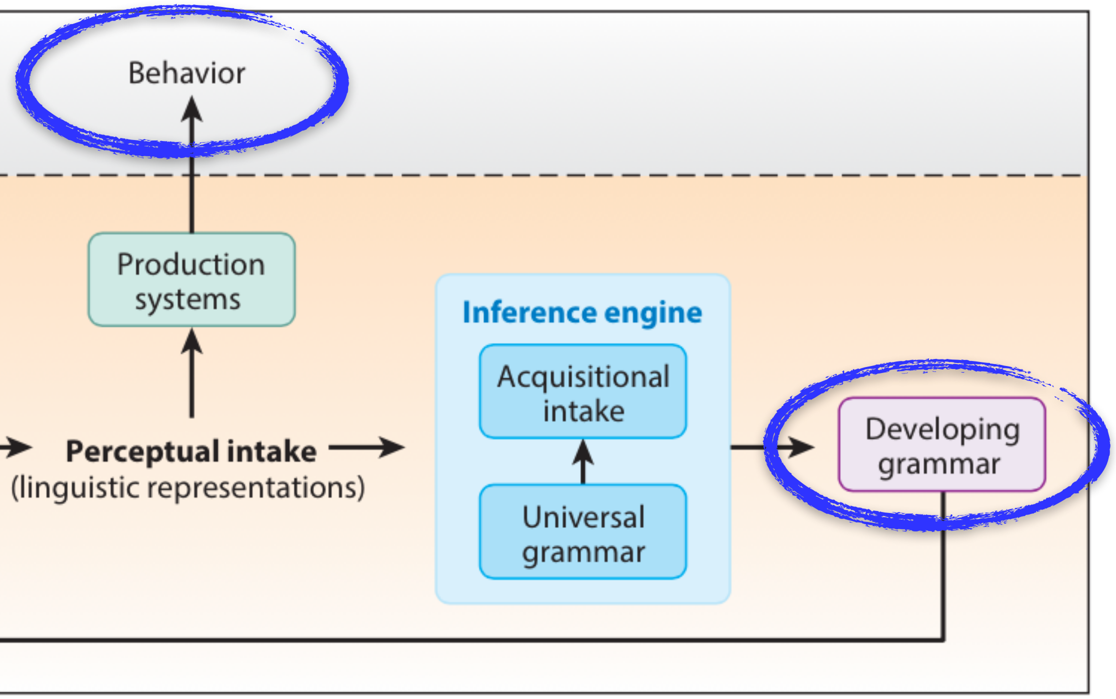
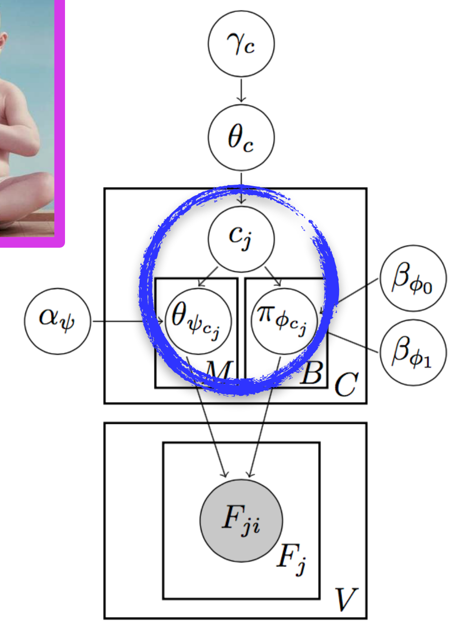


+= give, read, *say, …





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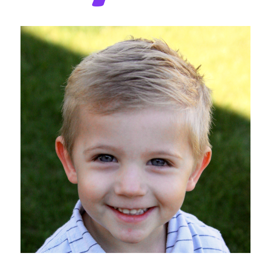
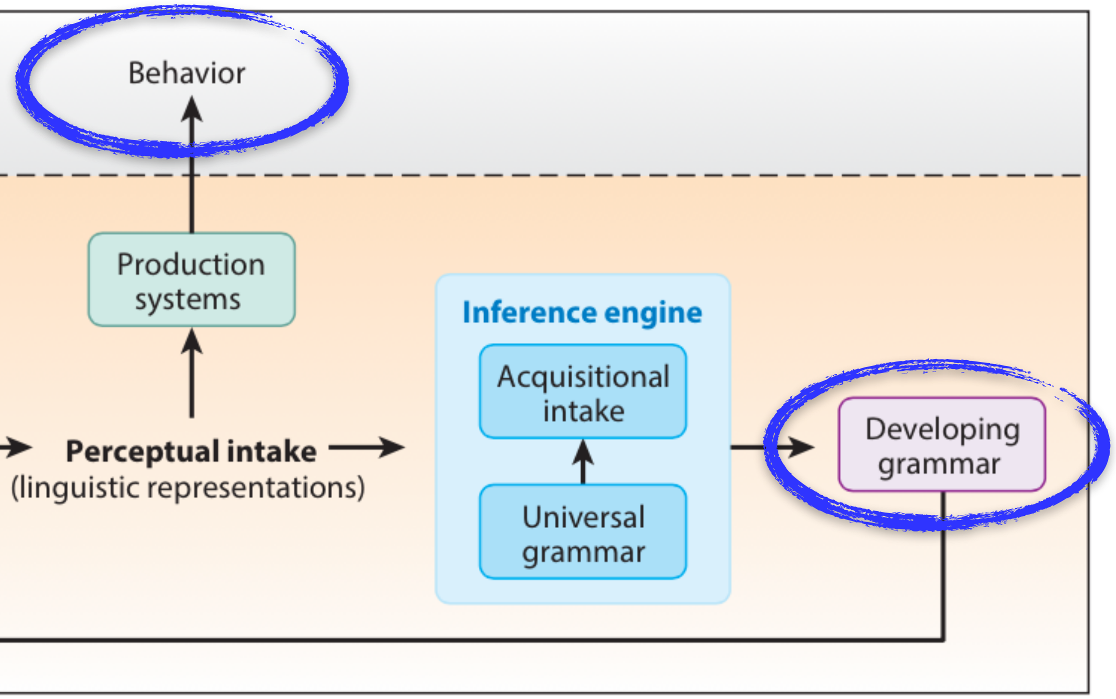
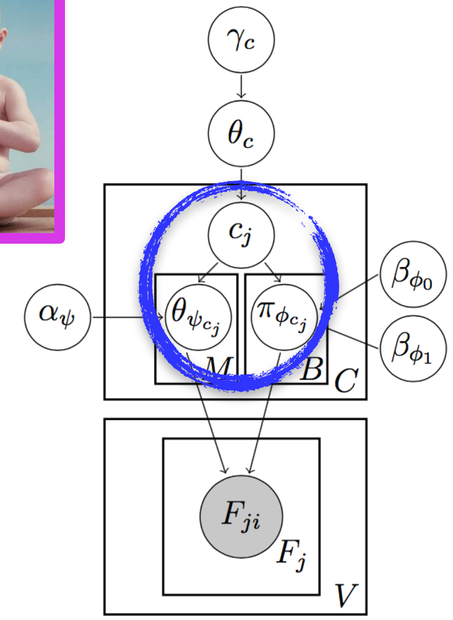
4yrs



+= give, read, *say, teach, …





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verb classes

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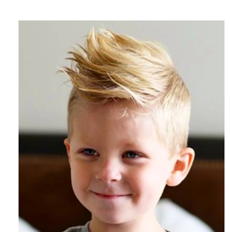
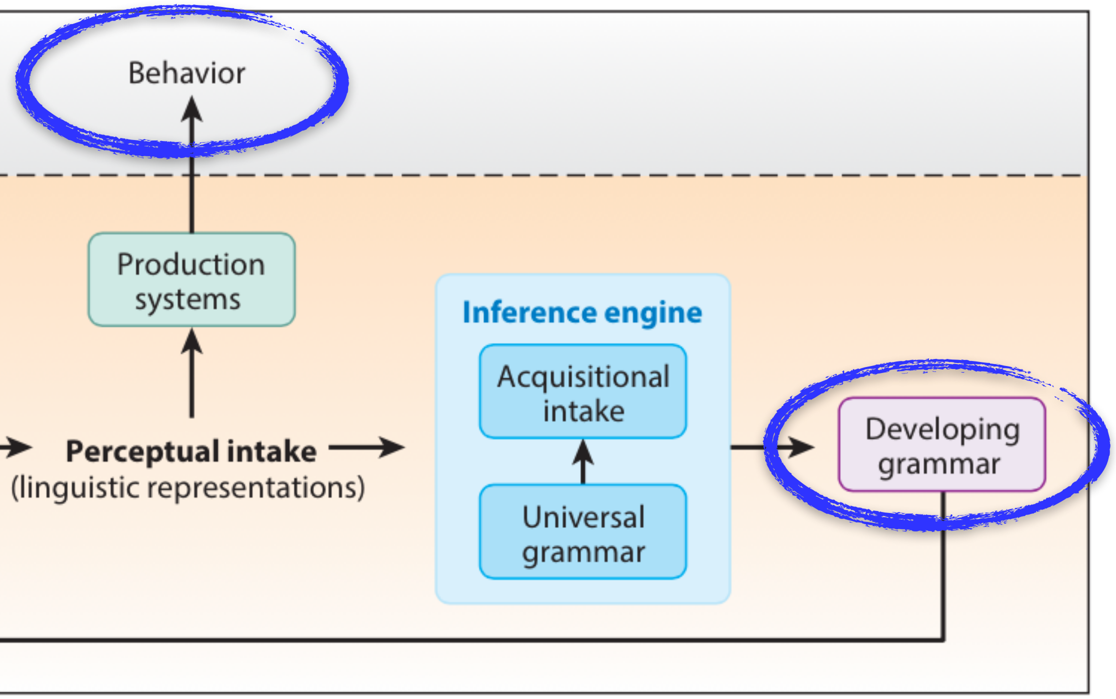
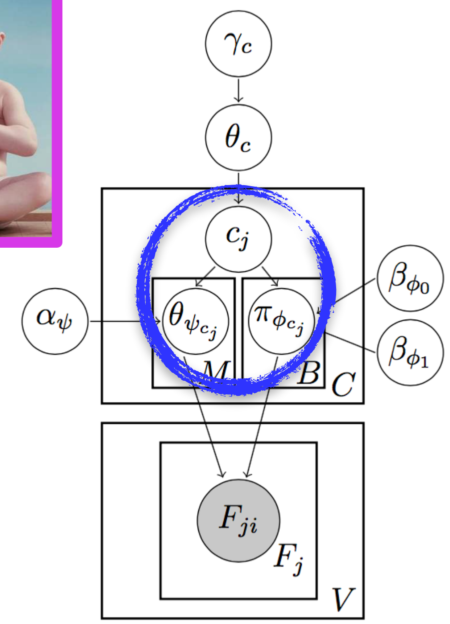
5yrs



+= ask, give, read, *say, teach, ...





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<3yrs **<4yrs** **<5yrs**

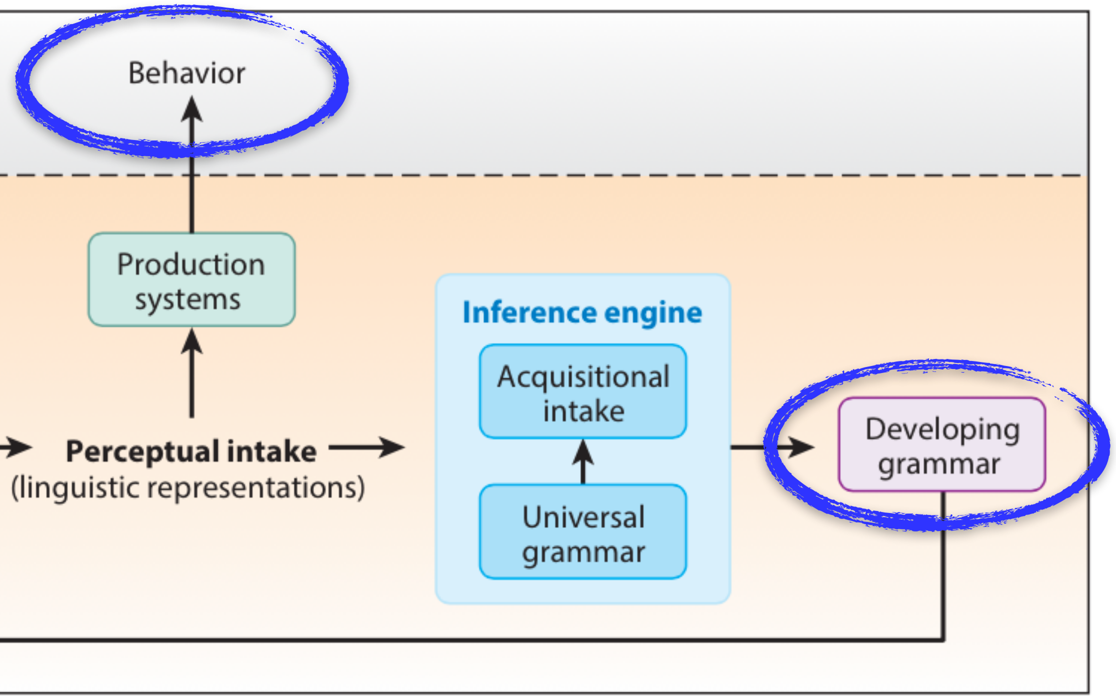
  

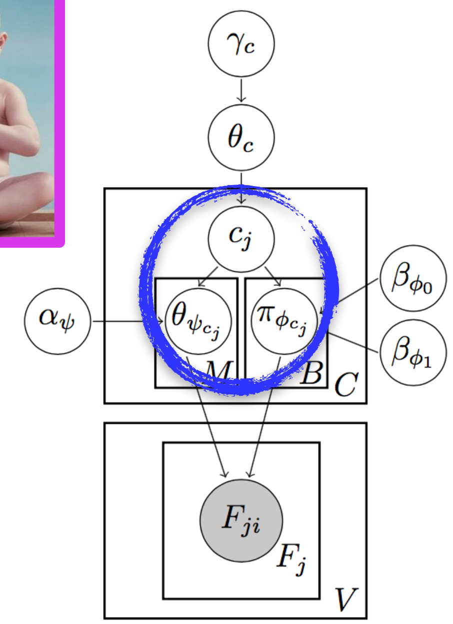
verb classes

Survey of **32** experimental studies on children's production and comprehension of specific verbs

Unaccusatives: Déprez & Pierce 1993, Snyder & Stromwold 1997, Gelman & Koenig 2001, Bunger & Lidz 2004, Bunger & Lidz 2008

"It ____."
done-to





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verb classes

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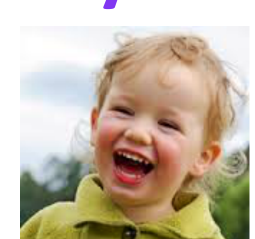
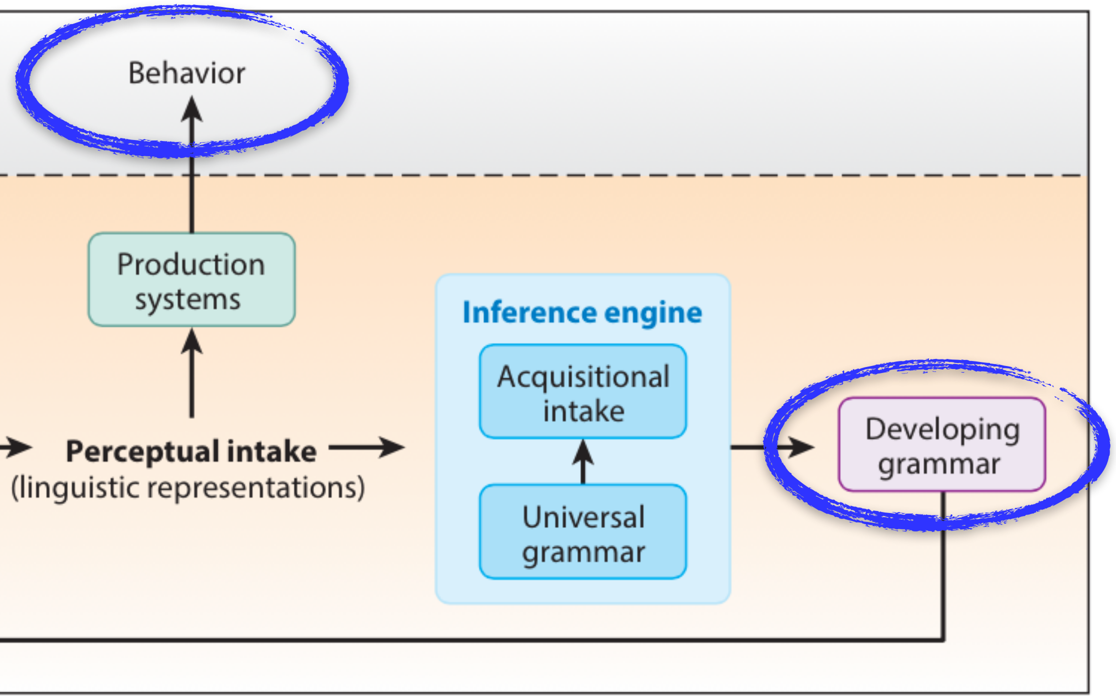
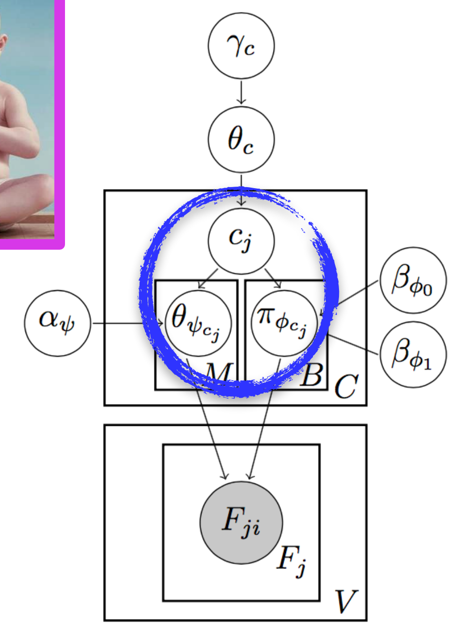
"It ____."
done-to

3yrs



+= break, fall, …





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<3yrs **<4yrs** **<5yrs**



verb classes

Survey of **32** experimental studies on children's production and comprehension of specific verbs

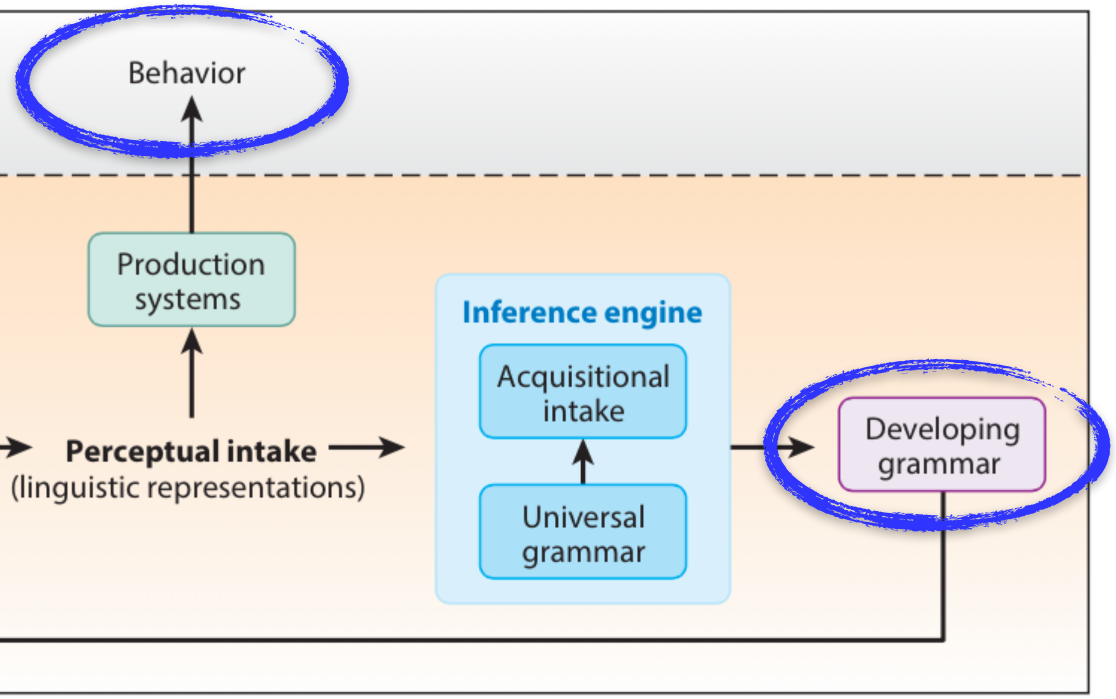
Control object & Raising object: Kirby 2009a, Kirby 2009b, Kirby 2010, Becker 2014

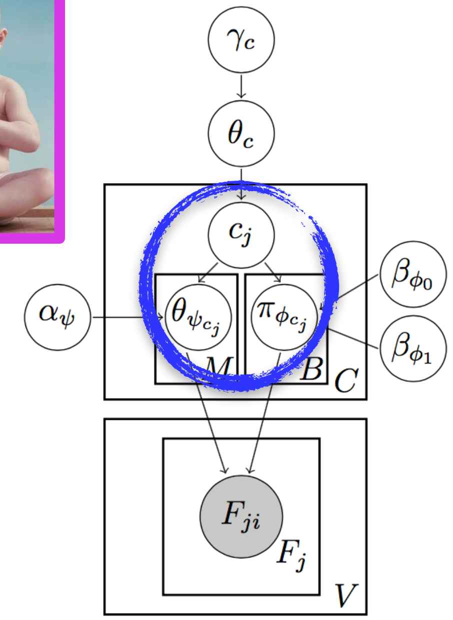
Control object

"I ___him to leave."

done-recipient (main)

doer (embedded)





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<3yrs

verb classes

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Control object

"I ___him to leave."

done-recipient (main)

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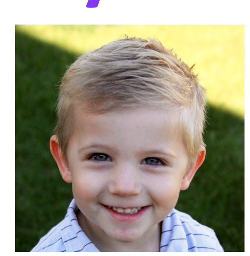
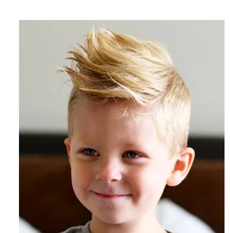
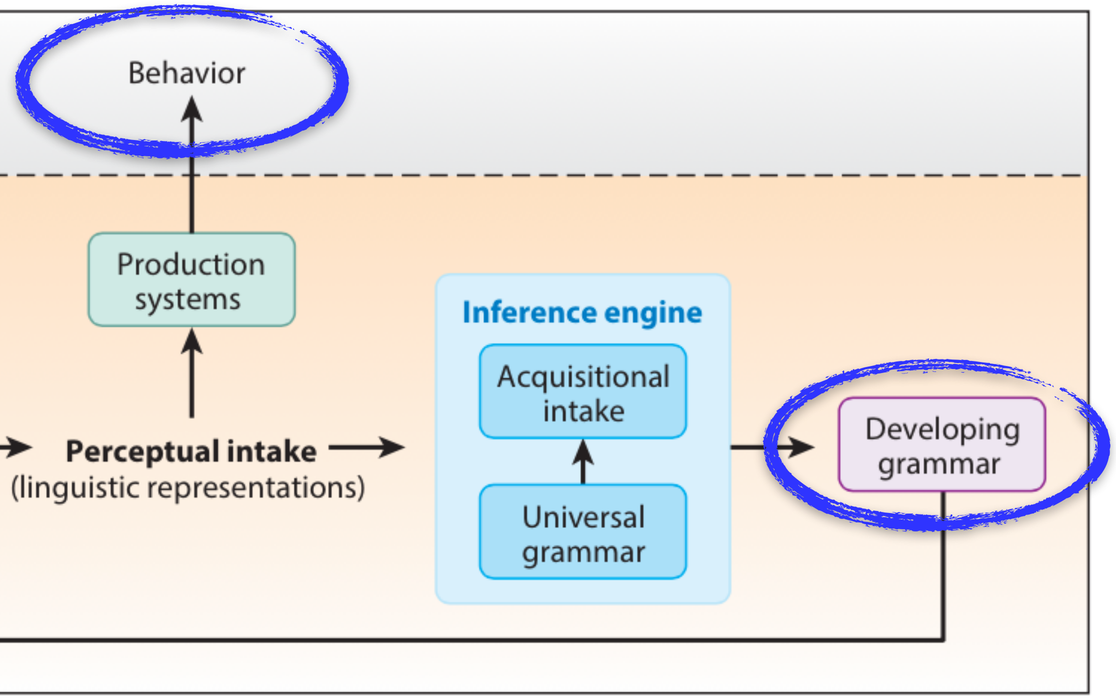
4yrs

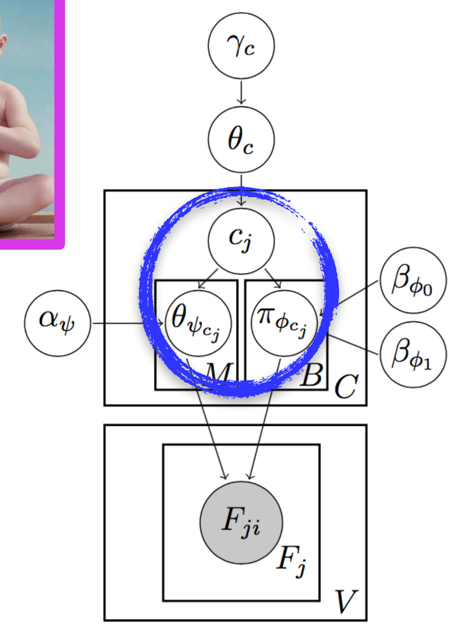


5yrs



+= ask, tell





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<3yrs

verb classes

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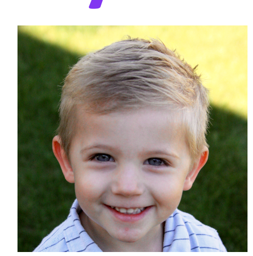
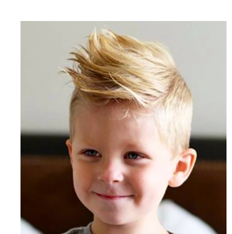
Raising object

"I ___him to leave."

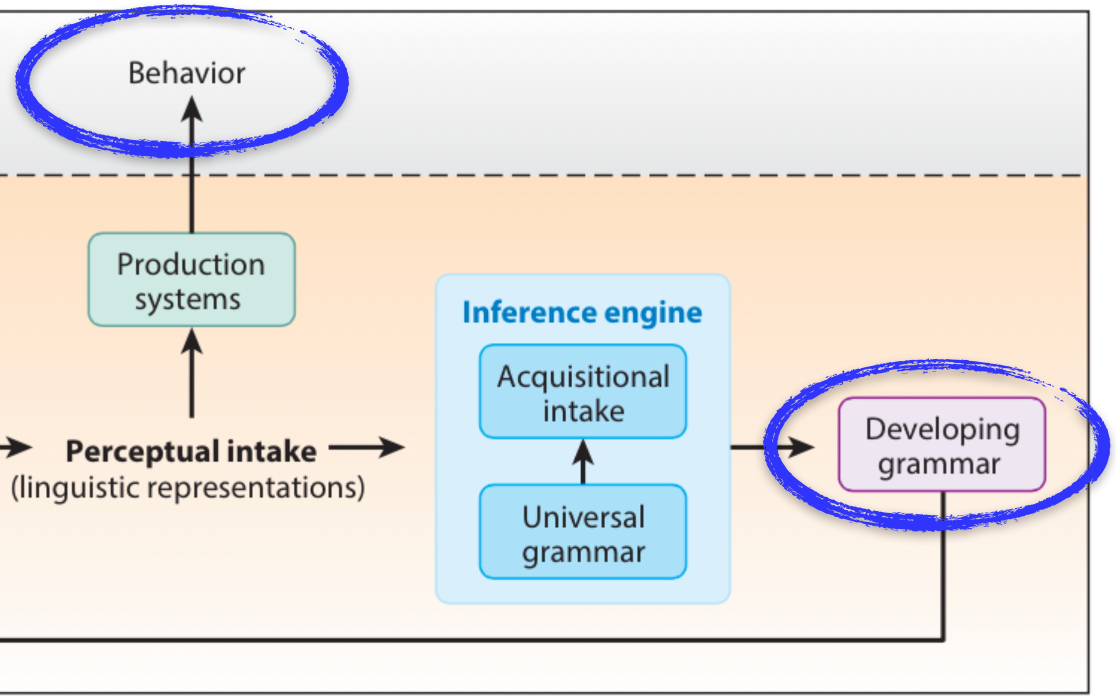
doer (embedded)

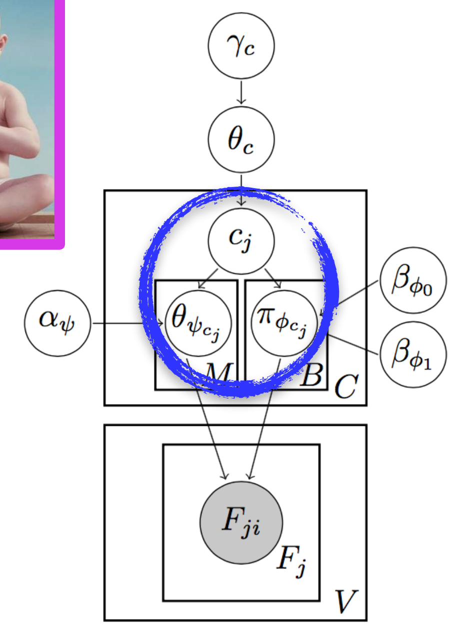
4yrs **5yrs**





+= need, want





Goal: Model the
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<3yrs **<4yrs** **<5yrs**



verb classes

Survey of **32** experimental studies on children's production and comprehension of specific verbs

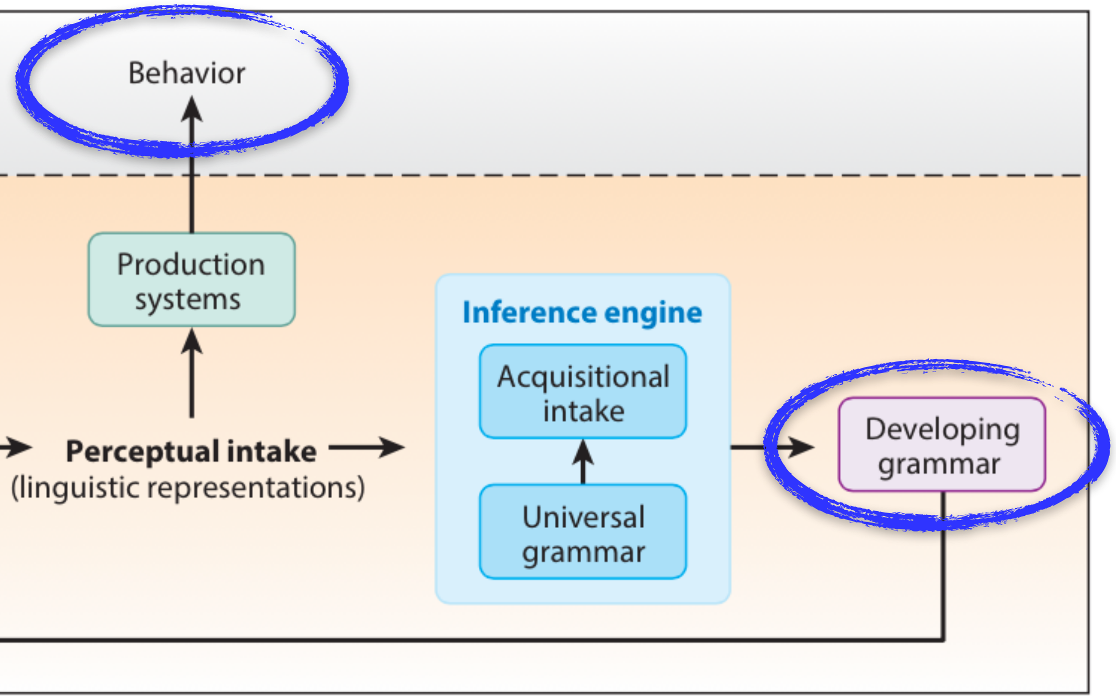
Control subject & Raising subject: Becker 2006, Becker 2007, Becker 2009, Becker 2014

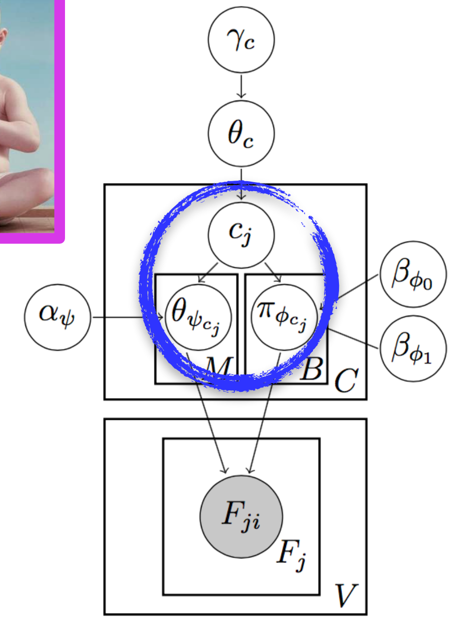
Control subject

"I ___ to leave."

doer (main)

doer (embedded)





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<3yrs

verb classes

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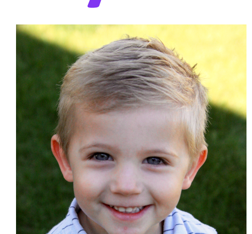
Control subject

"I ____ to leave."

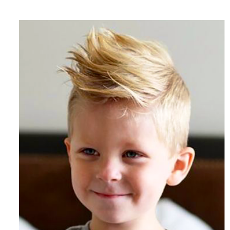
doer (main)

doer (embedded)

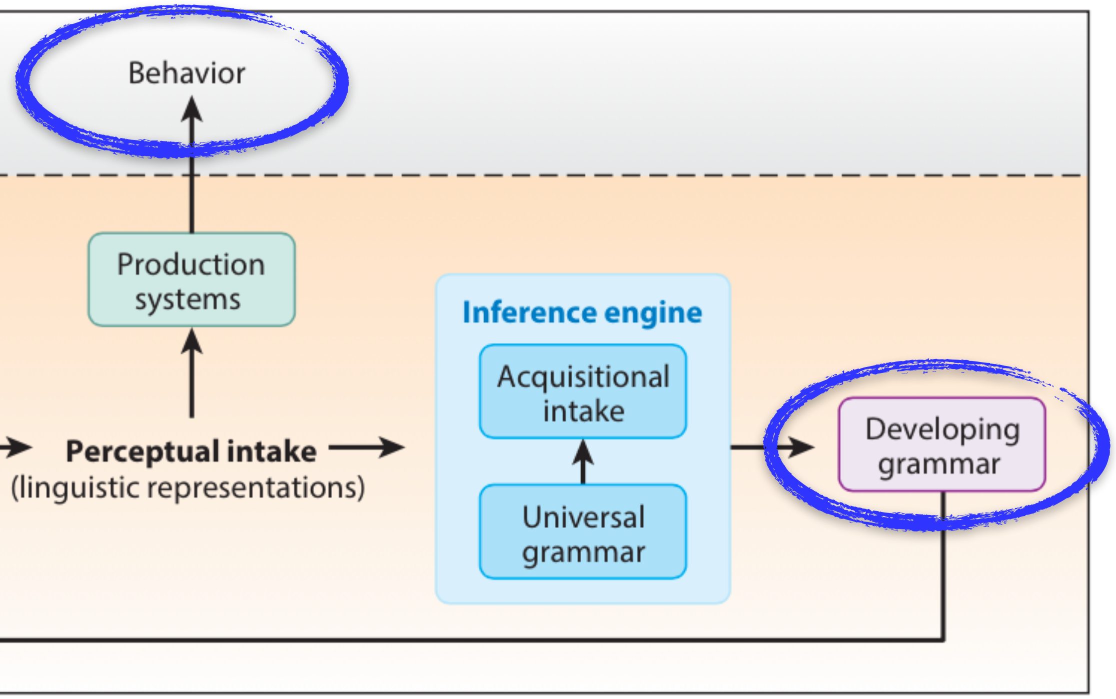
4yrs

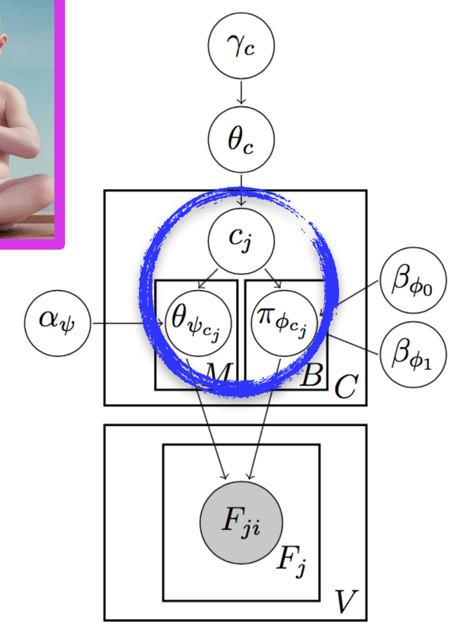


5yrs



+= try, want





Goal: Model the
developmental trajectory
from 3 to 4 to 5 years old

<3yrs

verb classes

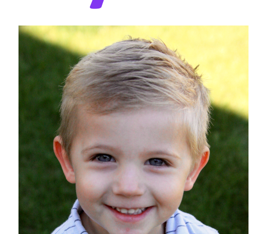
Survey of **32** experimental studies on children’s production and comprehension of specific verbs

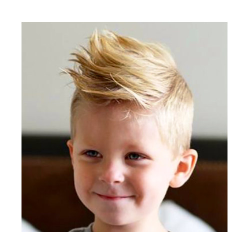
Control subject & Raising subject: Becker 2006, Becker 2007, Becker 2009, Becker 2014

Raising subject

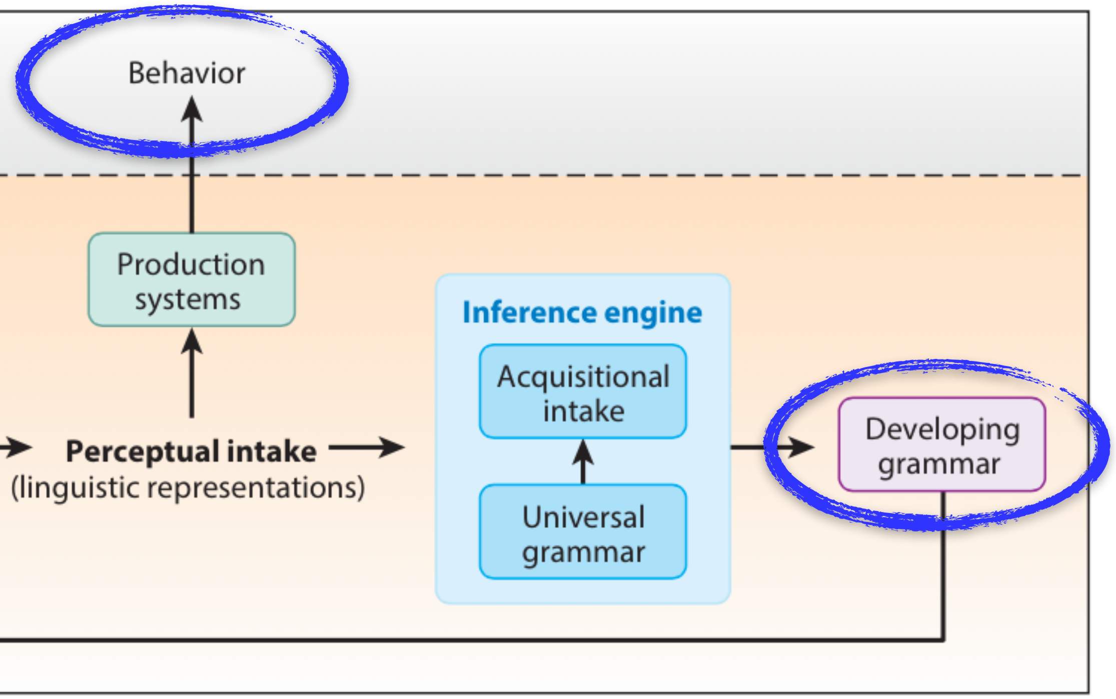
“I ___ to leave.”
doer (embedded)

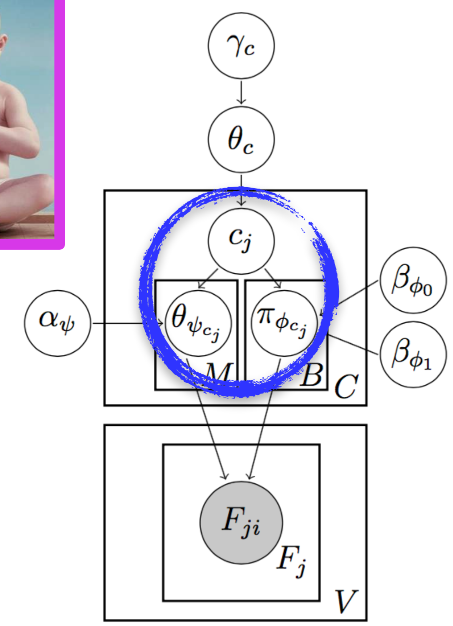
4yrs **5yrs**





+= seem





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

verb classes

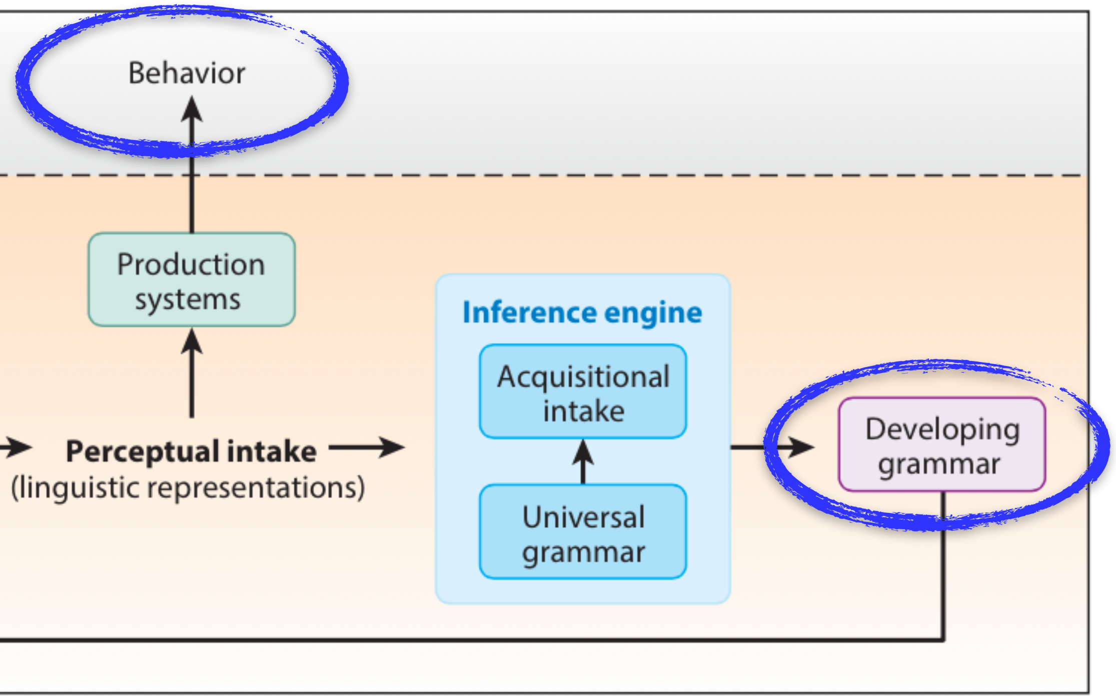
Survey of **32** experimental studies on children's production and comprehension of specific verbs

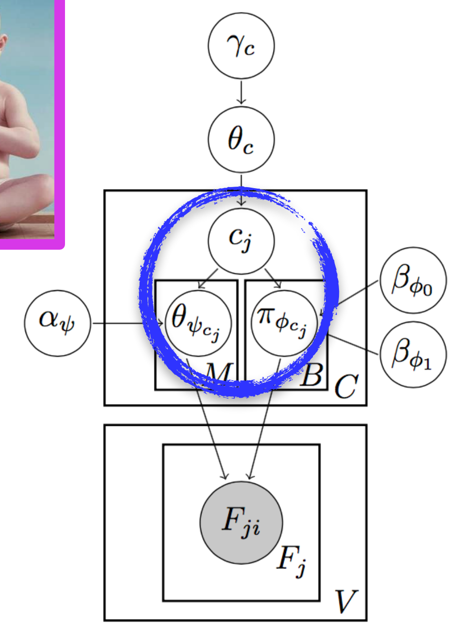
Subject-experiencer and Object-experiencer psych verbs: Hartshorne et al. 2015

Subject-experiencer

"Jack ___ Lily."

Experiencer





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs

verb classes

Survey of **32** experimental studies on children's production and comprehension of specific verbs

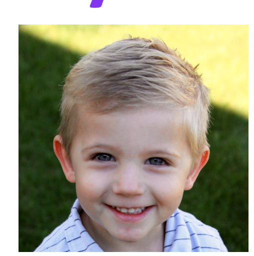
Subject-experiencer and Object-experiencer psych verbs: Hartshorne et al. 2015

Subject-experiencer

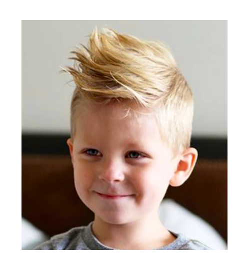
"Jack ____ Lily."

Experiencer

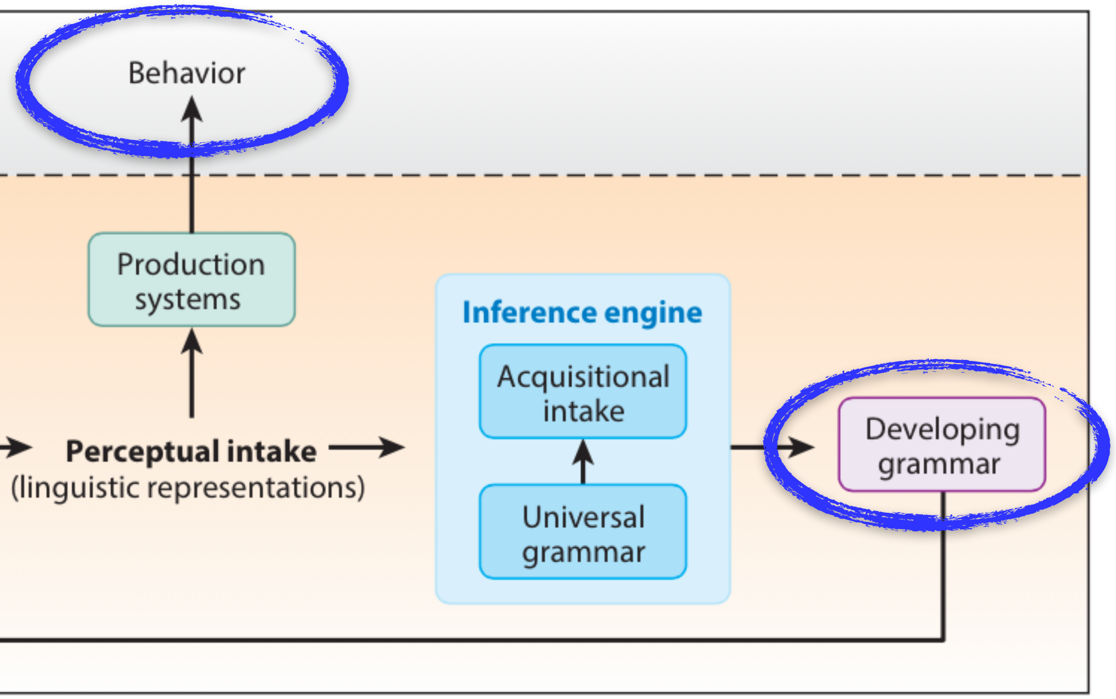
4yrs

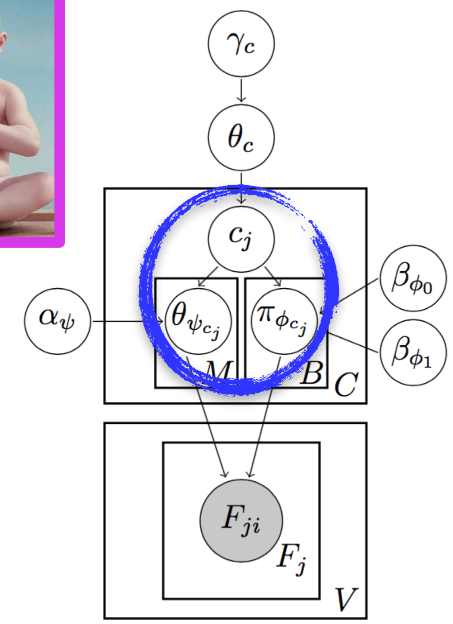


5yrs



+= like, love





Goal: Model the
developmental trajectory
from 3 to 4 to 5 years old

<3yrs

verb classes

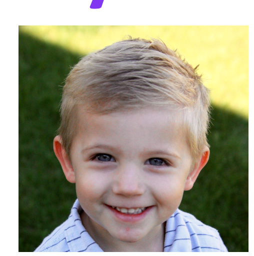
Survey of **32** experimental studies on children's production and comprehension of specific verbs

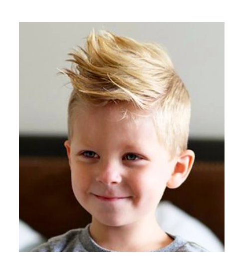
Subject-experiencer and Object-experiencer psych verbs: Hartshorne et al. 2015

Object-experiencer

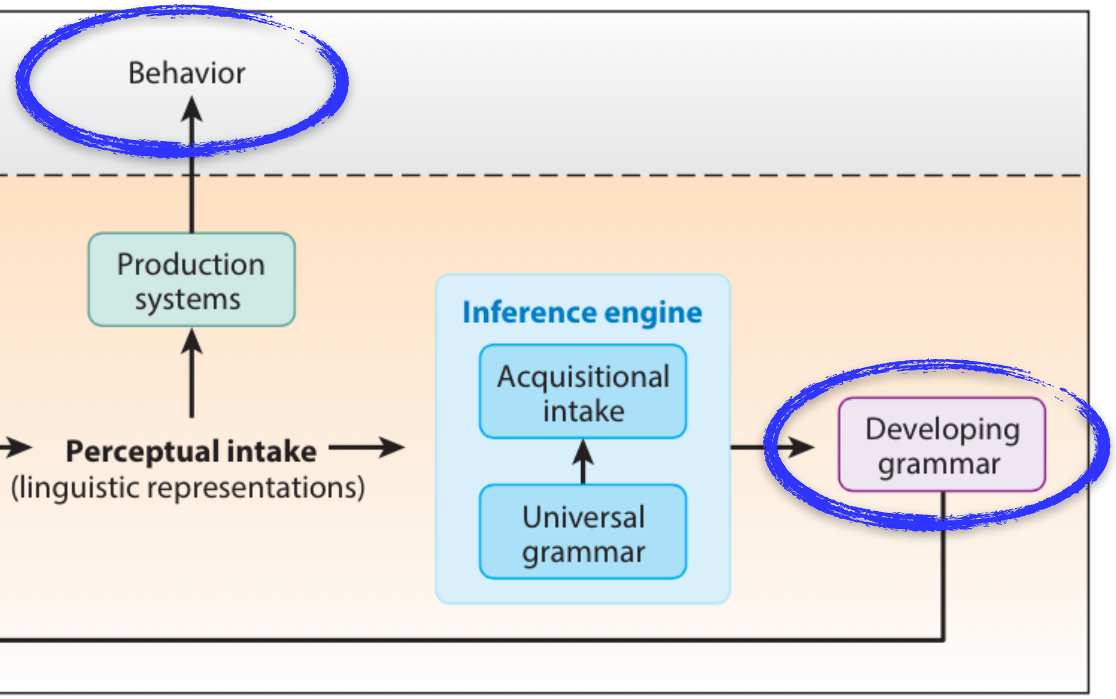
"Jack ____ Lily."
Experiencer

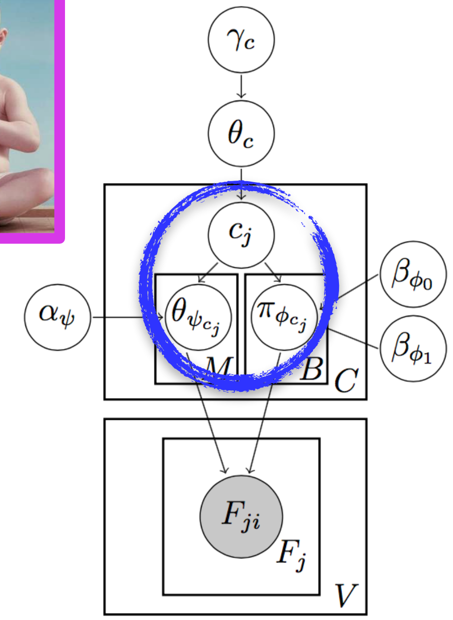
4yrs **5yrs**





+= frighten, scare, surprise





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**



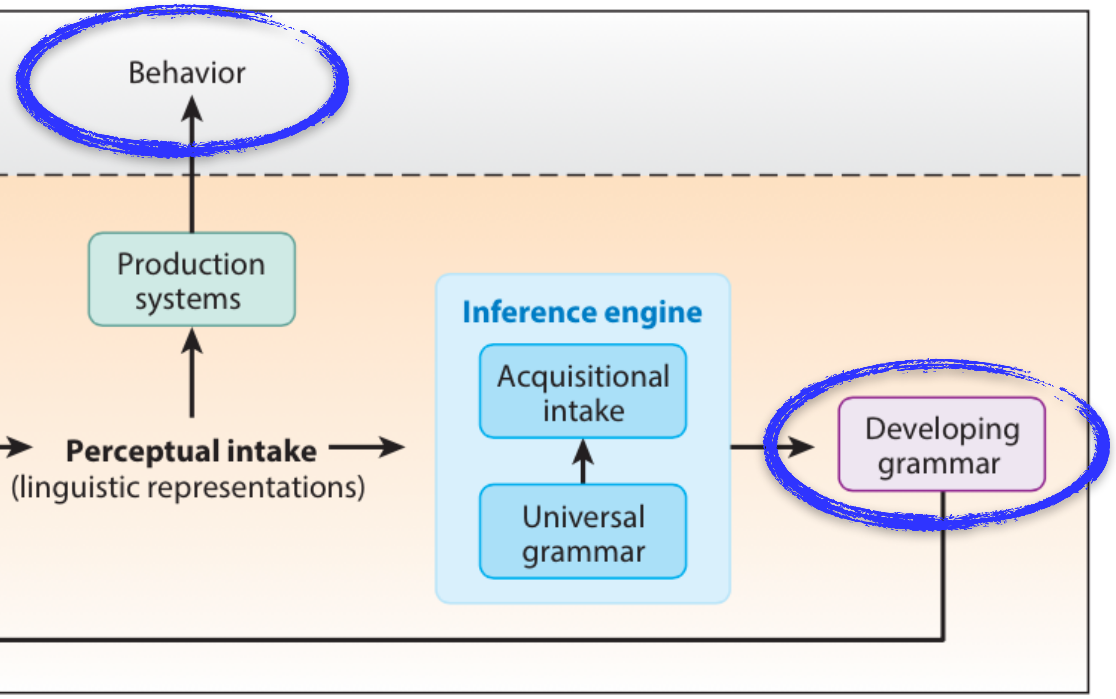
verb classes

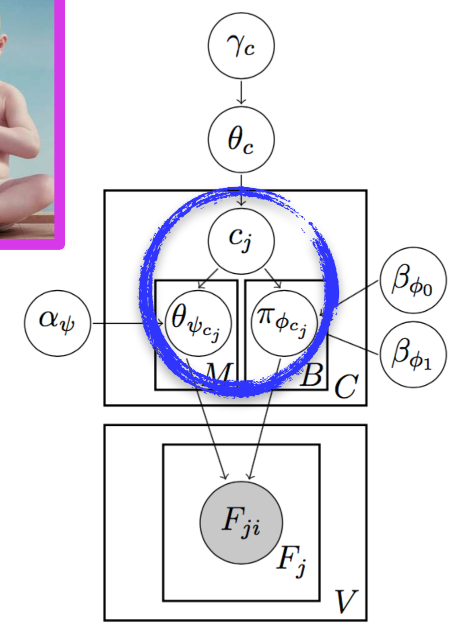
Survey of **32** experimental studies on children's production and comprehension of specific verbs

Complement-taking verbs [non-finite *to*, *that*, *whether/if*]: Bloom et al. 1984, Bloom et al. 1989, Diessel & Tomasello 2001, Papafragou et al. 2007, Kidd et al, 2006, Kidd et al. 2010

Non-finite to

"Jack ___ to go."





Goal: Model the
developmental trajectory
from 3 to 4 to 5 years old

<4yrs **<5yrs**

verb classes

Survey of **32** experimental studies on children's production and comprehension of specific verbs

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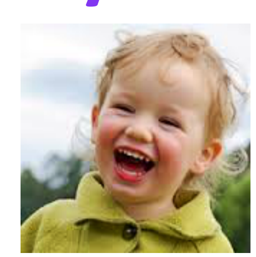
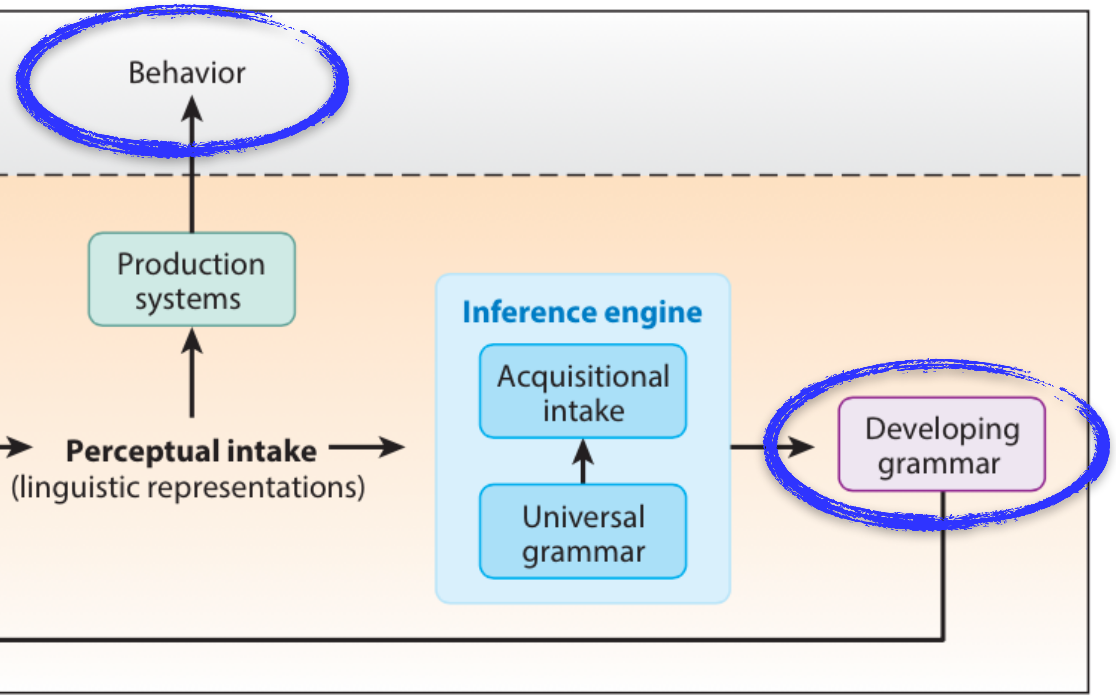
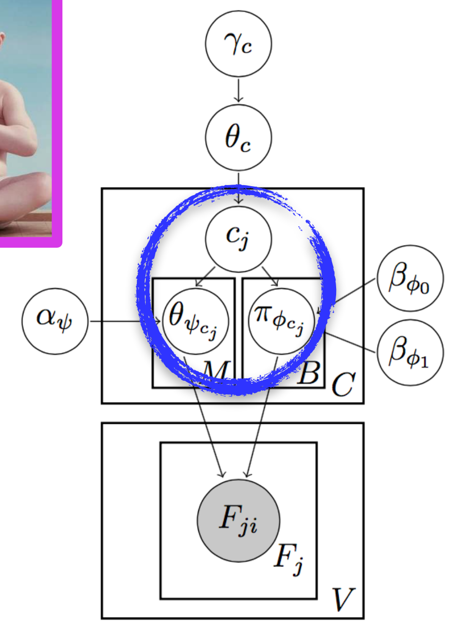
Non-finite to
"Jack ___ to go."

3yrs



+= get, start, suppose, …





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**



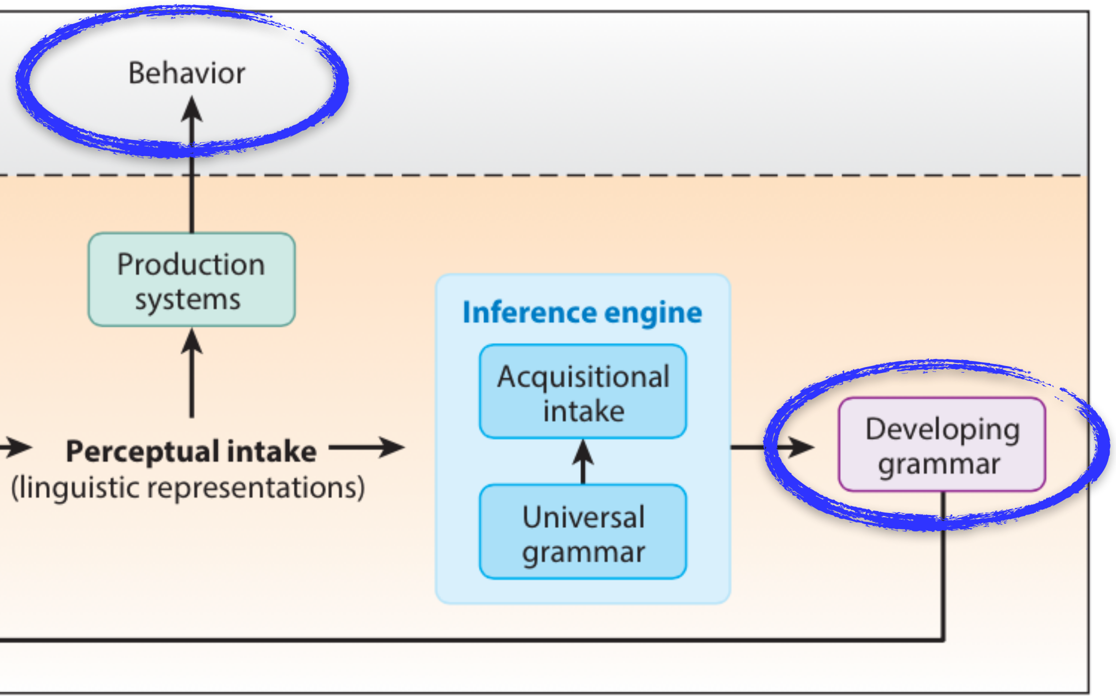
verb classes

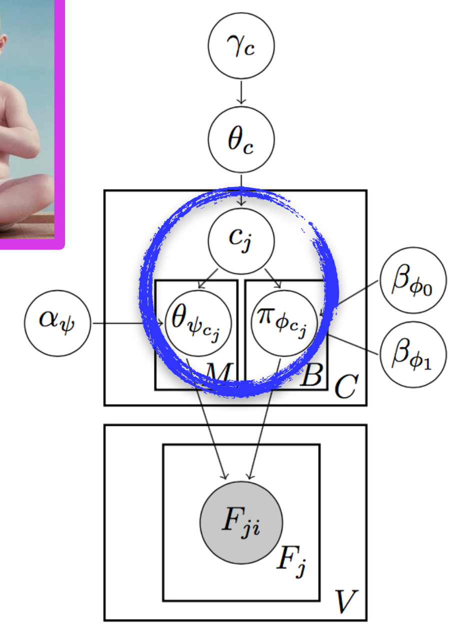
Survey of **32** experimental studies on children's production and comprehension of specific verbs

Complement-taking verbs [non-finite *to*, *that, whether/if*]: Bloom et al. 1984, Bloom et al. 1989, Diessel & Tomasello 2001, Papafragou et al. 2007, Kidd et al, 2006, Kidd et al. 2010

that

"Jack ___ that he can go."





Goal: Model the
developmental trajectory
from 3 to 4 to 5 years old

<4yrs **<5yrs**

verb classes

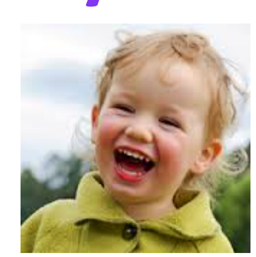
Survey of **32** experimental studies on children's production and comprehension of specific verbs

Complement-taking verbs [non-finite *to*, *that*, *whether/if*]: Bloom et al. 1984, Bloom et al. 1989, Diessel & Tomasello 2001, Papafragou et al. 2007, Kidd et al, 2006, Kidd et al. 2010

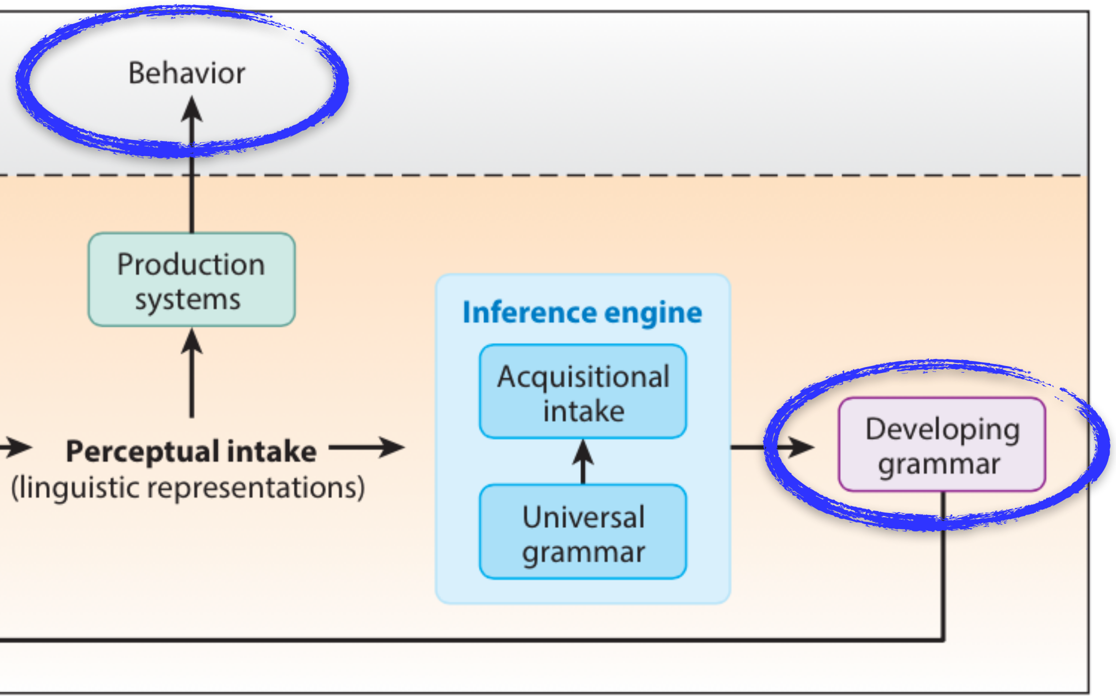
that

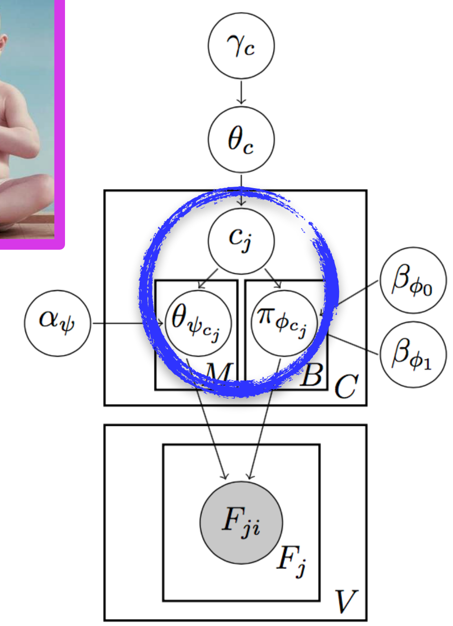
"Jack ___ that he can go."

3yrs



+= hope, know, say, …





Goal: Model the
developmental trajectory
from 3 to 4 to 5 years old

<3yrs **<4yrs**

verb classes

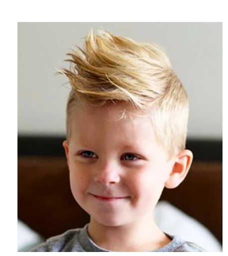
Survey of **32** experimental studies on children's production and comprehension of specific verbs

Complement-taking verbs [non-finite *to*, *that*, *whether/if*]: Bloom et al. 1984, Bloom et al. 1989, Diessel & Tomasello 2001, Papafragou et al. 2007, Kidd et al, 2006, Kidd et al. 2010

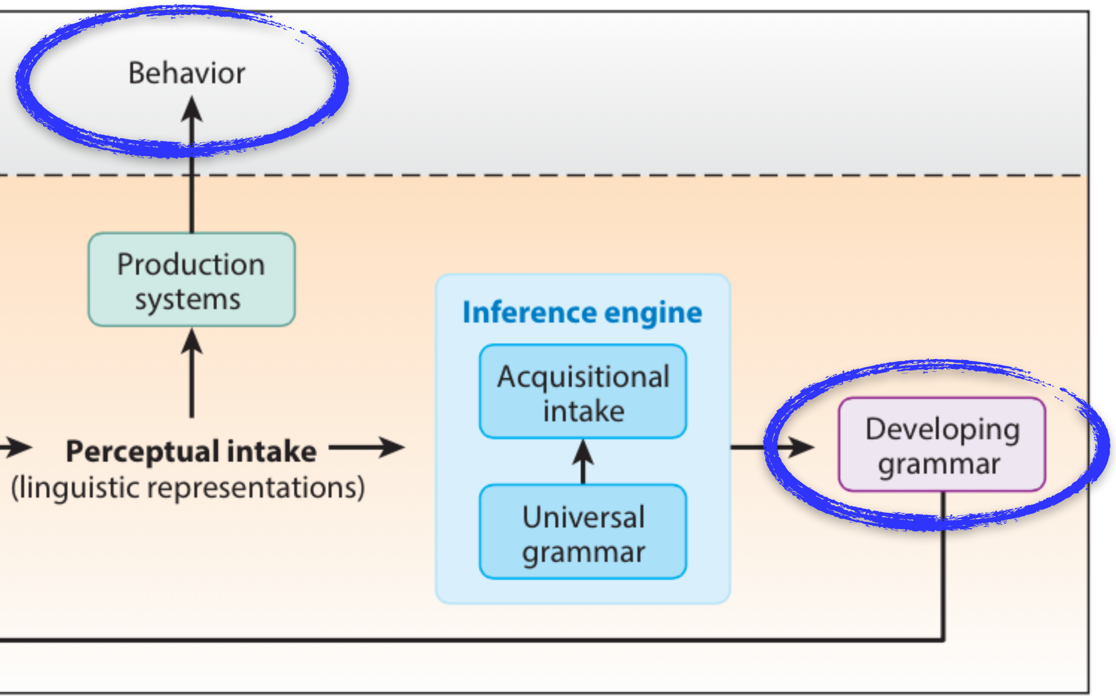
that

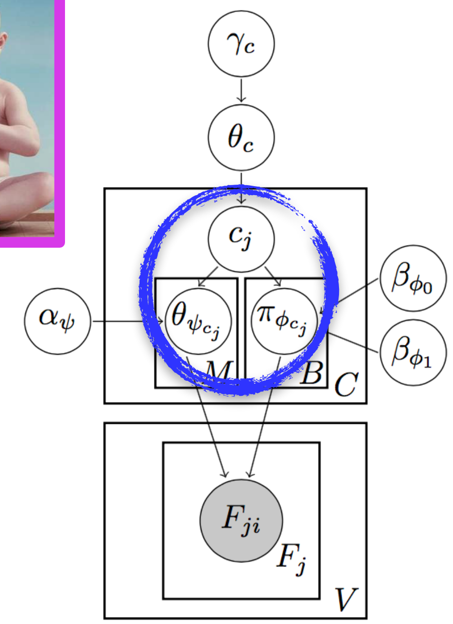
"Jack ___ that he can go."

5yrs



+= guess, hope, know, pretend, say, …





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**



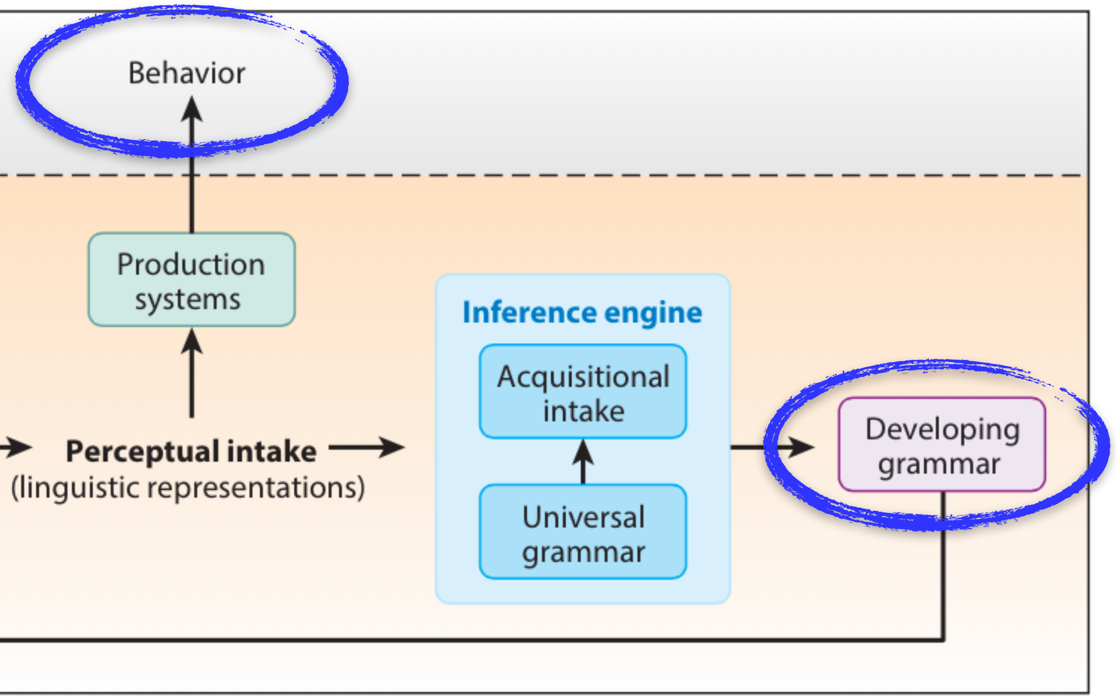
verb classes

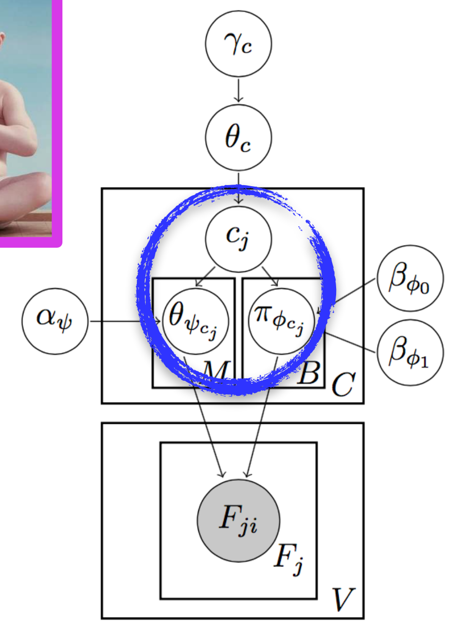
Survey of **32** experimental studies on children's production and comprehension of specific verbs

Complement-taking verbs [non-finite *to*, *that*, *whether/if*]: Bloom et al. 1984, Bloom et al. 1989, Diessel & Tomasello 2001, Papafragou et al. 2007, Kidd et al, 2006, Kidd et al. 2010

whether/if

"Jack ___ whether/if he can go."





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs**

verb classes

Survey of **32** experimental studies on children's production and comprehension of specific verbs

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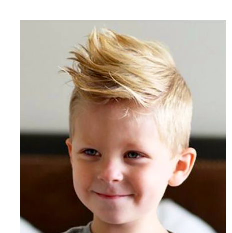
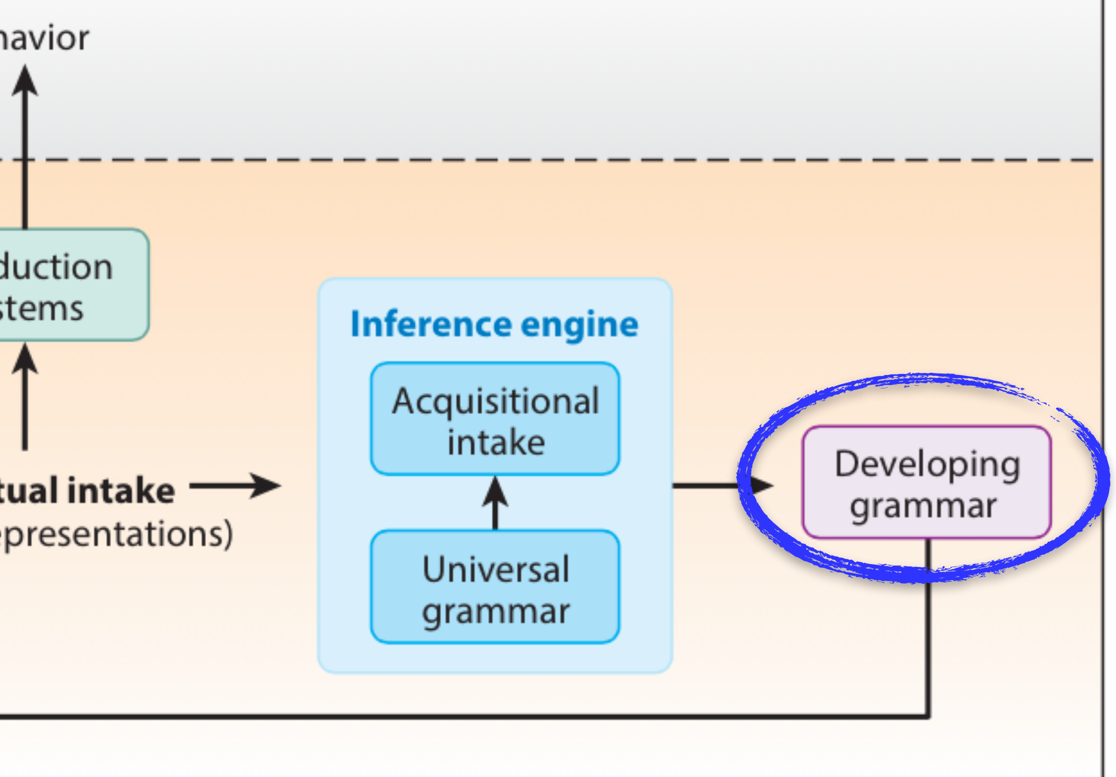
whether/if

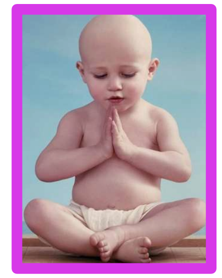
"Jack ___ whether/if he can go."

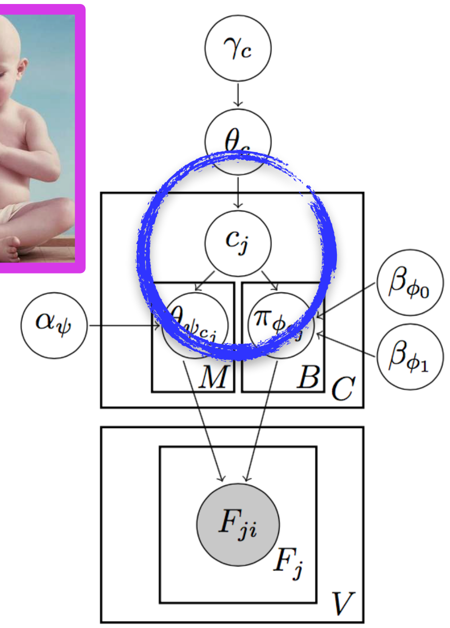
5yrs



+= ask, care, know, see, …







1% <= RI <= 99% CI

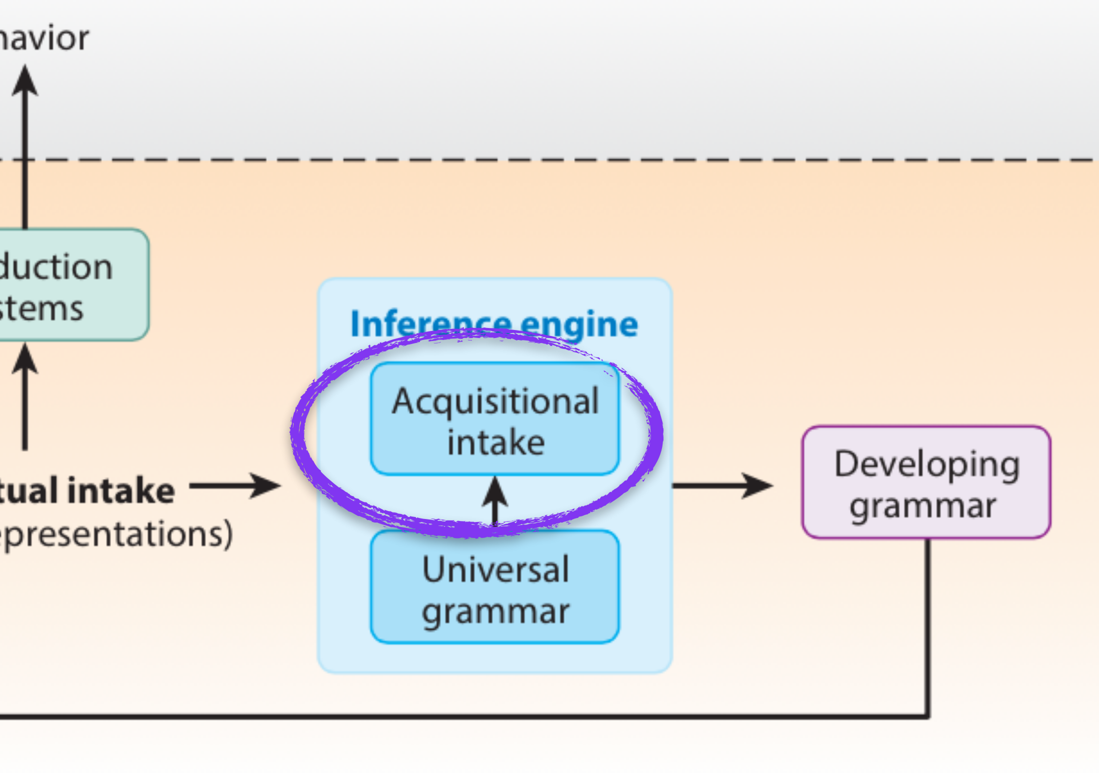
-1.0 <= ARI <= 1.0

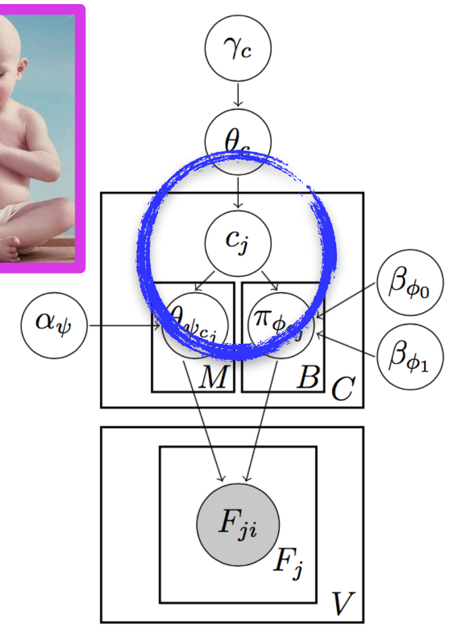
Goal: Model the
developmental trajectory
from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

15 classes **23 classes** **24 classes**





1% <= RI <= 99% CI

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Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

15 classes **23 classes** **24 classes**

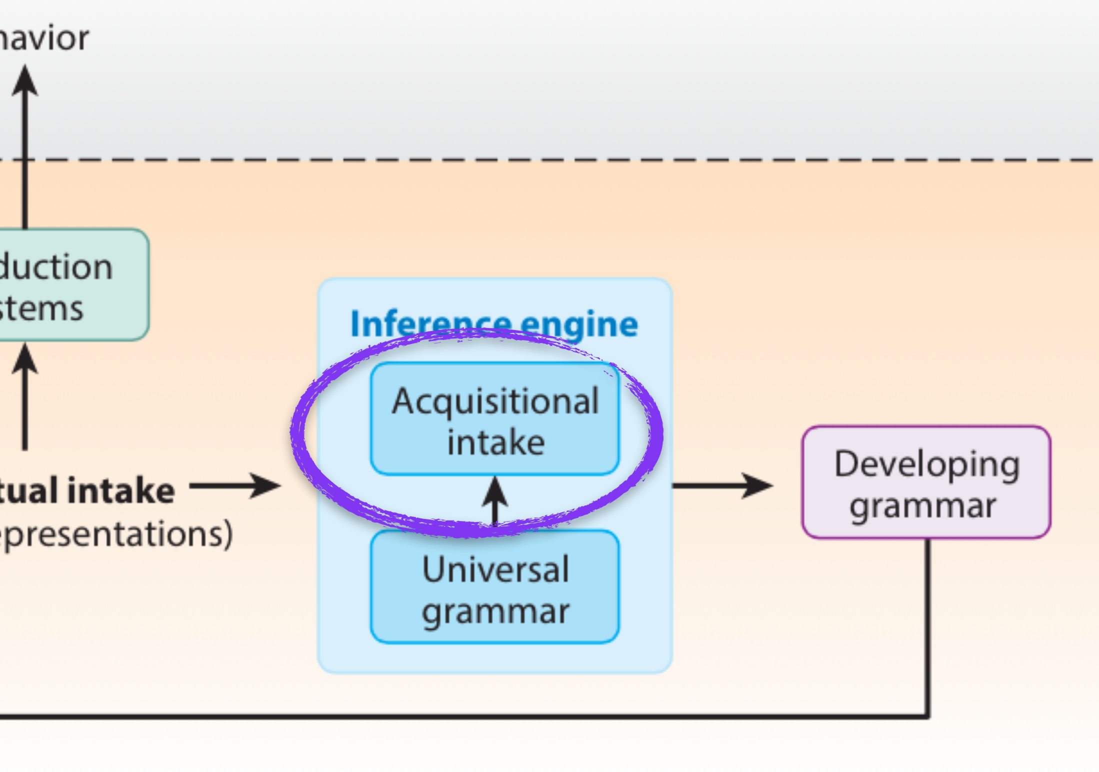
Animacy

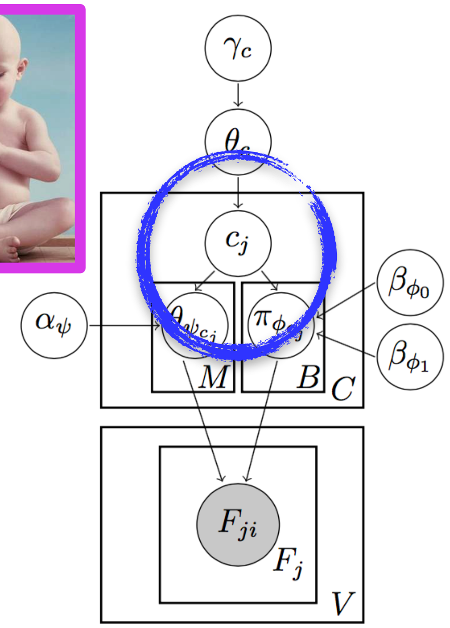
+animate

The penguin tried to climb.

-animate

The ice seemed to melt.





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-1.0 <= ARI <= 1.0

Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

15 classes **23 classes** **24 classes**

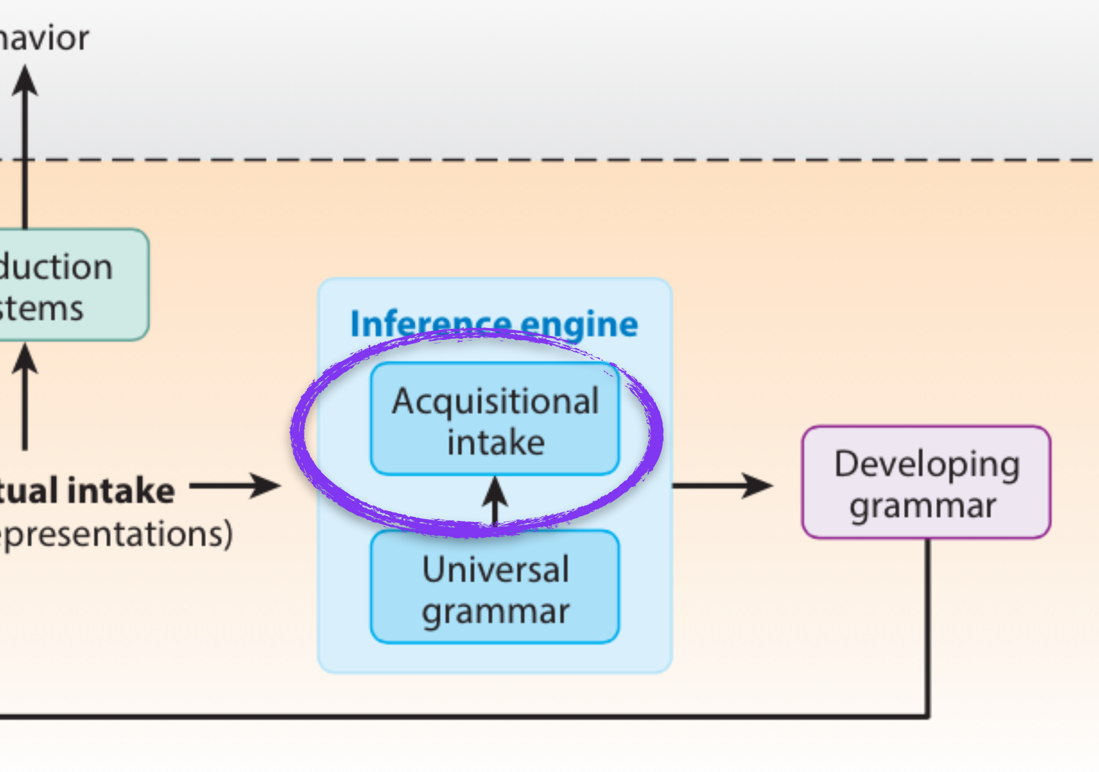
Animacy

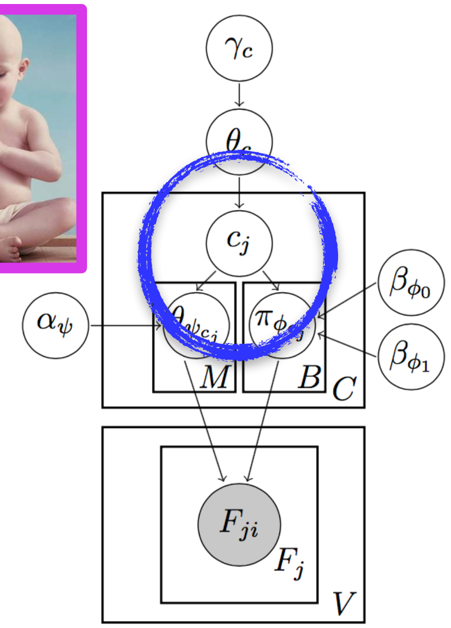
Syntactic frame

The ice seemed to melt.

NP ___ $S_{nonfinite}$ -surfmorph

NP ___$_{+past}$ $S_{nonfinite}$ +surfmorph





Goal: Model the developmental trajectory from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**

15 classes **23 classes** **24 classes**

1% <= RI <= 99% CI

-1.0 <= ARI <= 1.0

Animacy

Syntactic frame

+surfmorph -surfmorph

Thematic roles and how to use them

UTAH

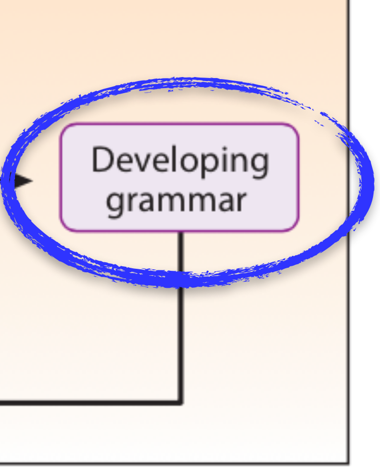
rUTAH

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

-expmap *Subject* *Object* *Indirect Object*

+expmap *Subject* *Object* *Indirect Object*

movement?



Animacy

Syntactic frame

1% <= RI <= 99% CI

-1.0 <= ARI <= 1.0

<4yrs

23 classes

<5yrs

24 classes

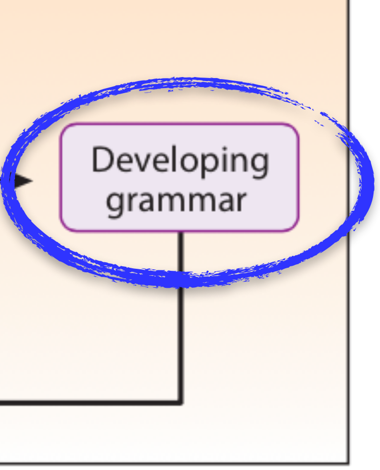
+surfmorph | -surfmorph

Thematic roles and how to use them

UTAH		rUTAH		UTAH		rUTAH	
+expmap	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*

3yrs

15 classes



1% <= RI <= 99% CI

-1.0 <= ARI <= 1.0

<4yrs

23 classes

<5yrs

24 classes

Animacy

Syntactic frame

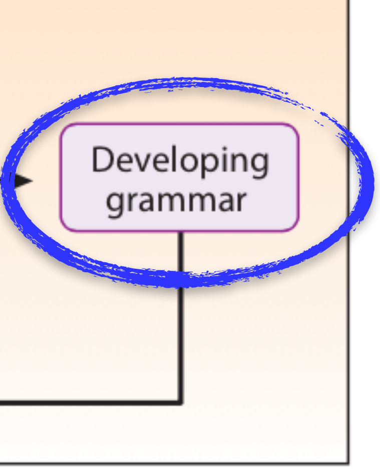
Thematic roles and how to use them

	+surfmorph				-surfmorph			
	UTAH		rUTAH		UTAH		rUTAH	
	+expmap	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*
RI	0.567	0.650	0.544	0.615	0.673	0.698	0.766	0.749
ARI	*0.053*	*0.063*	*0.050*	*0.144*	***0.213***	***0.238***	***0.221***	***0.193***

3yrs

15 classes

Two learning strategies are doing significantly better than chance based on both metrics.



<5yrs

24 classes

1% <= RI <= 99% CI

-1.0 <= ARI <= 1.0

Animacy

Syntactic frame

+surfmorph

-surfmorph

Thematic roles and how to use them

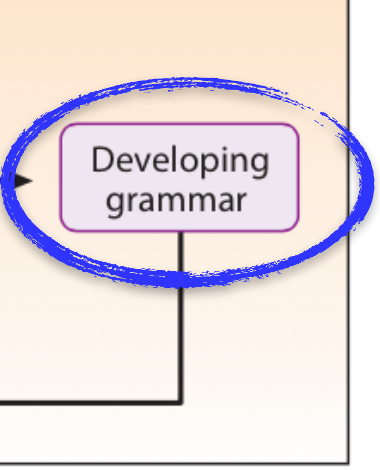
UTAH		rUTAH		UTAH		rUTAH	
+expmap	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*

3yrs

15 classes

<4yrs

23 classes



<5yrs

24 classes

1% <= RI <= 99% CI

-1.0 <= ARI <= 1.0

Animacy

Syntactic frame

Thematic roles and how to use them

	+surfmorph				-surfmorph			
	UTAH		rUTAH		UTAH		rUTAH	
	+expmap	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*
RI	0.639	0.758	0.670	0.504	0.773	0.756	0.716	0.743
ARI	*0.143*	***0.261***	*0.080*	*0.103*	*0.102*	*0.091*	*0.090*	*0.120*

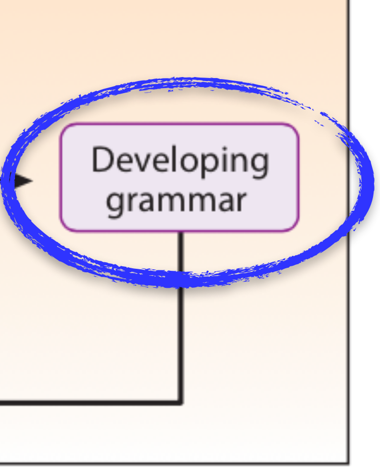
3yrs

15 classes

4yrs

23 classes

One strategy (a different one) is doing significantly better than chance.



1% <= RI <= 99% CI

-1.0 <= ARI <= 1.0

Animacy

Syntactic frame

+surfmorph -surfmorph

Thematic roles and how to use them

UTAH		rUTAH		UTAH		rUTAH	
+expmap	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*

3yrs

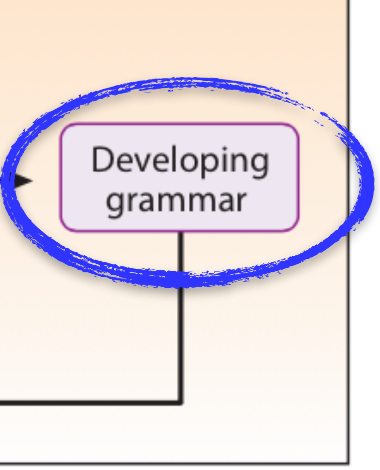
15 classes

4yrs

23 classes

<5yrs

24 classes



☹️ 😐 🙂

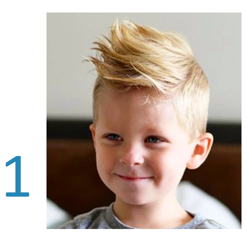
1% <= RI <= 99% CI

-1.0 <= ARI <= 1.0

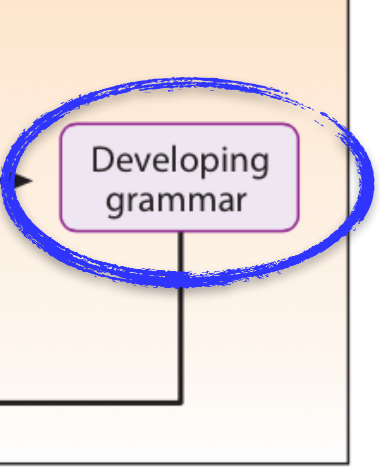
Animacy

Syntactic frame

Thematic roles and how to use them

	+surfmorph UTAH +expmap	+surfmorph UTAH -expmap	+surfmorph rUTAH +expmap	+surfmorph rUTAH -expmap	-surfmorph UTAH +expmap	-surfmorph UTAH -expmap	-surfmorph rUTAH +expmap	-surfmorph rUTAH -expmap	
	😐	😐	😐	😐	😐	😐	🙂	🙂	 **3yrs** **15 classes**
	😐	🙂	😐	😐	😐	😐	😐	😐	 **4yrs** **23 classes**
	🙂	😐	🙂	😐	🙂	😐	😐	🙂	 **5yrs** **24 classes**
RI	0.751	0.703	0.754	0.682	0.803	0.758	0.765	0.781	
ARI	*0.256*	*0.087*	*0.279*	*0.096*	*0.120*	*0.114*	*0.113*	*0.149*	

Several learning strategies are doing better than chance…



1% <= RI <= 99% CI

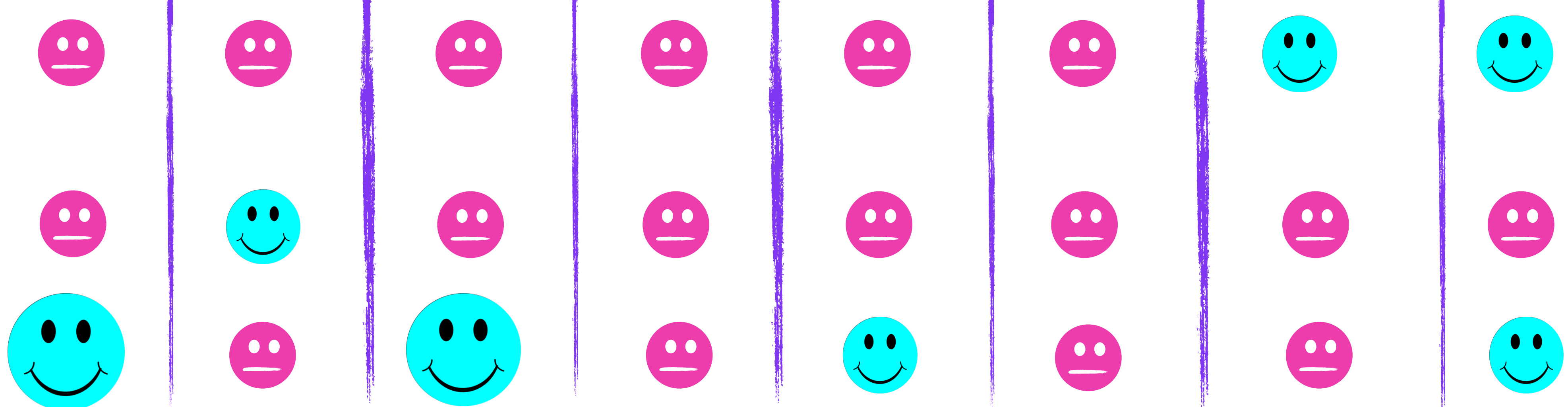
-1.0 <= ARI <= 1.0

Animacy

Syntactic frame

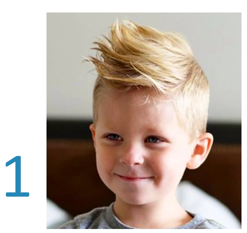
	+surfmorph				-surfmorph			
	UTAH		rUTAH		UTAH		rUTAH	
	+expmap	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*
RI	0.751	0.703	0.754	0.682	0.803	0.758	0.765	0.781
ARI	***0.256***	*0.087*	***0.279***	*0.096*	*0.120*	*0.114*	*0.113*	*0.149*

Thematic roles and how to use them



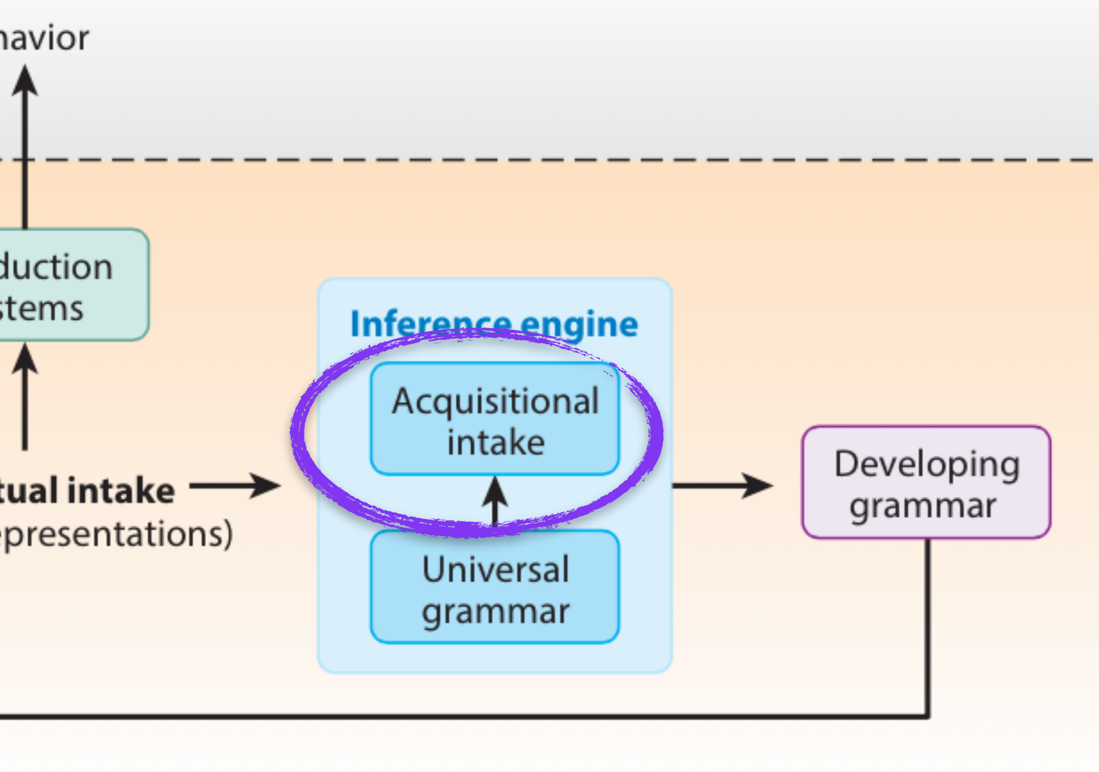
3yrs
15 classes

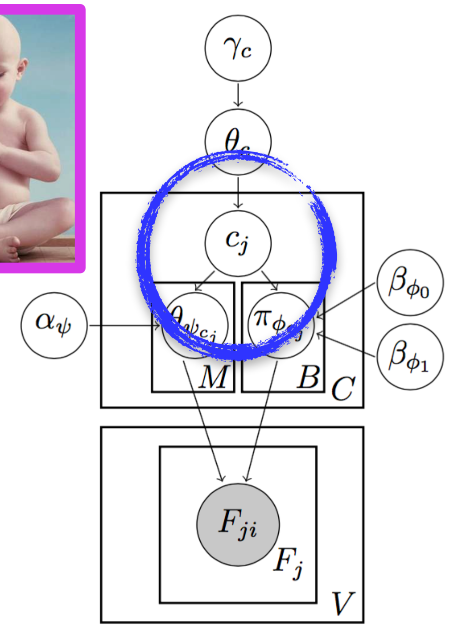
4yrs
23 classes



5yrs
24 classes

…but two have ARIs that seem much higher than the rest, and on par with the ARIs of previous strategies with significantly higher performance (ARI > 0.20).





1% <= RI <= 99% CI

-1.0 <= ARI <= 1.0

Goal: Model the **developmental trajectory** from 3 to 4 to 5 years old

<3yrs **<4yrs** **<5yrs**



15 classes **23 classes** **24 classes**

Animacy

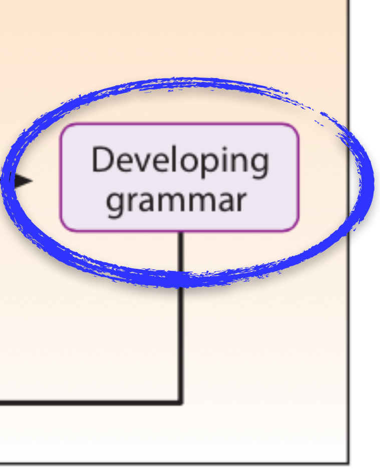
Syntactic frame

+surfmorph -surfmorph

Thematic roles and how to use them

UTAH rUTAH UTAH rUTAH

+expmap *-expmap* *+expmap* *-expmap* *+expmap* *-expmap* *+expmap* *-expmap*



Animacy

Syntactic frame

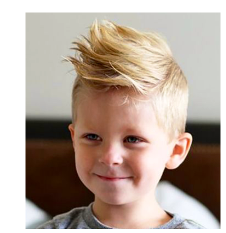
+surfmorph | -surfmorph

Thematic roles and how to use them

UTAH		rUTAH		UTAH		rUTAH	
+expmap	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*

3yrs
15 classes

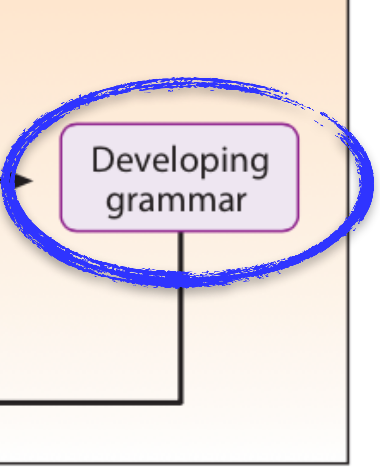
4yrs
23 classes



5yrs
24 classes

Focus on strategies with performance significantly above chance

What does this mean?



Animacy

Syntactic frame

+surfmorph

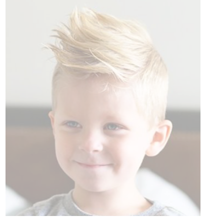
-surfmorph

Thematic roles and how to use them

UTAH		rUTAH		UTAH		rUTAH	
+expmap	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*

4yrs

23 classes



5yrs

24 classes

3yrs

rUTAH

Agent > **Experiencer** >

Theme > **Patient** >

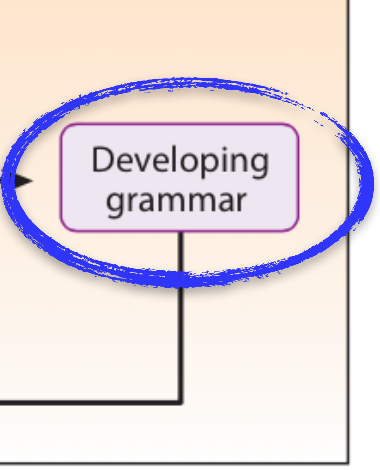
(**Source, Goal, Instrument**)

Syntactic frame

The ice seemed to melt.

NP ___ $S_{nonfinite}$ -surfmorph

Before 3, children ignore verb morphology and seem to be using relative information about thematic roles.



Animacy

Syntactic frame

+surfmorph

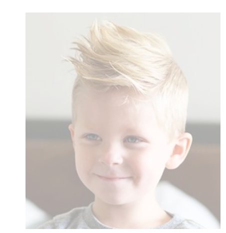
-surfmorph

Thematic roles and how to use them

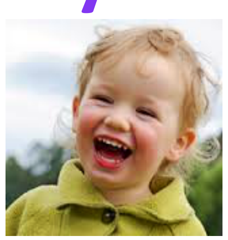
UTAH		rUTAH		UTAH		rUTAH	
+expmap	***-expmap***	*+expmap*	*-expmap*	*+expmap*	*-expmap*	*+expmap*	*-expmap*

5yrs

24 classes



3yrs



-surfmorph

rUTAH

4yrs

By 4, children heed verb morphology, are using the UTAH intermediate representation, and don't expect a mapping a priori.

Syntactic frame

+surfmorph

NP ____$_{\textbf{+past}}$ S$_{\text{nonfinite}}$

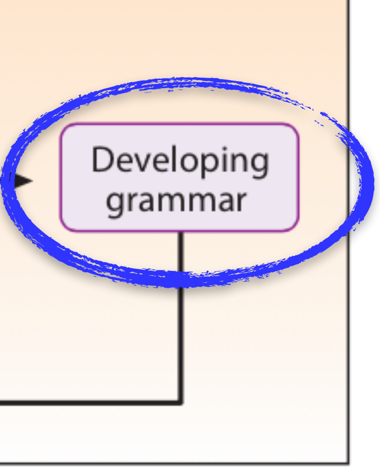
Thematic roles

and how to use them

UTAH

-expmap

Subject ***Object*** ***Indirect Object***



Animacy

Syntactic frame

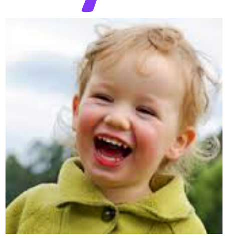
+surfmorph -surfmorph

Thematic roles and how to use them

UTAH **rUTAH** UTAH rUTAH

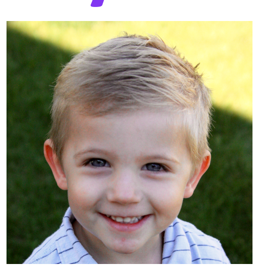
+expmap *-expmap* ***+expmap*** *-expmap* *+expmap* *-expmap* *+expmap* *-expmap*

3yrs



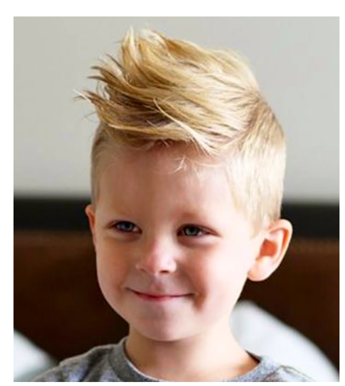
-surfmorph
rUTAH

4yrs



+surfmorph
UTAH
-expmap

5yrs



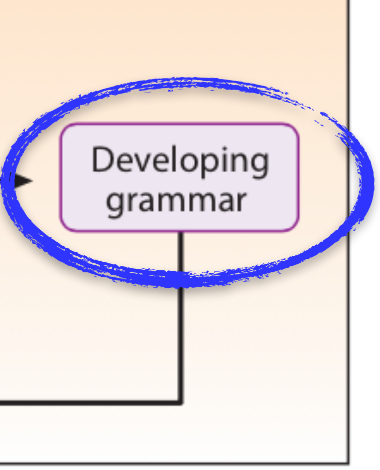
By 5, children still heed verb morphology, but now may be using either the UTAH or rUTAH representation and expect a mapping.

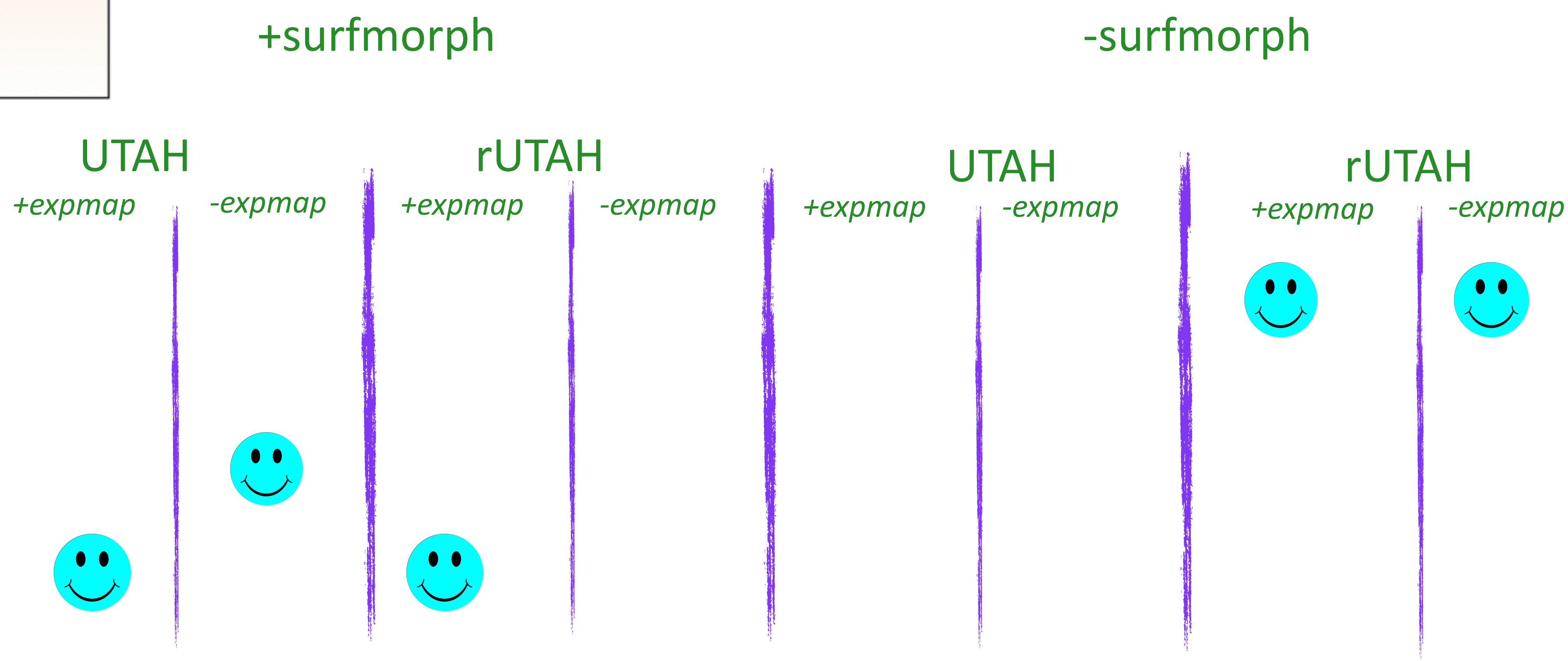
UTAH

rUTAH **Agent > Experiencer > Theme > Patient > (Source, Goal, Instrument)** +expmap

Subject ***Object*** ***Indirect Object***

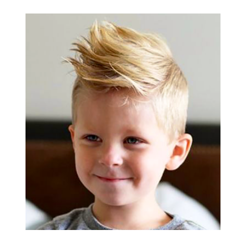
movement?





3yrs
15 classes

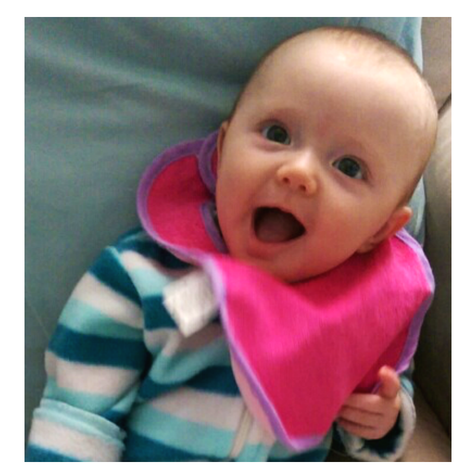
4yrs
23 classes

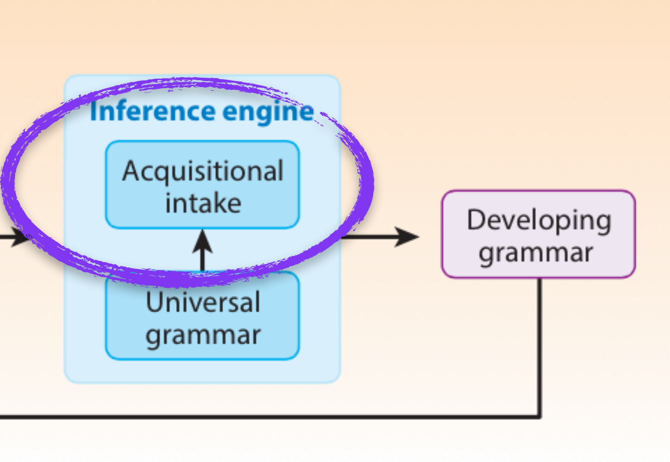


5yrs
24 classes

Animacy
Syntactic frame
Thematic roles and how to use them

Using animacy, syntactic frame, and thematic role information can be a pretty good match for what children seem to be doing when creating verb classes.





-animate
Subject

The ice seemed to melt.

NP ____ $S_{nonfinite}$

Highest

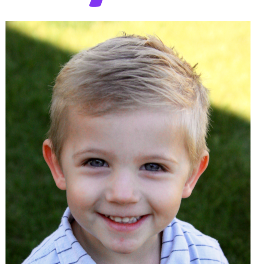
Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

Subject *Object* *Indirect Object*

3yrs

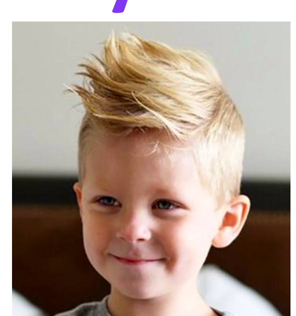
-surfmorph
rUTAH

4yrs

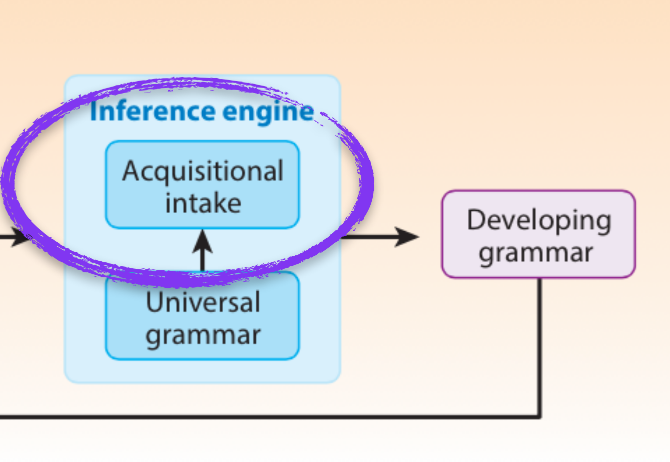


+surfmorph
UTAH
-expmap

5yrs



+surfmorph
UTAH rUTAH
+expmap



-animate
Subject

The ice seemed to melt.

NP ____ $_{\text{+past}}$ S$_{\text{nonfinite}}$

Subject *Object* *Indirect Object*

3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

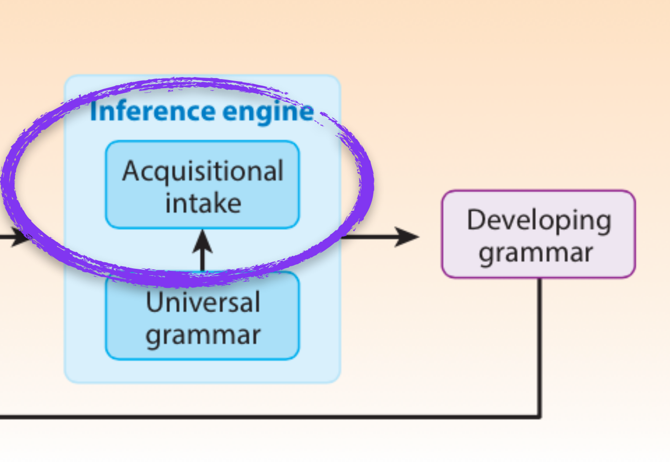
-expmap

5yrs

+surfmorph

UTAH rUTAH

+expmap



-animate
Subject

The ice seemed to melt.

NP ____**+past** S$_{nonfinite}$

+movement

Highest *-movement*

Theme

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

3yrs

-surfmorph
rUTAH

4yrs

+surfmorph
UTAH
-expmap

5yrs

+surfmorph
UTAH rUTAH
+expmap

3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

5yrs

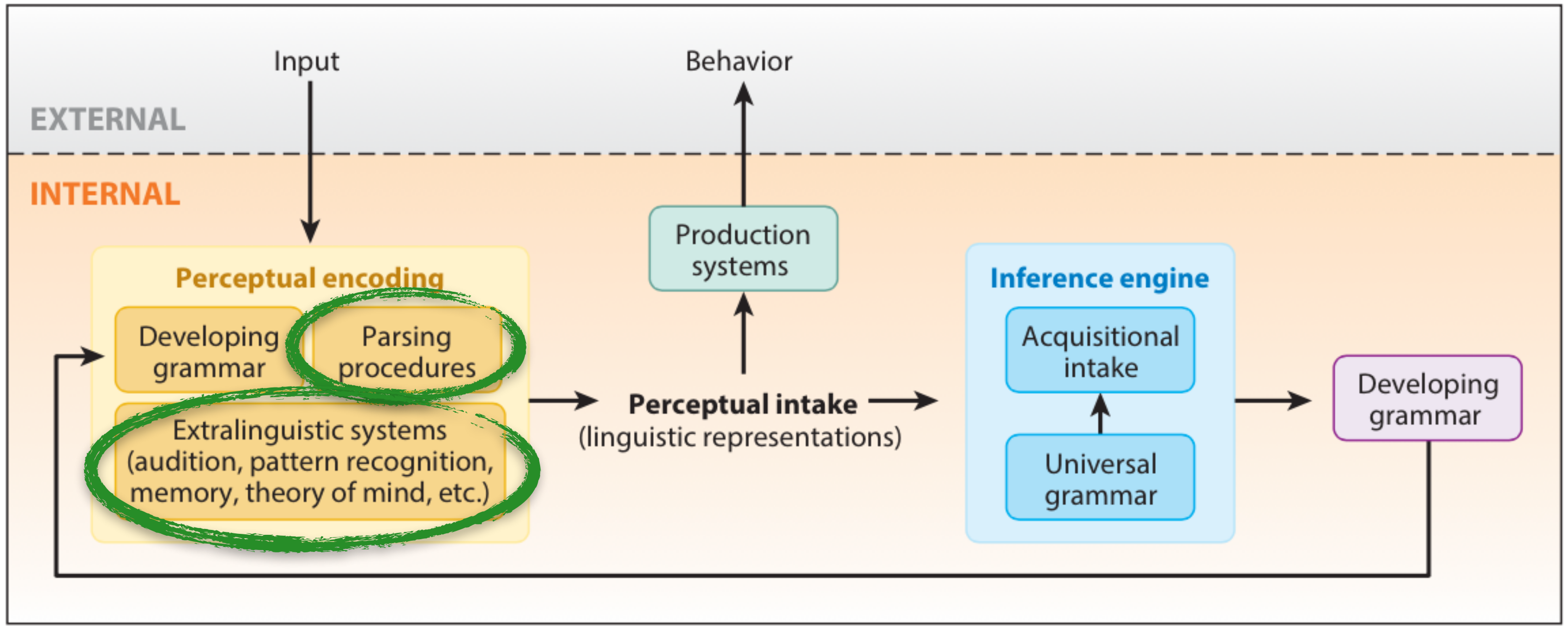
+surfmorph

UTAH rUTAH

+expmap

What seems to develop earlier
(perhaps because it's easy to derive from existing biases):

-surfmorph: Preference to ignore surface morphology
(perhaps due to processing limitations)



3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

5yrs

+surfmorph

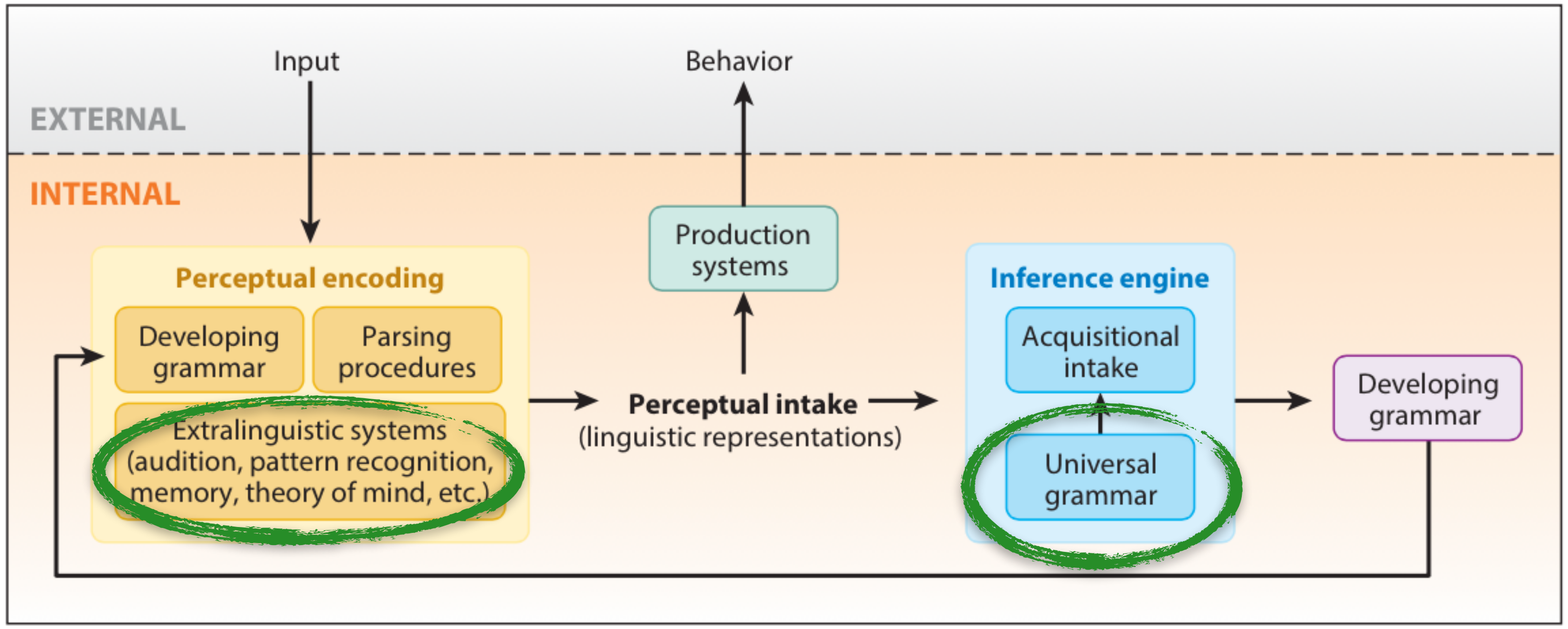
UTAH rUTAH

+expmap

What seems to be available earlier (perhaps because it doesn't involve abstracting over conceptual information):

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

rUTAH: More detailed thematic representation



3yrs **4yrs** **5yrs**

-surfmorph

rUTAH

+surfmorph

UTAH

-expmap

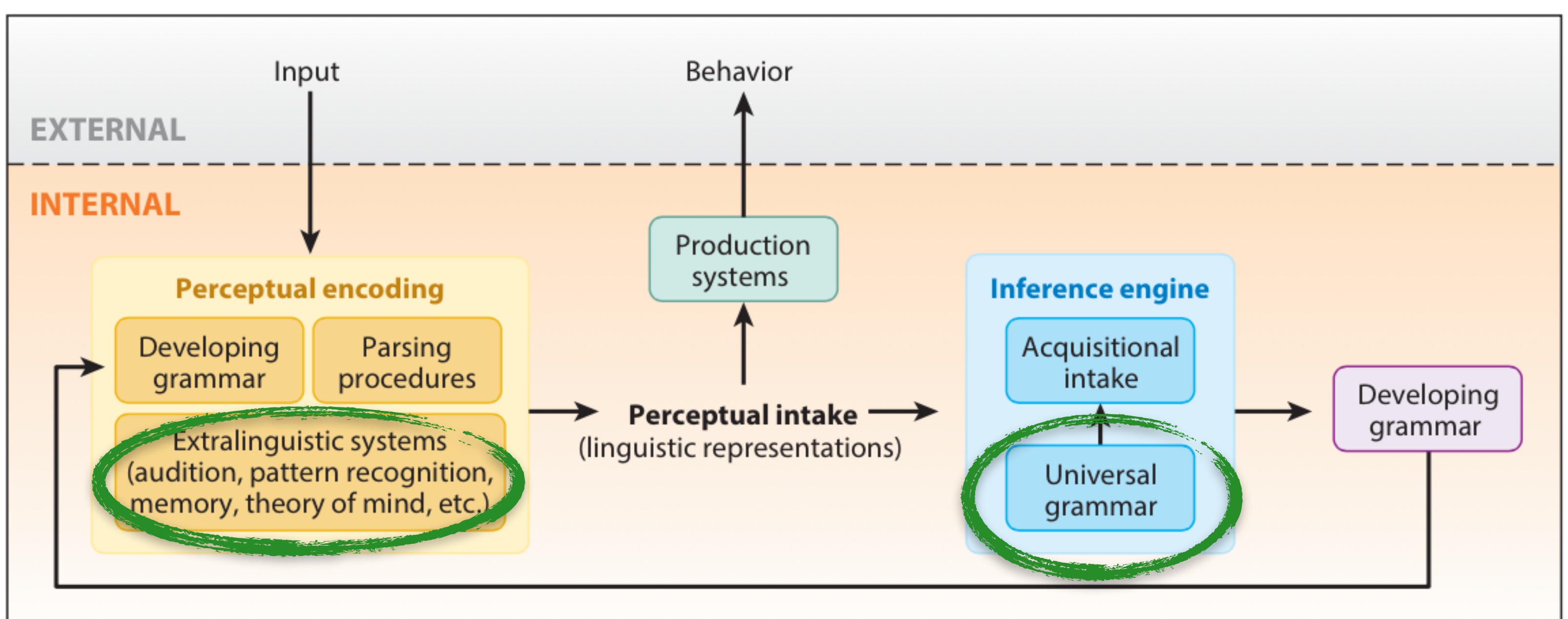
+surfmorph

UTAH rUTAH

+expmap

What seems to develop somewhat earlier (perhaps because it's easy to derive from existing biases):

UTAH: More abstract, categorical thematic representation



3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

5yrs

+surfmorph

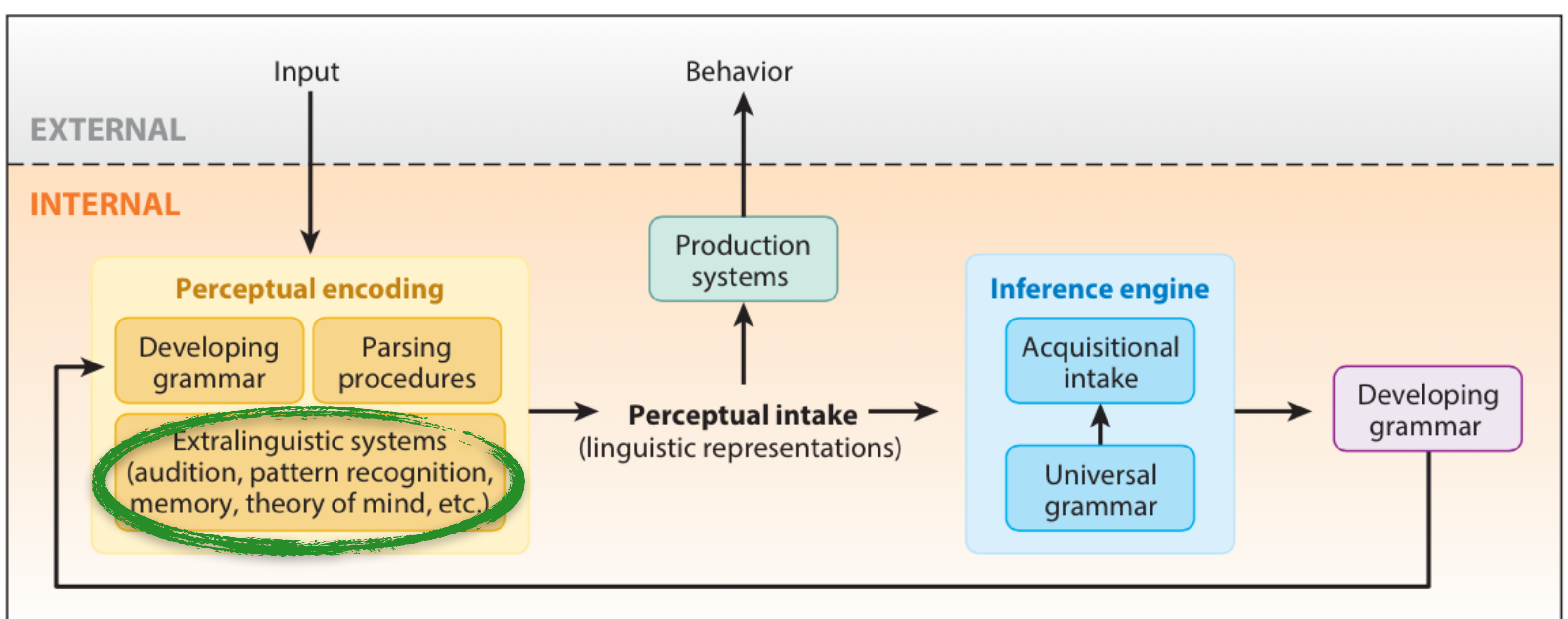
UTAH rUTAH

+expmap

Subject *Object* *Indirect Object*

What seems to develop somewhat earlier (perhaps because it's easy to derive from existing biases):

-expmap: No prior expectation about how to map — learn this from the intake



3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

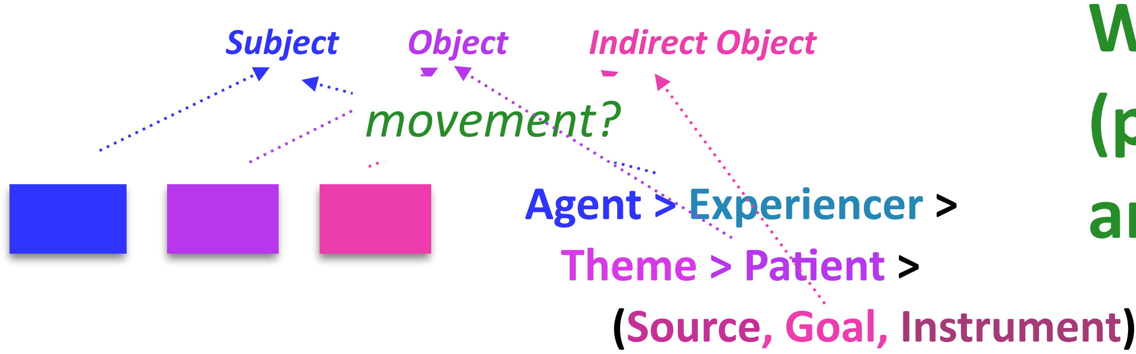
-expmap

5yrs

+surfmorph

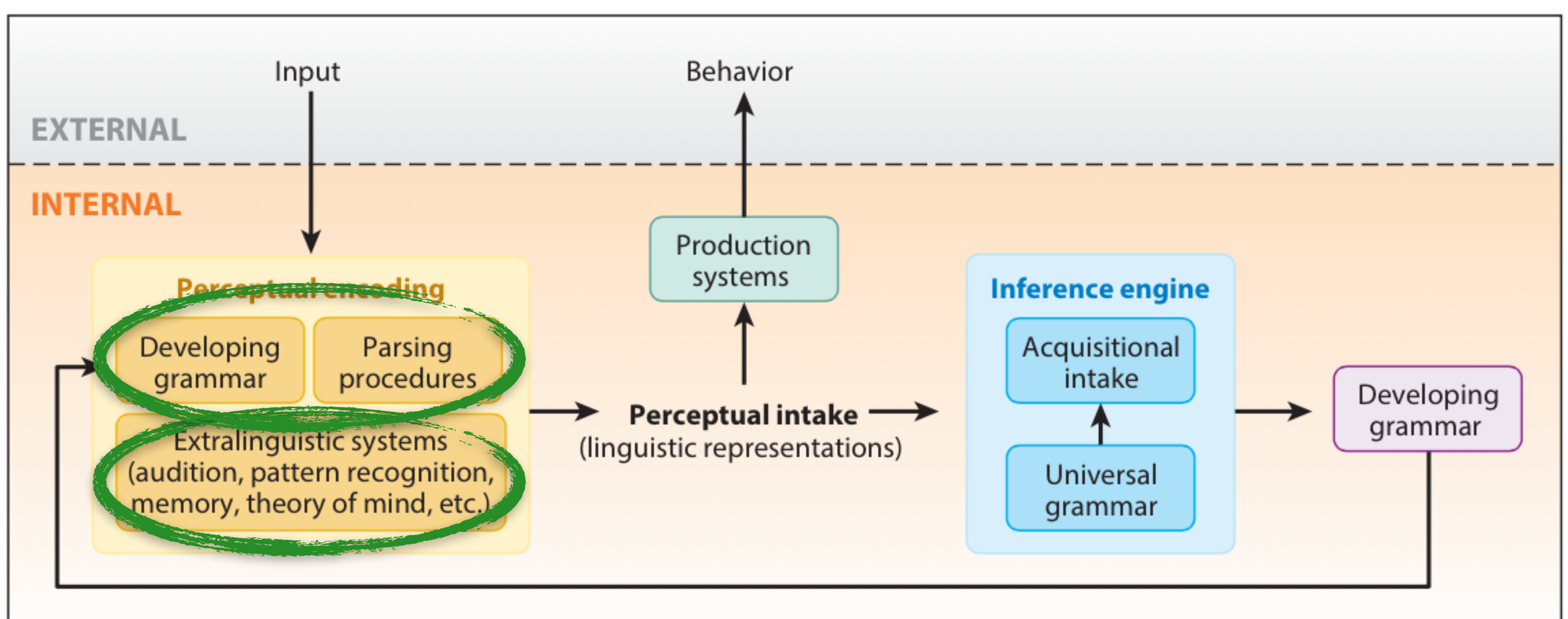
UTAH **rUTAH**

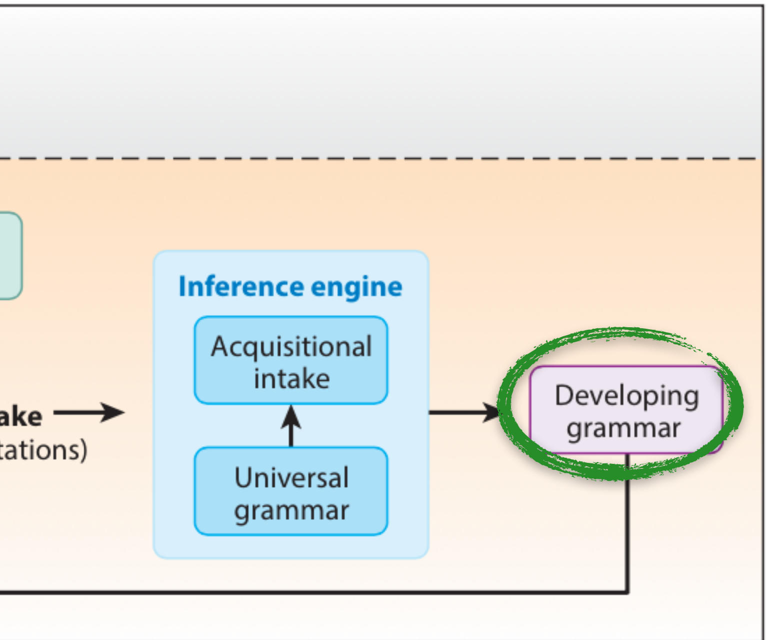
+expmap



What seems to develop later (perhaps building on prior knowledge and the intake):

rUTAH, +expmap: more detailed thematic representation coupled with expectation of mapping





3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

5yrs

+surfmorph

UTAH rUTAH

+expmap

Bigger theoretical takeaway:

Everyone's right about the representation at some stage of development.

+animate

-surfmorph

NP ____ $S_{nonfinite}$

+surfmorph

NP ____$_{\mathbf{+past}}$ $S_{nonfinite}$

UTAH

rUTAH **Agent > Experiencer >**
Theme > Patient >
(Source, Goal, Instrument)

-expmap ***Subject*** ***Object*** ***Indirect Object***

+expmap *movement?*

3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

5yrs

+surfmorph

UTAH rUTAH

+expmap

So now what?

So now what?

3yrs	4yrs	5yrs
		
-surfmorph	+surfmorph	+surfmorph
rUTAH	UTAH	UTAH rUTAH
	-expmap	+expmap

(1) A broader assessment of children's verb class knowledge

So now what?

3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

5yrs

+surfmorph

UTAH rUTAH

+expmap

(1) A broader assessment of children's verb class knowledge

We need more observable behavior for more verbs in children's input to match modeling results against.

<3yrs

239 verbs

15 classes

of 60 verbs

<4yrs

267 verbs

23 classes

of 76 verbs

<5yrs

284 verbs

24 classes

of 82 verbs

Input

Children's behavior

So now what?

3yrs	4yrs	5yrs
-surfmorph	+surfmorph	+surfmorph
rUTAH	UTAH	UTAH rUTAH
	-expmap	+expmap

(1) A broader assessment of children's verb class knowledge

This will further test these theoretical proposals, and validate (or not) the current findings.

<3yrs	<4yrs	<5yrs	
			
239 verbs	267 verbs	284 verbs	**Input**
15 classes of 60 verbs	**23 classes of 76 verbs**	**24 classes of 82 verbs**	**Children's behavior**

So now what?

3yrs	4yrs	5yrs
-surfmorph	+surfmorph	+surfmorph
rUTAH	UTAH	UTAH rUTAH
	-expmap	+expmap

(1) A broader assessment of children's verb class knowledge

(a) More verbs

<3yrs

239 verbs
15 classes
of 60 verbs

<4yrs

267 verbs
23 classes
of 76 verbs

<5yrs

284 verbs
24 classes
of 82 verbs

Input

Children's behavior

So now what?

3yrs

-surfmorph

rUTAH

4yrs

+surfmorph

UTAH

-expmap

5yrs

+surfmorph

UTAH rUTAH

+expmap

(1) A broader assessment of children's verb class knowledge

(a) More verbs

(b) More behaviors

transitive

unergative

intransitive

non-finite -ing

small clause

wager-class

<3yrs

239 verbs

15 classes

of 60 verbs

<4yrs

267 verbs

23 classes

of 76 verbs

<5yrs

284 verbs

24 classes

of 82 verbs

Input

Children's behavior

So now what?

3yrs -surfmorph rUTAH

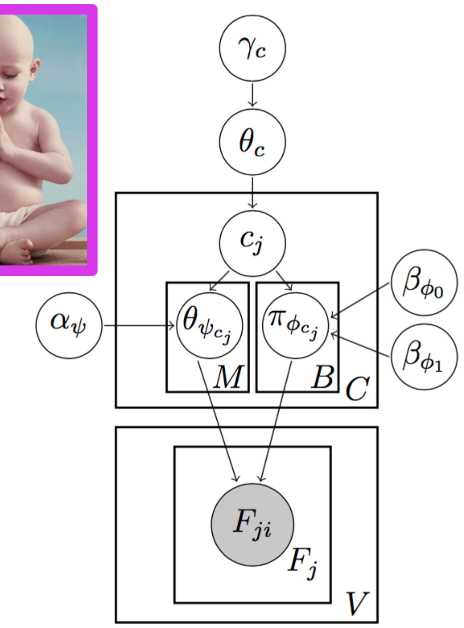
4yrs +surfmorph UTAH -expmap

5yrs +surfmorph UTAH rUTAH +expmap

(1) A broader assessment of children's verb class knowledge

experimental

(2) Models incorporating more cognitively plausible assumptions



+memory & processing limitations

+predicting experimental behavior

+incorporating additional age-appropriate information

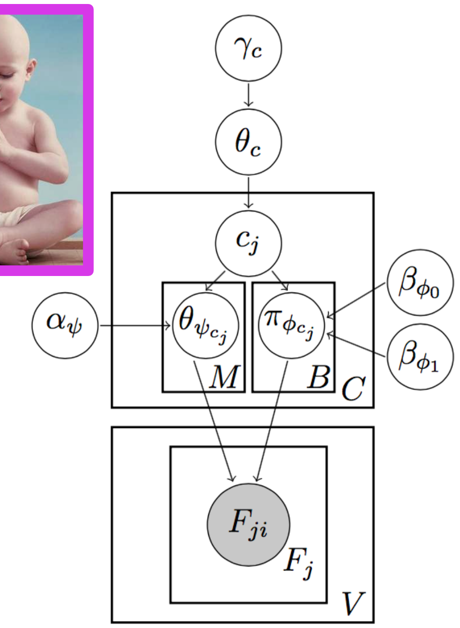
So now what?

(1) A broader assessment of children's verb class knowledge

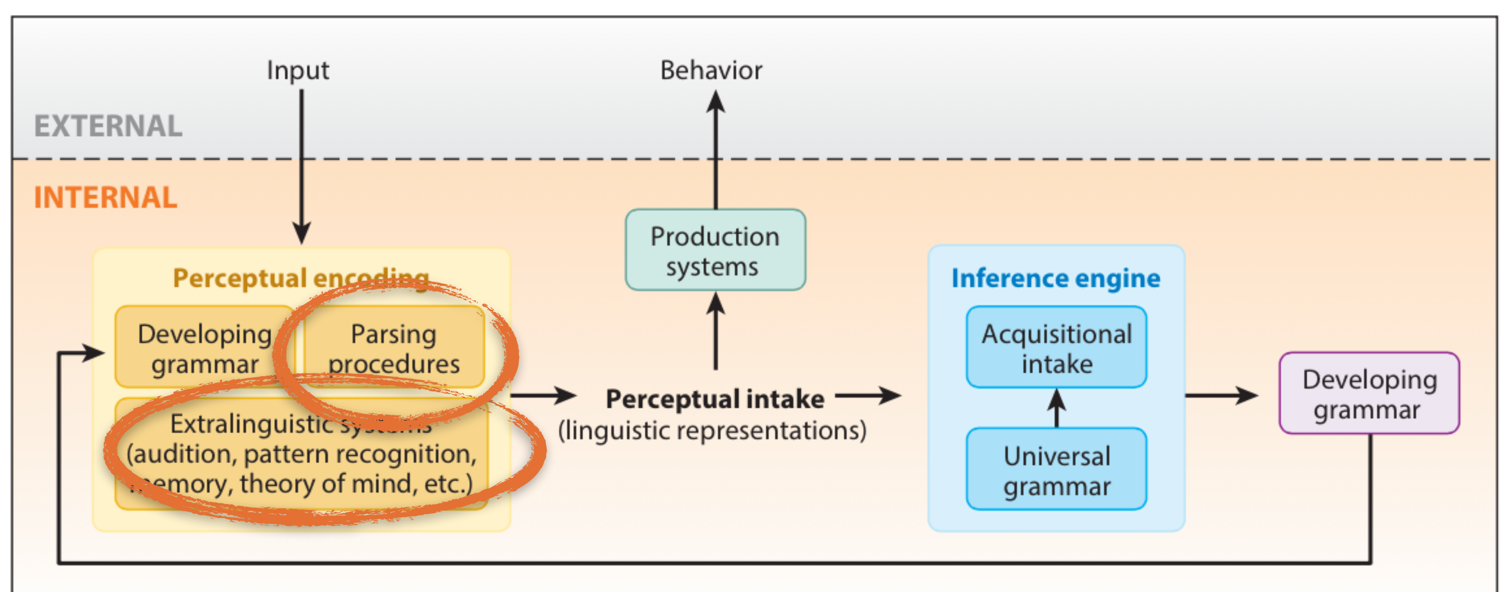
3yrs	4yrs	5yrs
-surfmorph	+surfmorph	+surfmorph
rUTAH	UTAH	UTAH rUTAH
	-expmap	+expmap

experimental

(2) Models incorporating more cognitively plausible assumptions



What happens when we embed these theories in a learning model that learns incrementally and has age-appropriate memory & processing limitations?



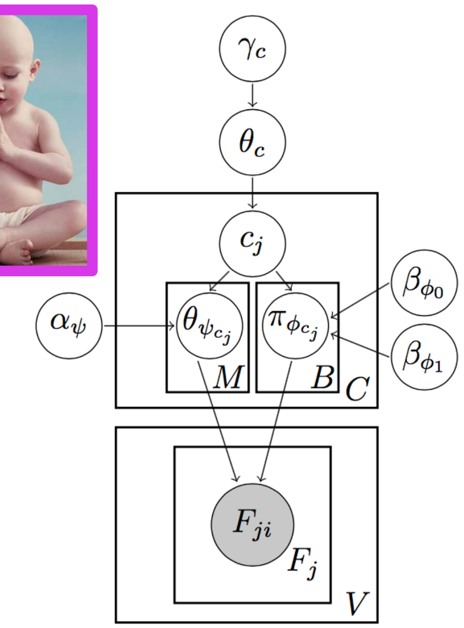
So now what?

(1) A broader assessment of children's verb class knowledge

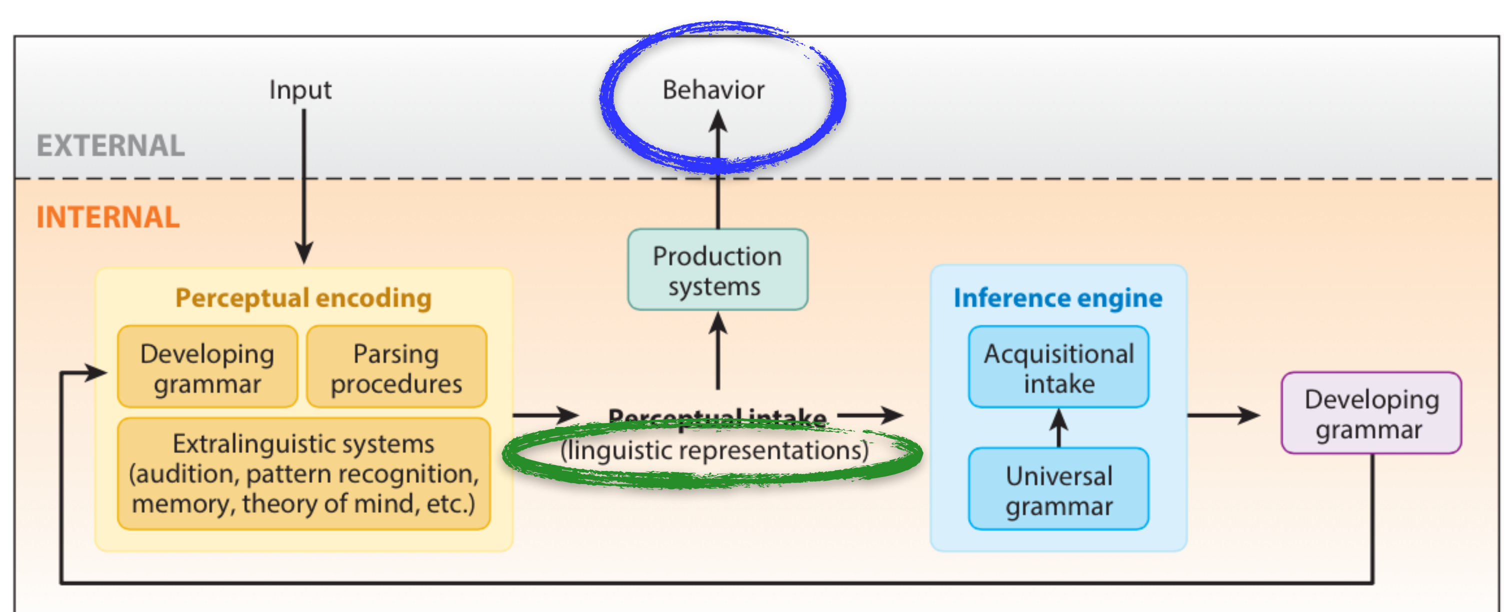
3yrs	4yrs	5yrs
-surfmorph	+surfmorph	+surfmorph
rUTAH	UTAH	UTAH rUTAH
	-expmap	+expmap

experimental

(2) Models incorporating more cognitively plausible assumptions



What kinds of child behavior does the model predict in the experimental scenarios already available, based on its internal representations?



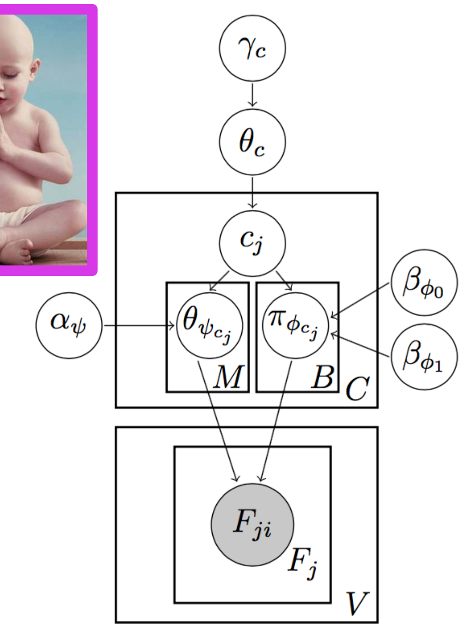
So now what?

(1) A broader assessment of children's verb class knowledge

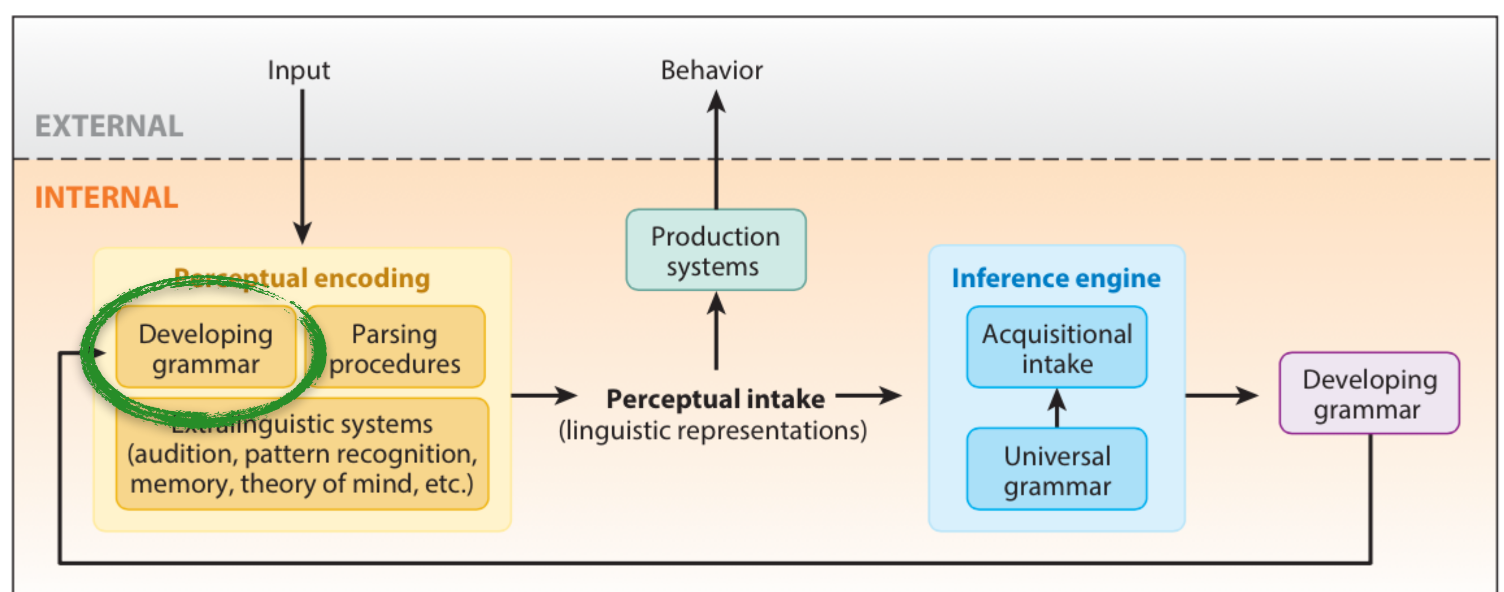
3yrs	4yrs	5yrs
-surfmorph	+surfmorph	+surfmorph
rUTAH	UTAH -expmap	UTAH rUTAH +expmap

experimental

(2) Models incorporating more cognitively plausible assumptions



What other types of information may be available, especially throughout development as children learn from their intake?



So now what?

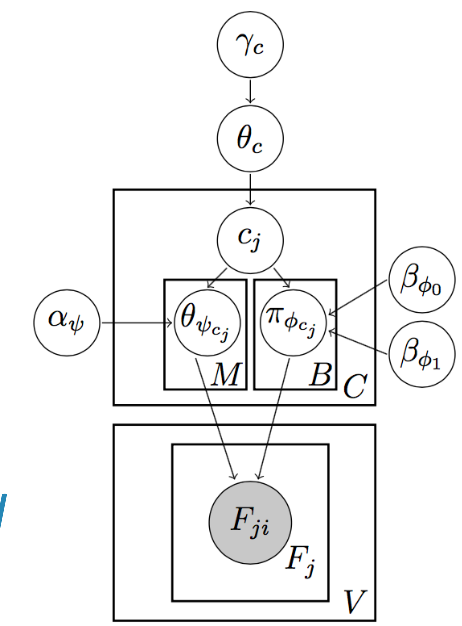
3yrs	4yrs	5yrs
-surfmorph	+surfmorph	+surfmorph
rUTAH	UTAH -expmap	UTAH rUTAH +expmap

(1) A broader assessment of children's verb class knowledge

experimental

(2) Models incorporating more cognitively plausible assumptions

computational



(3) Other theories of representation

Are there other options for linking thematic role information to syntactic structure that we can explore in this framework?

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

Subject *Object* *Indirect Object*

???

So now what?

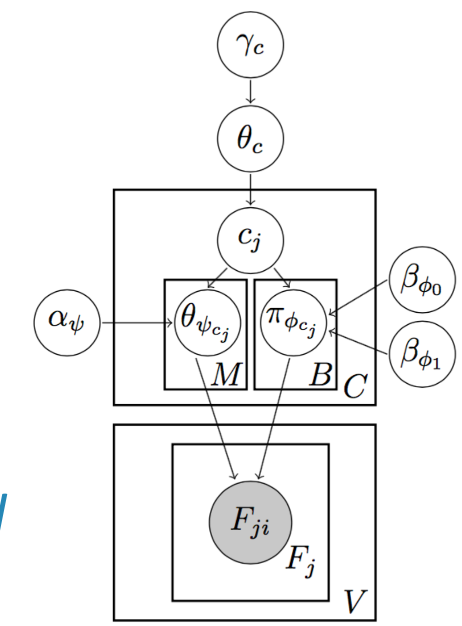
3yrs	4yrs	5yrs
-surfmorph	+surfmorph	+surfmorph
rUTAH	UTAH	UTAH rUTAH
	-expmap	+expmap

(1) A broader assessment of children's verb class knowledge

experimental

(2) Models incorporating more cognitively plausible assumptions

computational



(3) Other theories of representation

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Instrument)

???

theoretical

Subject *Object* *Indirect Object*