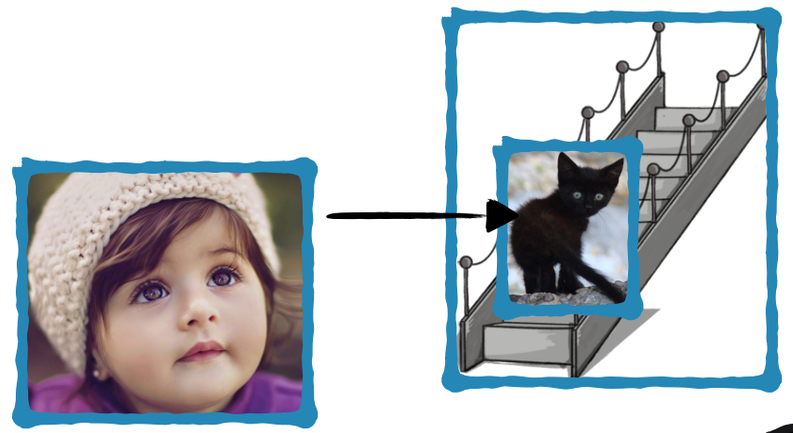
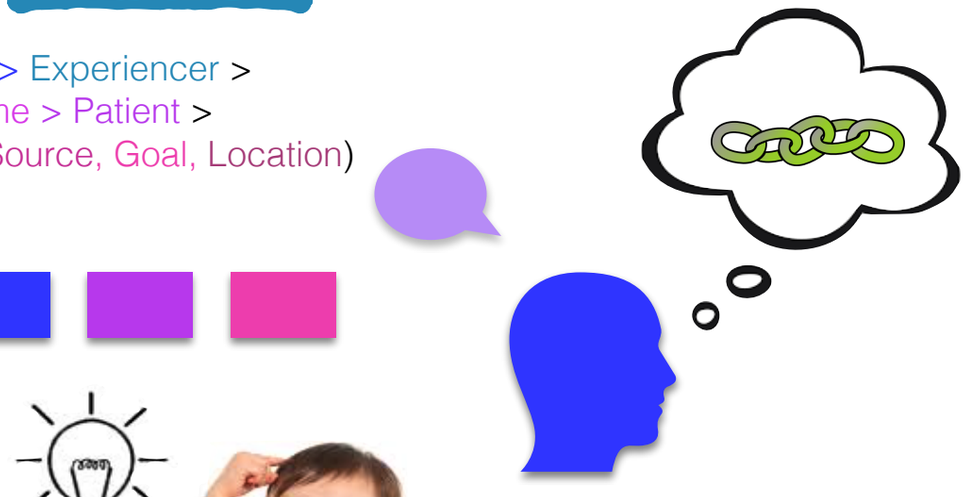
Quantitative approaches to learning linking theories in language

Lisa Pearl

University of California, Irvine



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



Computation of Language Laboratory

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University of California, Irvine

Linking theories

The little girl *blicked* the kitten on the stairs.

Linking theories

What is this likely to mean?

The little girl *blicked* the kitten on the stairs.

Linking theories

What is this likely to mean?

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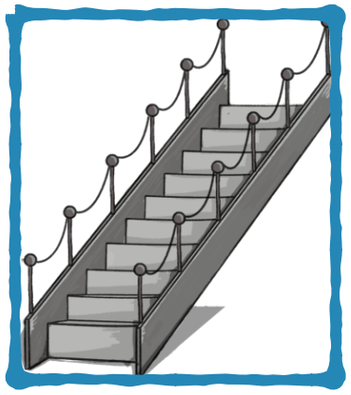


Event participants

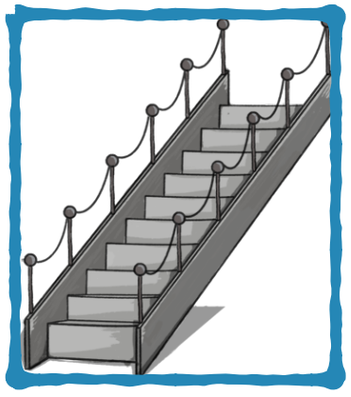
Linking theories

What is this likely to mean?

Syntactic positions

Subject | Object | Oblique Object

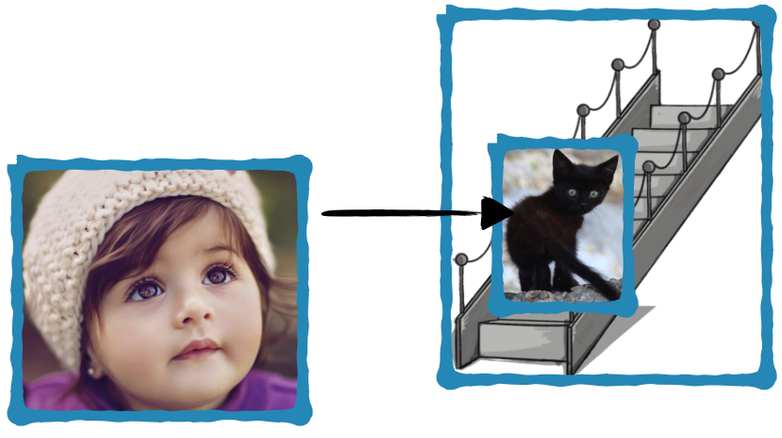
The little girl *blicked* the kitten on the stairs.



Event participants

Linking theories

This event is much more likely…



Syntactic positions

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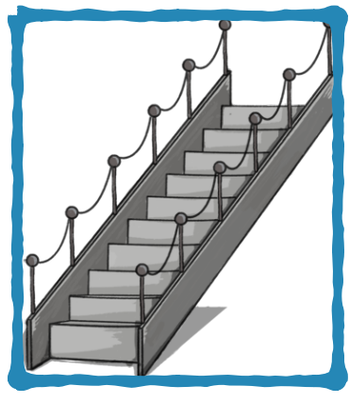
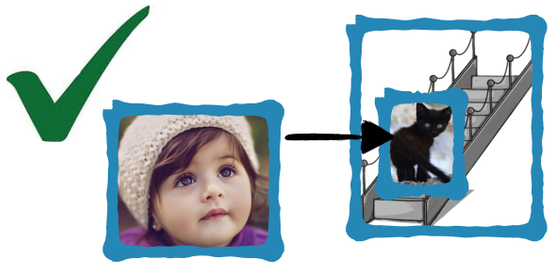
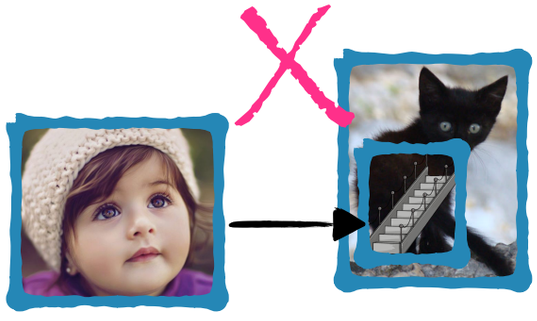
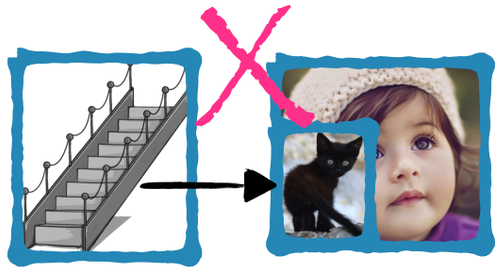


Event participants

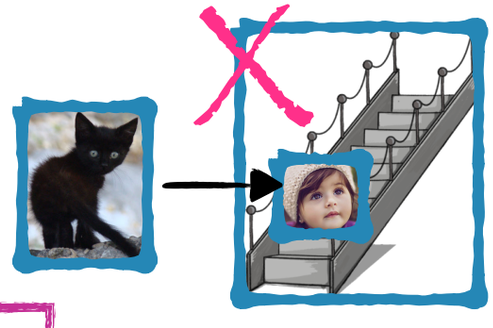
Linking theories







…compared to these.



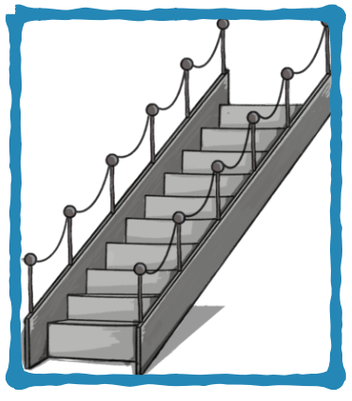
Syntactic positions

Subject

Object

Oblique Object

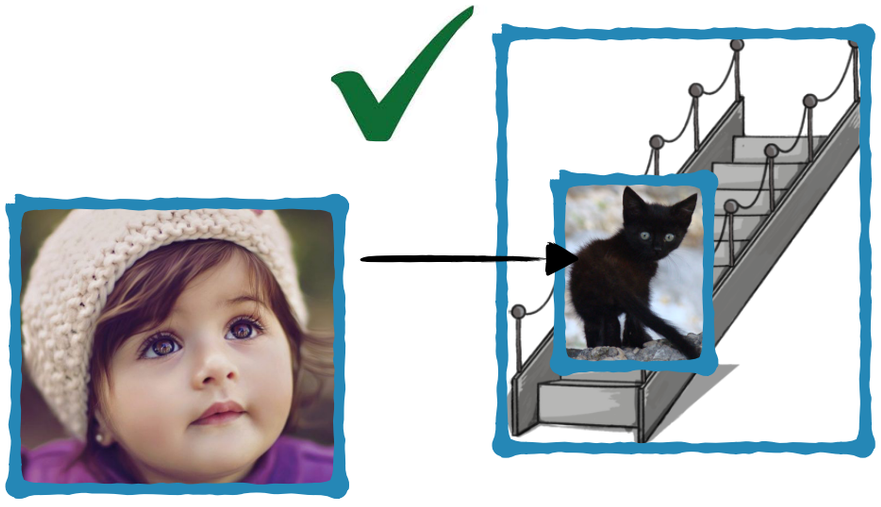
The little girl *blicked* the kitten on the stairs.



Event participants

Linking theories

Why?



Syntactic positions

Subject | Object | Oblique Object

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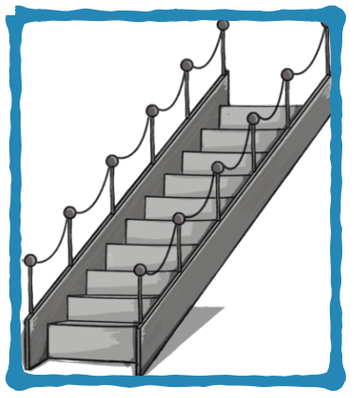
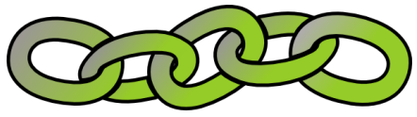
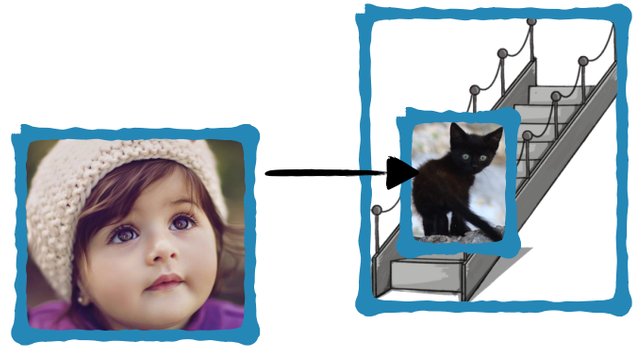


Event participants

Linking theories



We as adults have linking theories that help us interpret verbs in combination with their arguments.



Syntactic positions

Subject

Object

Oblique Object

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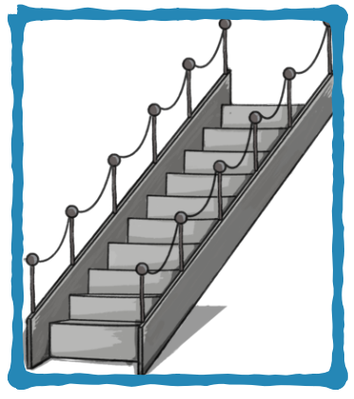


Event participants

Linking theories

These linking theories are mental representations that we as adults have developed. They let us link event participants and syntactic positions, so we know how to interpret an utterance — even when we don't know what the verb means.

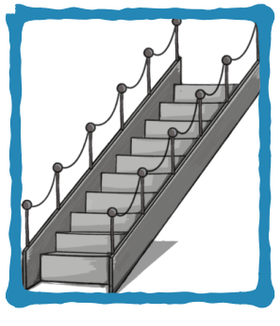
Syntactic positions

Subject

Object

Oblique Object

The little girl *blicked* the kitten on the stairs.



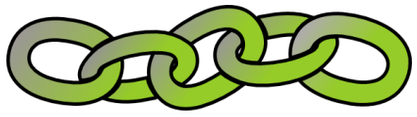
Event participants

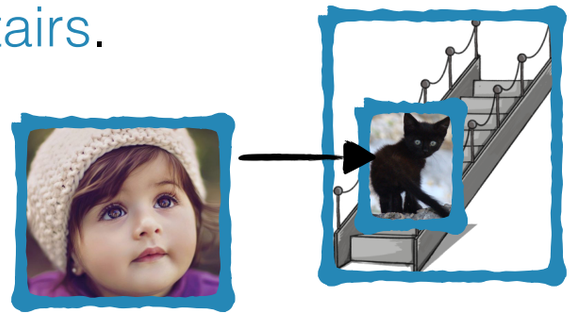
Linking theories

Subject Object Oblique Object

The little girl *blicked* the kitten on the stairs.

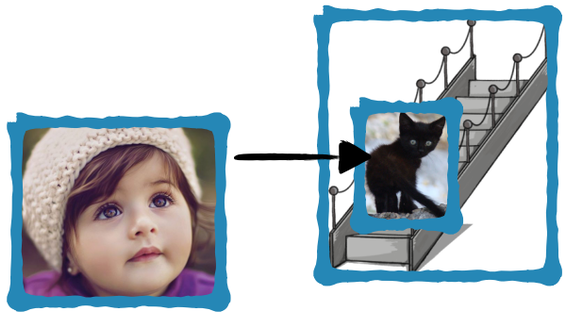
What does a linking theory look like?





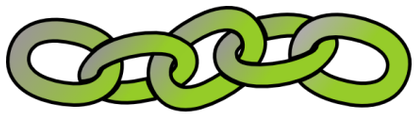
Linking theories

What does a linking theory look like?



Subject Object Oblique Object

Syntax The little girl *blicked* the kitten on the stairs.



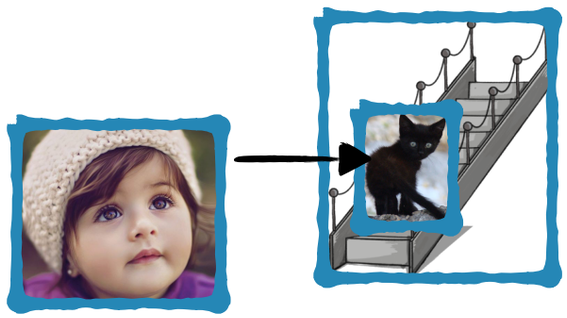
Current proposals involve prior (innate) knowledge

Event participant roles
=
Thematic roles

Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

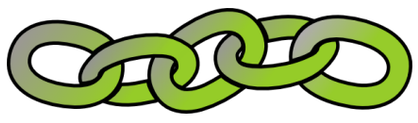
What does a linking theory look like?



Subject Object Oblique Object

Syntax The little girl *blicked* the kitten on the stairs.

Mapping to syntax



Intermediate representations

Event participant roles
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Linking theories

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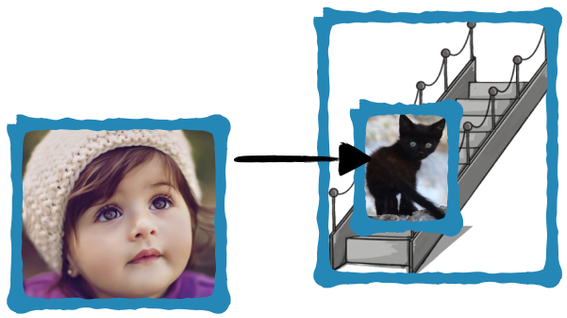

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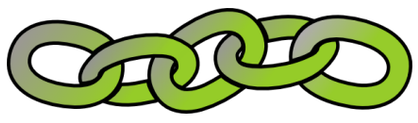


Intermediate representations

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

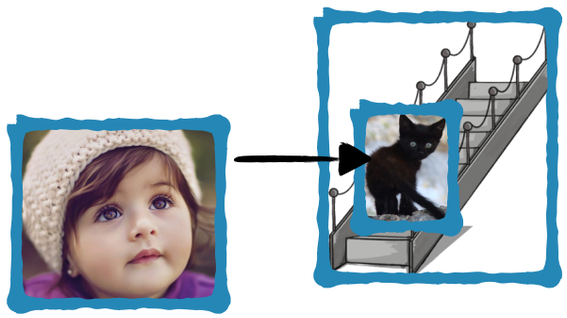
Baker 1988, Baker 1997, Dowty 1991, Fillmore 1968, Grimshaw 1990, Jackendoff 1987, Perlmutter & Postal 1984, Speas 1990

Event participant roles
=
Thematic roles

Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

What does a linking theory look like?



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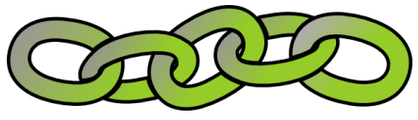
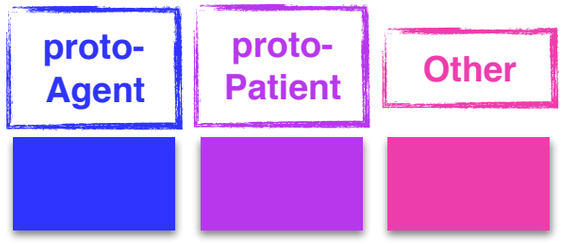


Intermediate representations

UTAH

Thematic roles map to one of three **fixed macro-roles**.



Event participant roles
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Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

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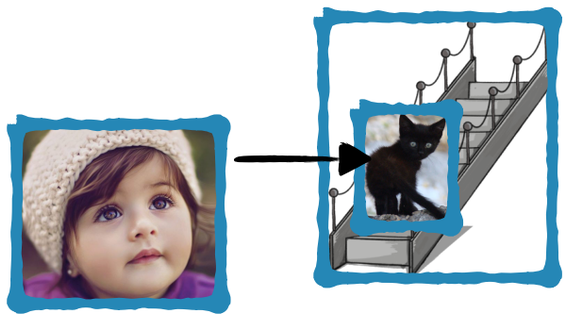

Subject Object Oblique Object

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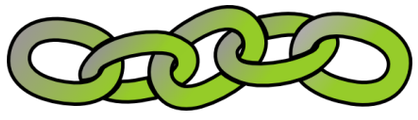
Mapping to syntax



Intermediate representations

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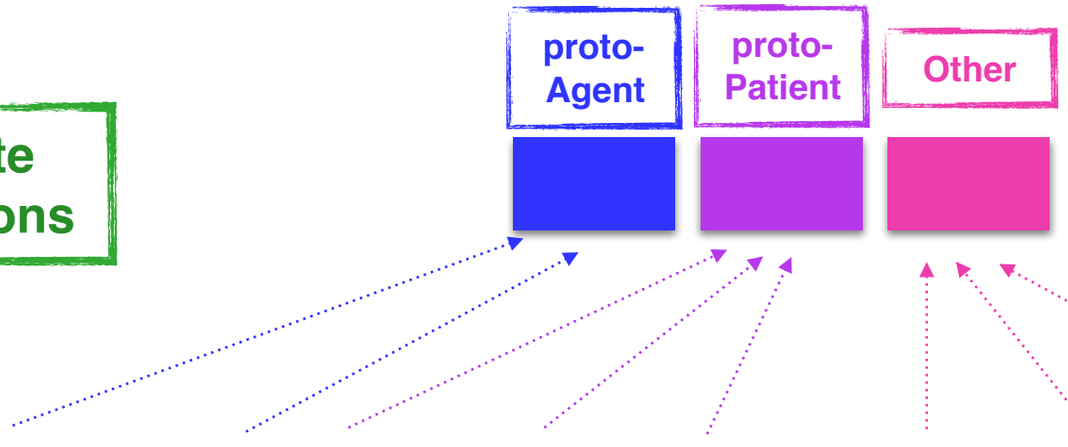
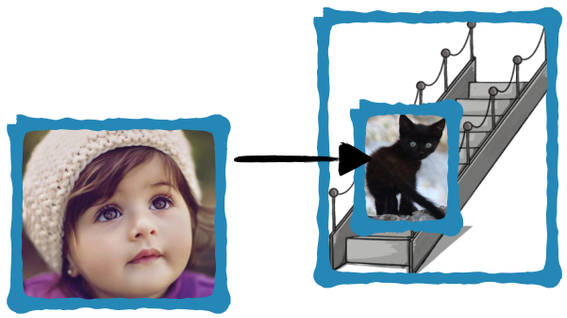


Event participant roles = Thematic roles

Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

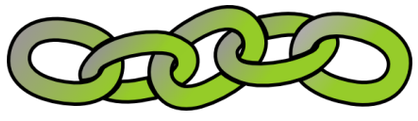
What does a linking theory look like?



Subject Object Oblique Object

Syntax The little girl *blicked* the kitten on the stairs.

Mapping to syntax

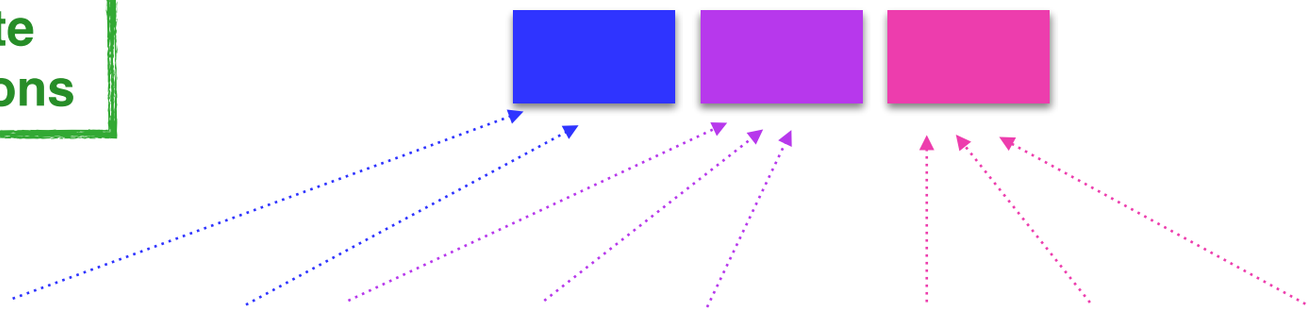


These map to syntactic positions.

UTAH

fixed

Intermediate representations



Event participant roles
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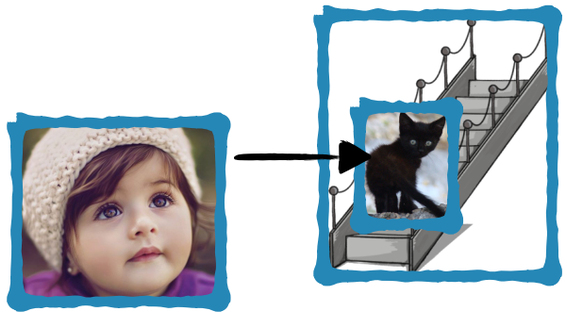
Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

What does a linking theory look like?



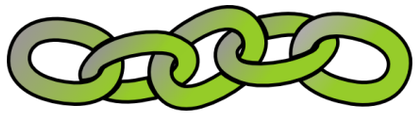
Syntax

Subject — Object — Oblique Object

The little girl *blicked* the kitten on the stairs.

These map to syntactic positions.

Mapping to syntax



UTAH

fixed

Intermediate representations

Event participant roles
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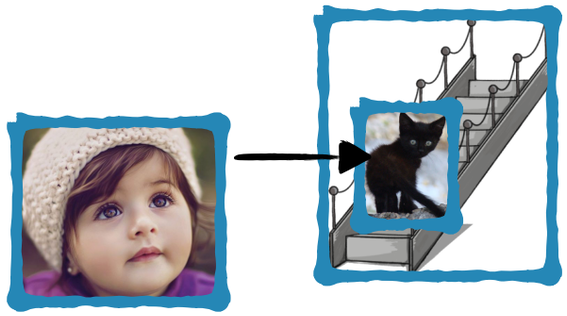
Linking theories

What does a linking theory look like?



Syntax

Subject — Object — Oblique Object

The little girl *blicked* the kitten on the stairs.

Mapping to syntax

Intermediate representations

UTAH

fixed

The (relativized) **UTAH**

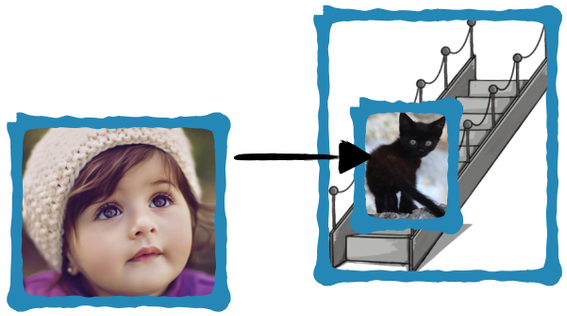
Larson 1988, Larson 1990

Event participant roles
=
Thematic roles

Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

What does a linking theory look like?



Syntax

Subject — Object — Oblique Object

The little girl *blicked* the kitten on the stairs.

Mapping to syntax

Intermediate representations

UTAH

fixed

rUTAH

Event participant roles
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Thematic roles

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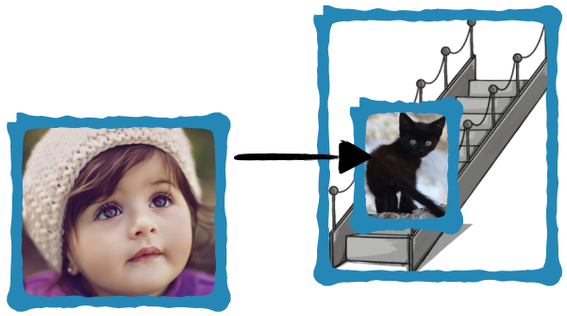
Linking theories

What does a linking theory look like?



Syntax

Subject — Object — Oblique Object

The little girl *blicked* the kitten on the stairs.

Mapping to syntax

Intermediate representations

UTAH

fixed

rUTAH

Thematic roles are **ordered relative** to each other.

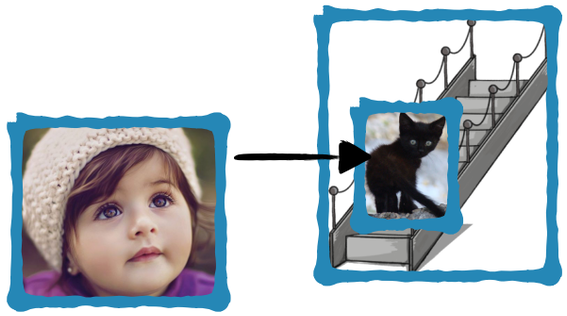
Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

Event participant roles = Thematic roles

Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

What does a linking theory look like?



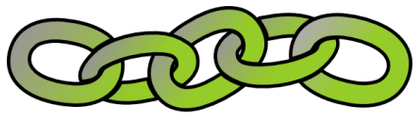
Syntax

Subject — Object — Oblique Object

The little girl *blicked* the kitten on the stairs.

Mapping to syntax

Whichever ones are present map in order to the available syntactic positions.



Intermediate representations

UTAH

fixed

rUTAH

relative

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

Event participant roles

=

Thematic roles

Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

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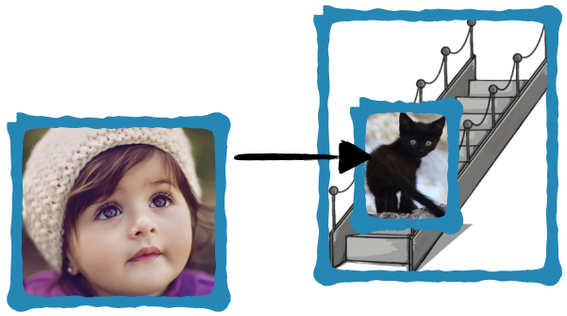
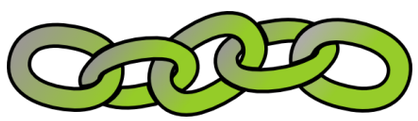


Syntax

Mapping to syntax



Intermediate representations

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Whichever ones are present map in order to the available syntactic positions.

UTAH

fixed

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relative

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Event participant roles = Thematic roles

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Linking theories

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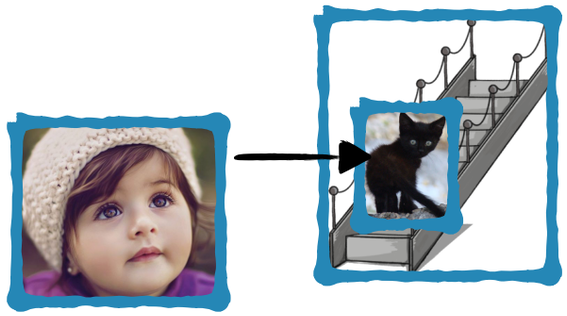


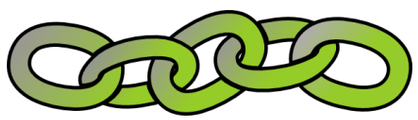
Syntax

Subject Object Oblique Object

The little girl *blicked* the kitten on the stairs.

Mapping to syntax

UTAH & rUTAH assume the mapping to syntax is innate.



UTAH

fixed

rUTAH

relative

Intermediate representations

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

Event participant roles = Thematic roles

Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

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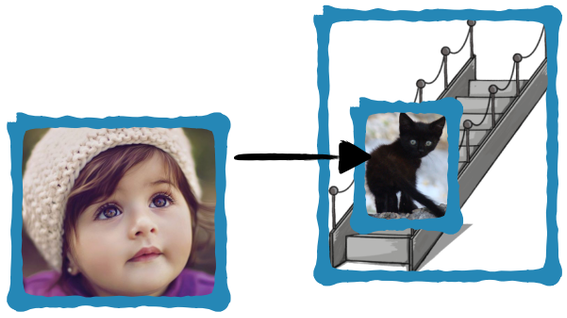


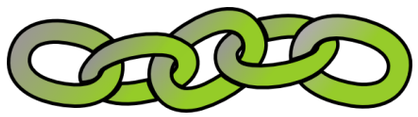
Subject Object Oblique Object

Syntax The little girl *blicked* the kitten on the stairs.

Mapping to syntax

But it could be that this mapping is derived from language experience.

UTAH **rUTAH**



Intermediate representations

fixed

relative

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

Event participant roles = Thematic roles

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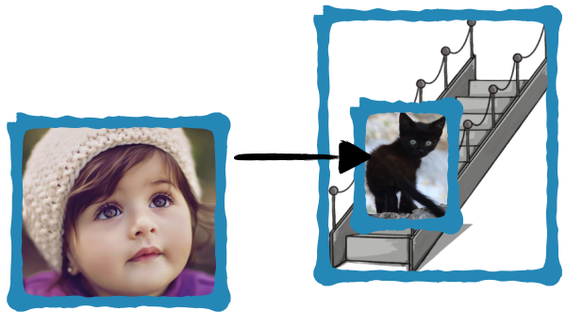
Linking theories

What does a linking theory look like?



Syntax

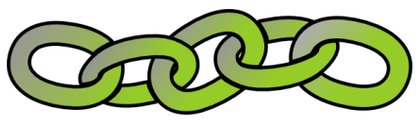
Subject Object Oblique Object

The little girl *blicked* the kitten on the stairs.

But it could be that this mapping is derived from language experience.

Mapping to syntax

UTAH **rUTAH**



Intermediate representations

fixed

relative

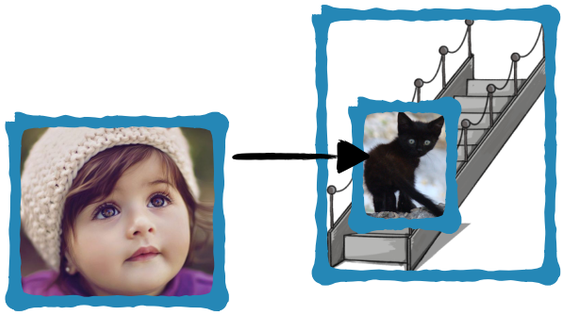
Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

Event participant roles = Thematic roles

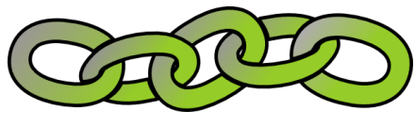
Agent, Experiencer, Patient, Theme, Goal, Source, Location…

Linking theories

The little girl *blicked* the kitten on the stairs.



How do we tell which linking theory proposal is likely to be correct?



rUTAH

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

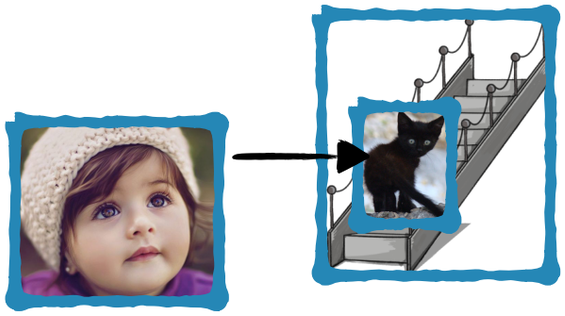
relative

UTAH

fixed

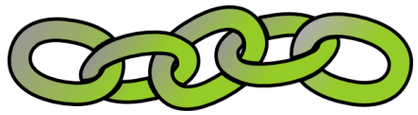
Linking theories

The little girl *blicked* the kitten on the stairs.



Argument from acquisition:
Which linking theory proposals are compatible with the observed development of this knowledge in children?

Pearl 2017, Pearl et al. 2017



rUTAH

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

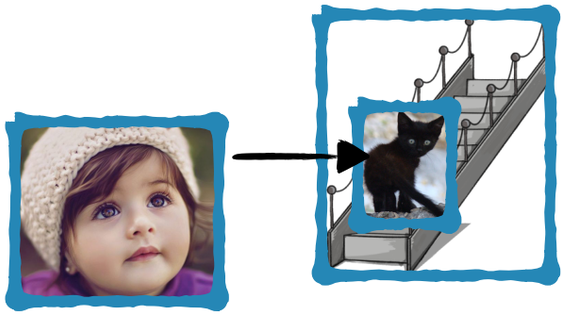
relative

UTAH

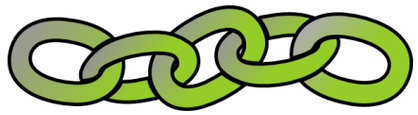
fixed

Linking theories

The little girl *blicked* the kitten on the stairs.



Good news: These proposals make developmental predictions.



rUTAH

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

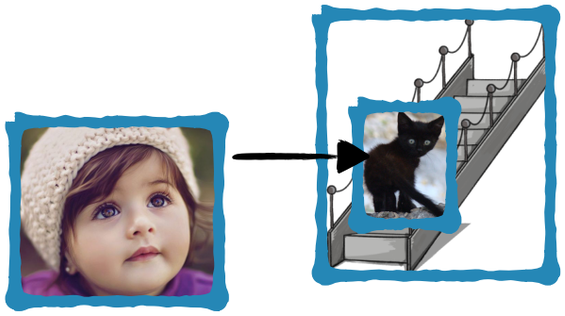
relative

UTAH

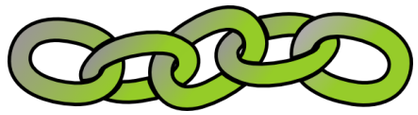
fixed

Linking theories

The little girl *blicked* the kitten on the stairs.



Proposals relying on innate knowledge typically assume early maturation: the knowledge is **present as early as we can test for it**.



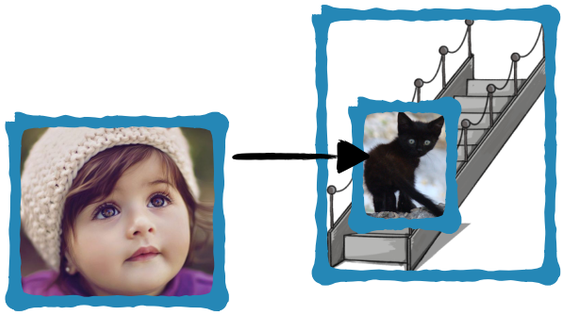
rUTAH Agent > Experiencer > Theme > Patient > (Source, Goal, Location) **relative**

UTAH

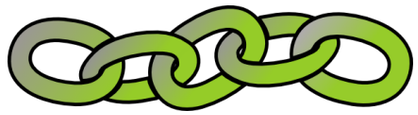
fixed

Linking theories

The little girl *blicked* the kitten on the stairs.



Implication: A learner who has knowledge of the mapping to syntax should always match real children's behavior best.



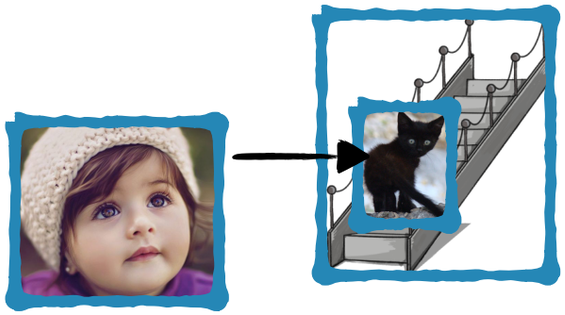
rUTAH Agent > Experiencer > Theme > Patient > (Source, Goal, Location) **relative**

UTAH

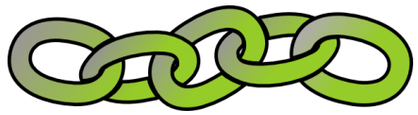
fixed

Linking theories

The little girl *blicked* the kitten on the stairs.



Proposals relying on derived knowledge typically assume it **takes some time** for children to derive the knowledge from their input.



rUTAH

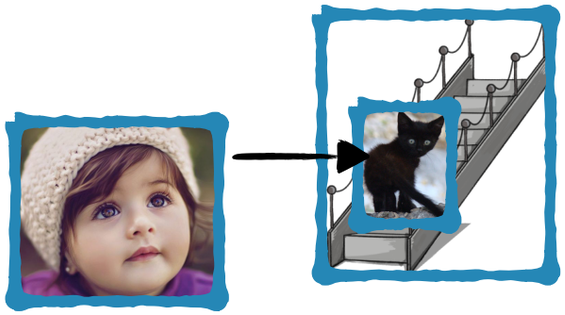
Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

relative

UTAH

fixed

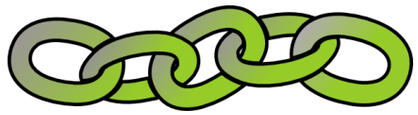
Linking theories



The little girl *blicked* the kitten on the stairs.

Implication: A learner who has knowledge of the mapping to syntax should *not* always match real children's behavior best.

A learner *without* this knowledge should match younger children best.



rUTAH

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

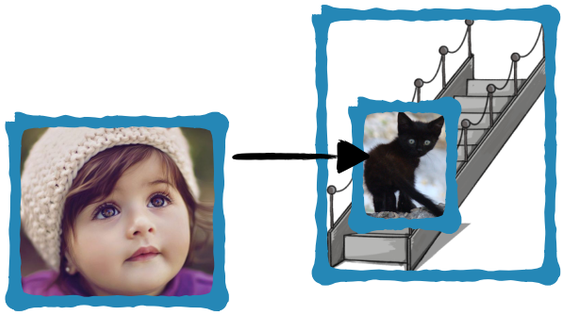
relative

UTAH

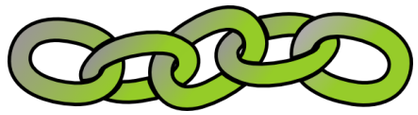
fixed

Linking theories

The little girl *blicked* the kitten on the stairs.



The same evaluation can be done for learners who use a fixed thematic system vs. a relative thematic system. Which ones match real children's behavior best?



rUTAH

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

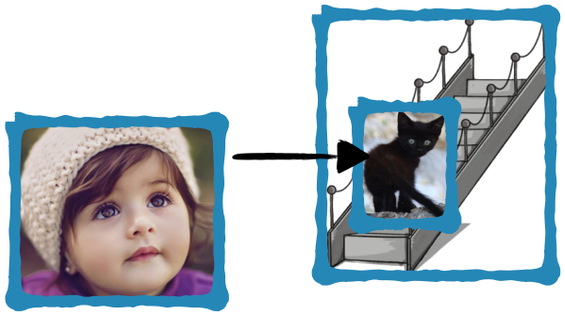
relative

UTAH

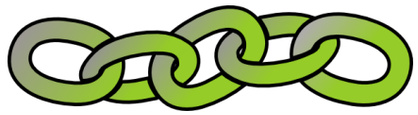
fixed

Linking theories

The little girl *blicked* the kitten on the stairs.



So what behavior should we look at that would leverage linking theory knowledge?



rUTAH

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

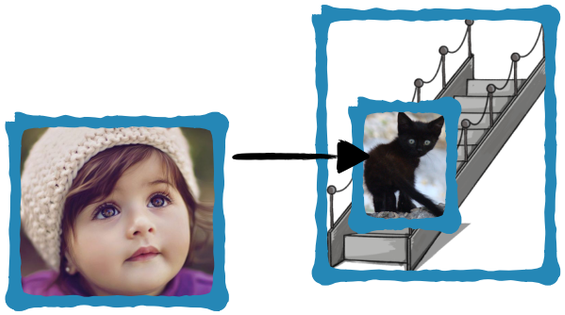
relative

UTAH

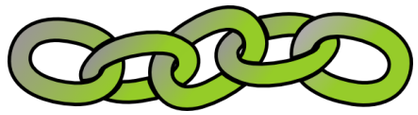
fixed

Linking theories

The little girl *blicked* the kitten on the stairs.



One answer: The development of **verb classes** — how children cluster verbs together in order to generalize about verb linguistic behavior.



rUTAH

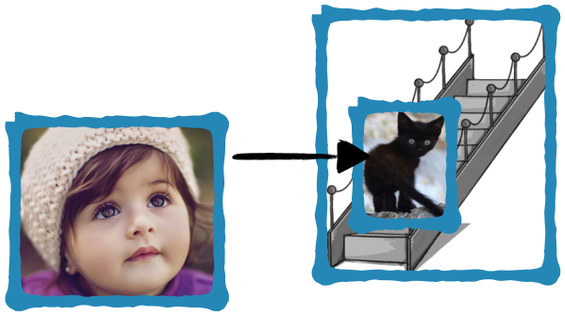
Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

relative

UTAH

fixed

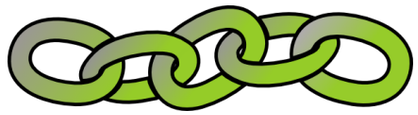
Linking theories



The little girl *blicked* the kitten on the stairs.

Why **verb classes**? Linking theories are precisely about one key aspect of verb behavior: how verb arguments are interpreted.

So, linking theory knowledge could affect how children cluster verbs together into verb classes.



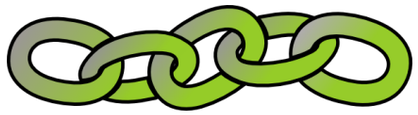
rUTAH

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

relative

UTAH

fixed



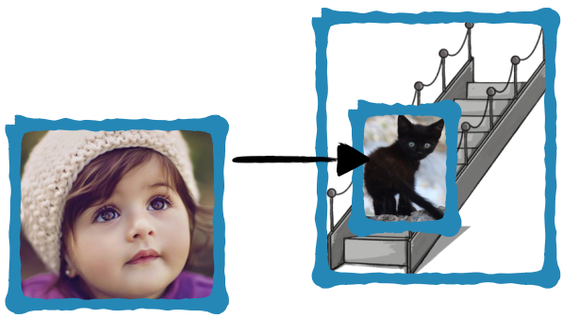
Linking theories

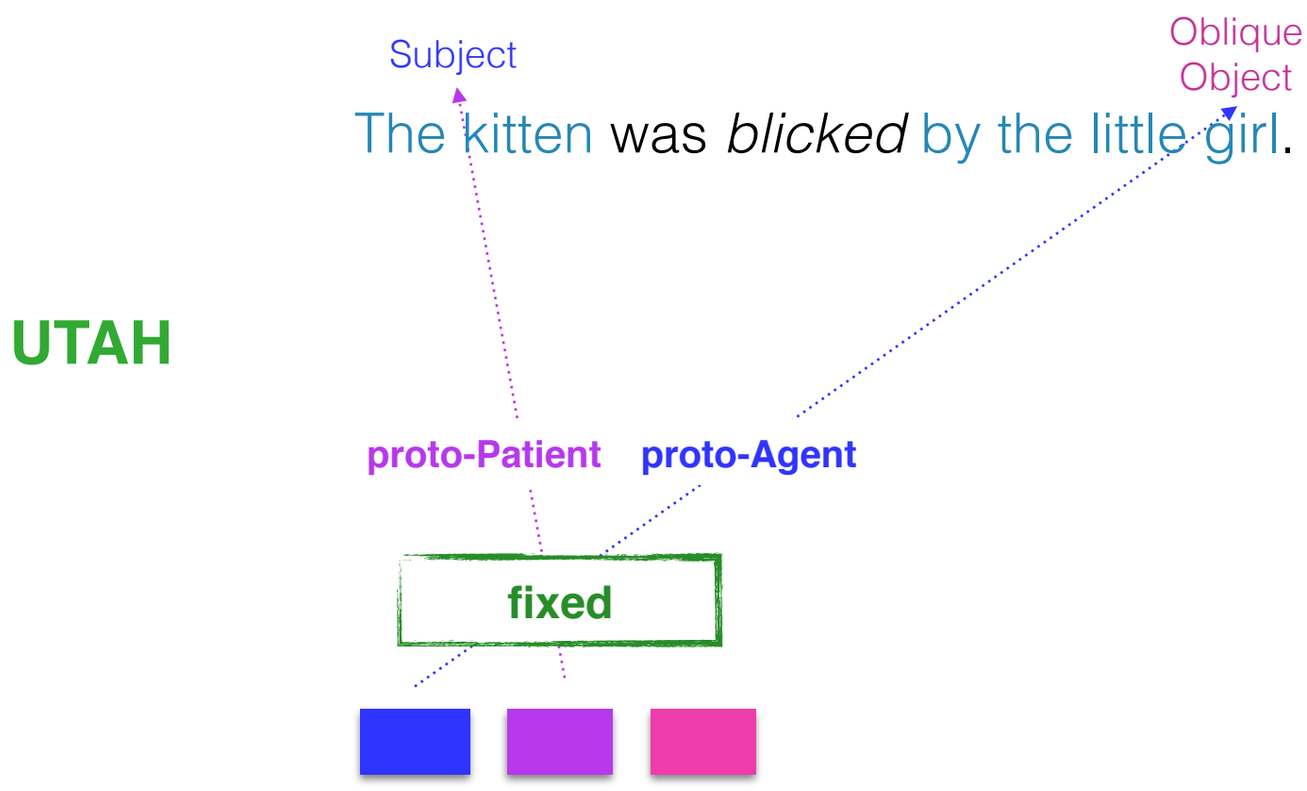
rUTAH

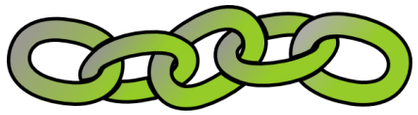
relative

fixed

How does linking knowledge affect verb clustering in children?







rUTAH

relative

fixed

Linking theories

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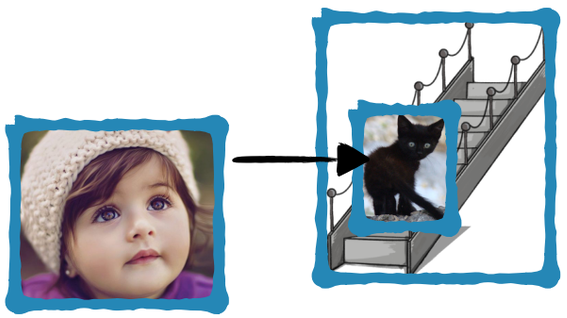
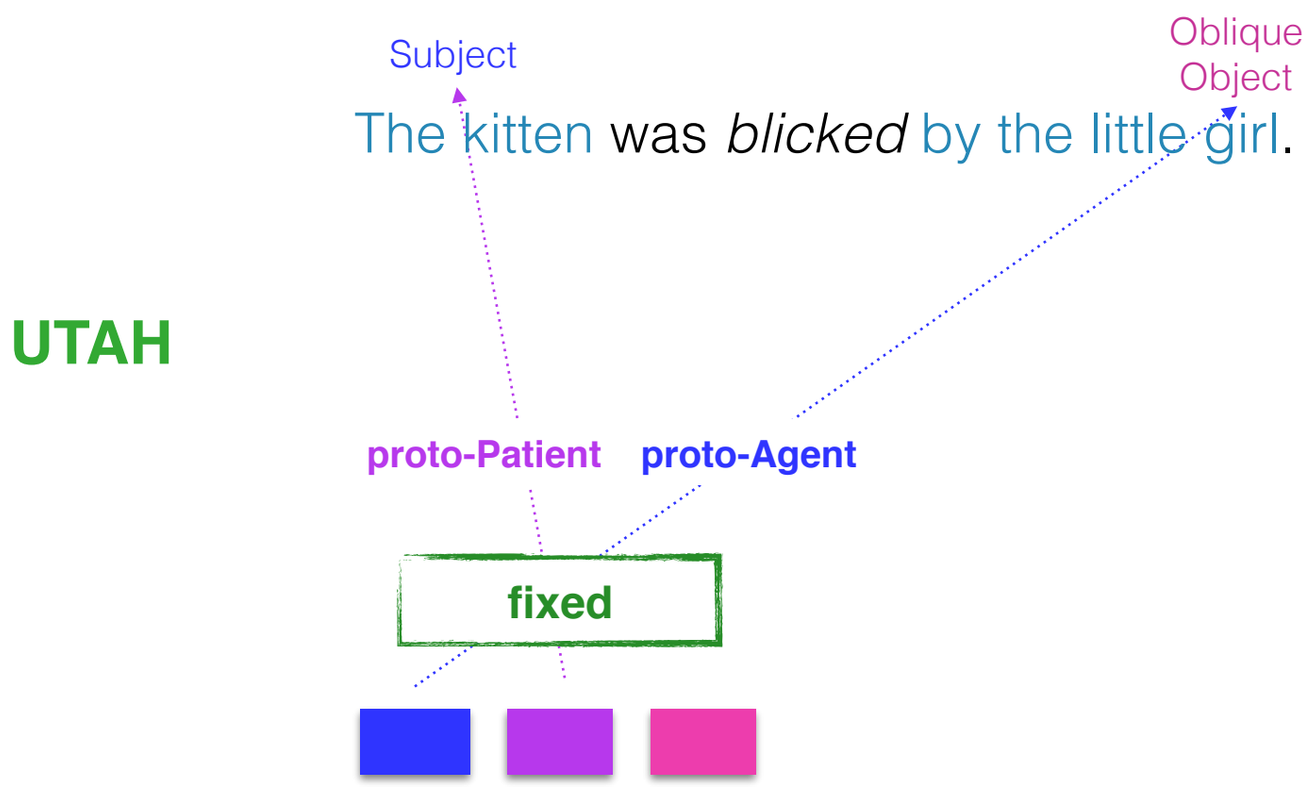


If children expect a mapping already, it's salient when the mapping doesn't hold.

Interpretation: movement, which is used to cluster verbs.



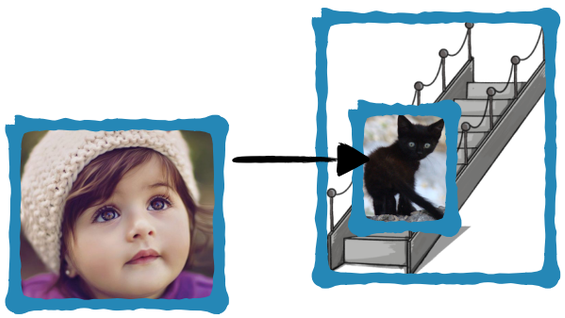
Linking theories

rUTAH

relative

fixed

How does linking knowledge affect verb clustering in children?



If children expect a mapping already, it's salient when the mapping doesn't hold.

Interpretation: movement, which is used to cluster verbs.

blick: 2 movement

UTAH

Subject

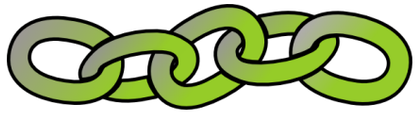
Oblique Object

The kitten was *blicked* by the little girl.

proto-Patient

proto-Agent

fixed



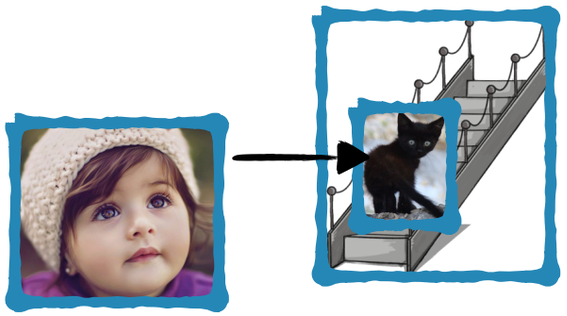
Linking theories

UTAH

relative

fixed

How does linking knowledge affect verb clustering in children?



If children expect a mapping already, it's salient when the mapping doesn't hold.

Interpretation: movement, which is used to cluster verbs.

blick: 2 movement

rUTAH

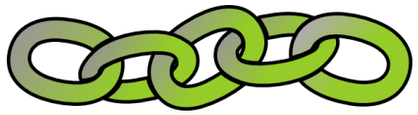
Subject — Oblique Object

The kitten was *blicked* by the little girl.

2nd-Highest — Highest

relative

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



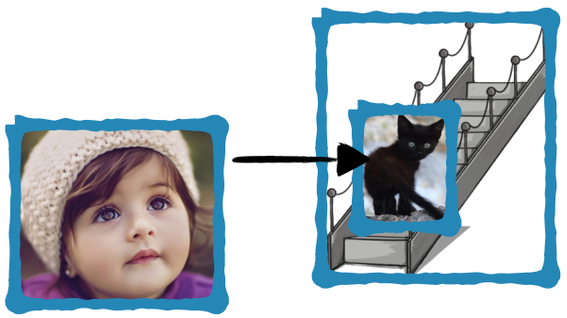
Linking theories

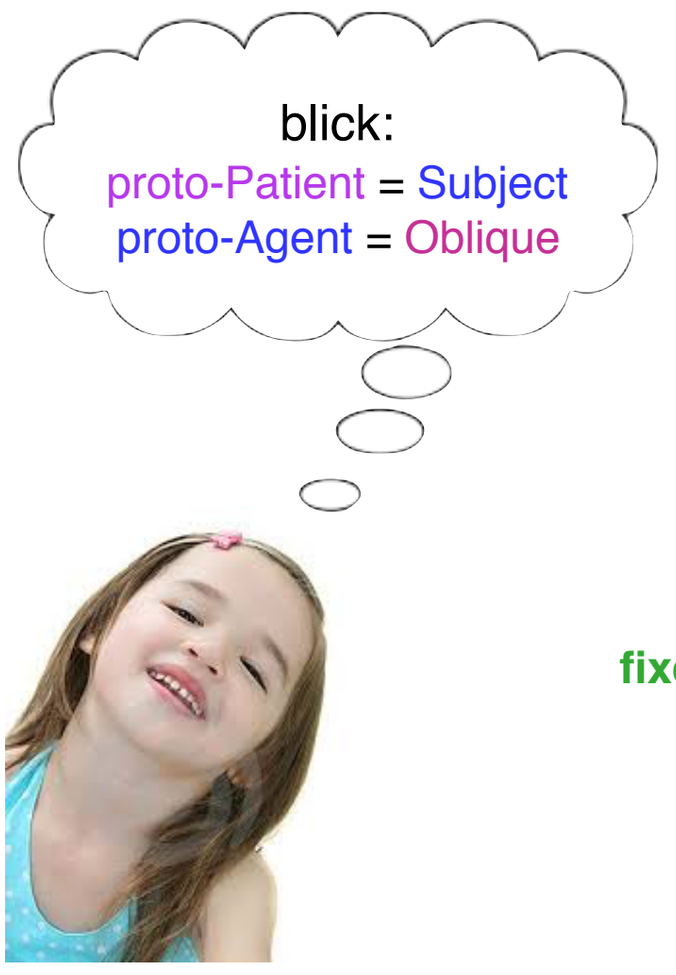
rUTAH

UTAH

relative

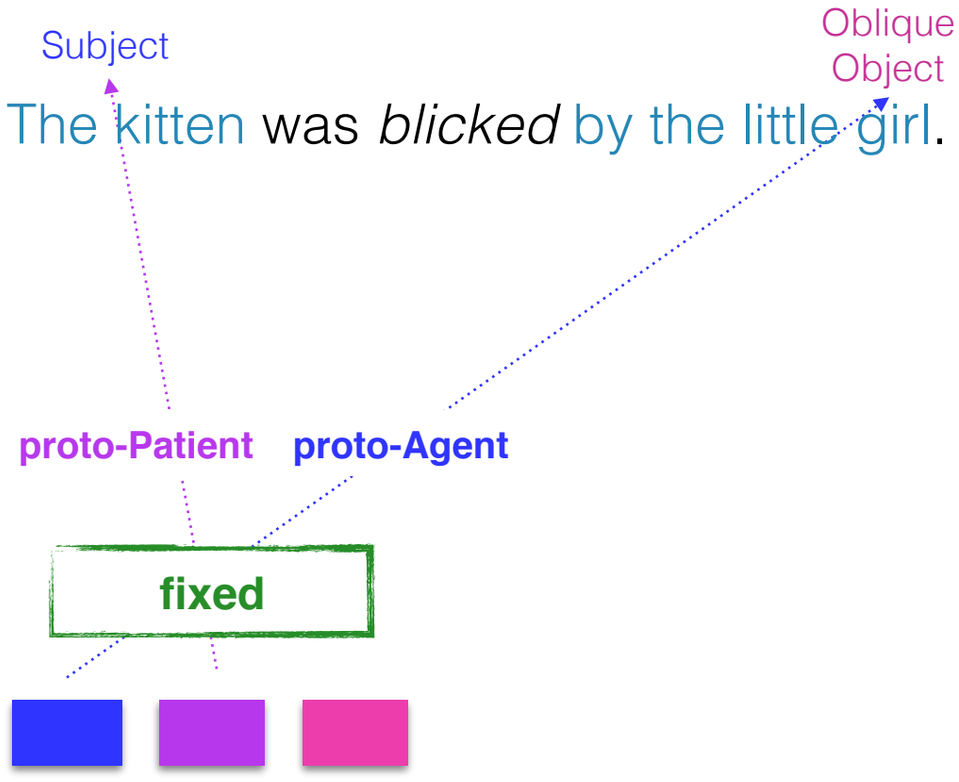
How does linking knowledge affect verb clustering in children?

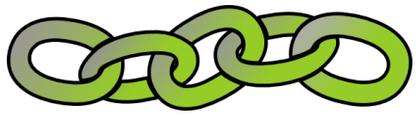




fixed

If children don't expect a mapping already, they may track the details of where certain thematic representations appear and use that to cluster verbs.





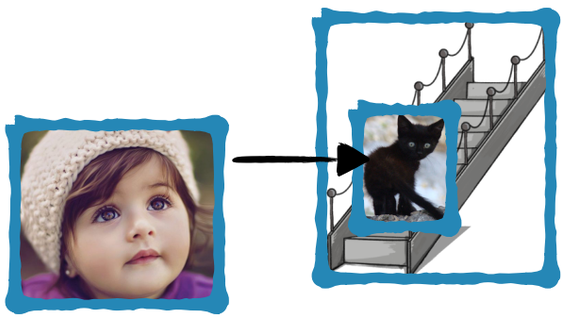
Linking theories

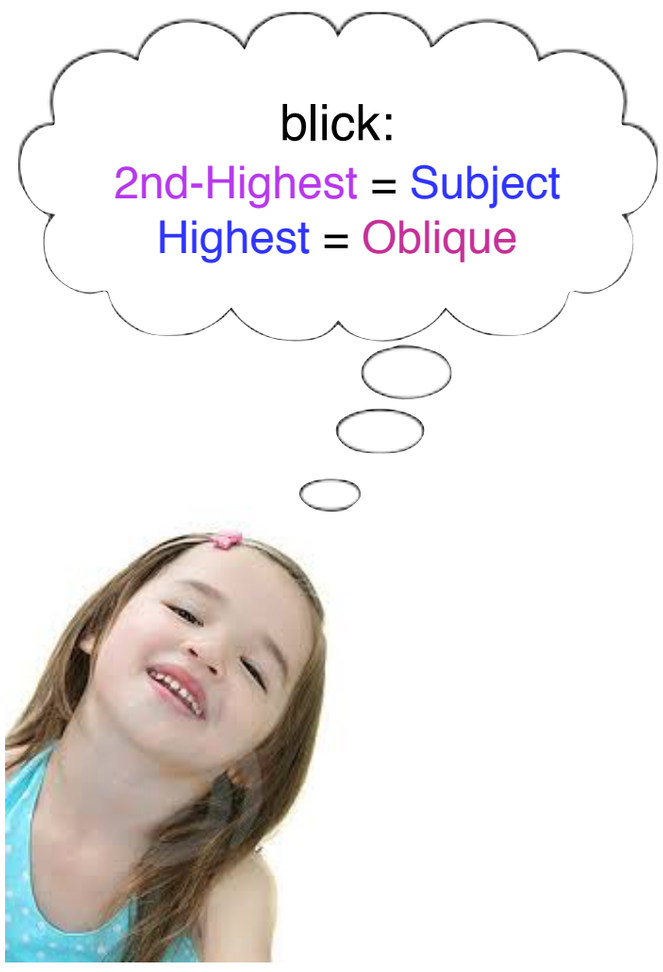
rUTAH

UTAH

fixed

How does linking knowledge affect verb clustering in children?





relative

If children don't expect a mapping already, they may track the details of where certain thematic representations appear and use that to cluster verbs.

Subject

Oblique Object

The kitten was *blicked* by the little girl.

2nd-Highest

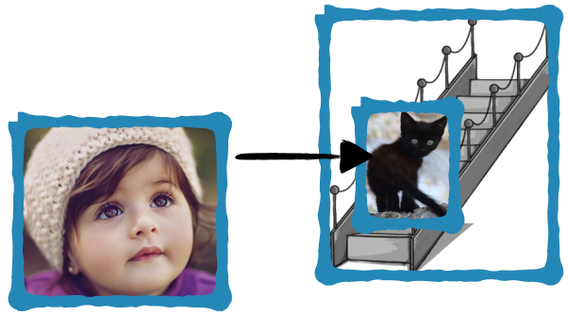
Highest

relative

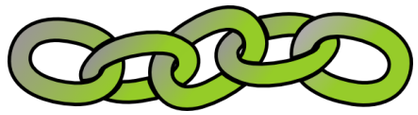
Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

Linking theories

The little girl *blicked* the kitten on the stairs.



Strong empirical foundation:
We have a lot of empirical data about the development of **verb classes**: experimental studies of children's behavior (output of learning) and corpus studies of their input.



rUTAH

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

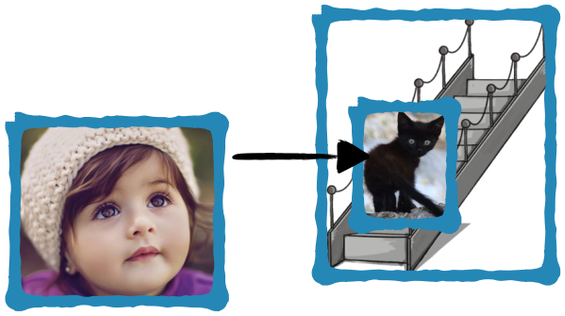
relative

UTAH

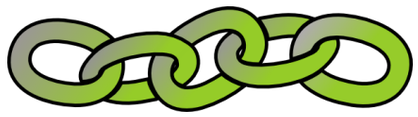
fixed

The Plan

The little girl *blicked* the kitten on the stairs.



1. Evaluating different linking theory proposals using developmental modeling



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

rUTAH

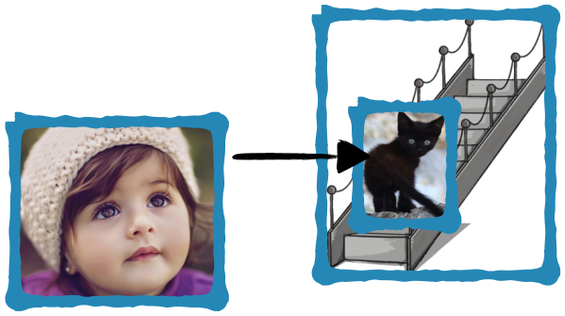
UTAH

relative

fixed

The Plan

The little girl *blicked* the kitten on the stairs.



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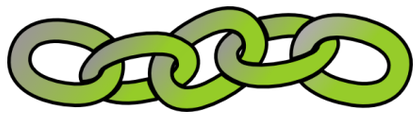


rUTAH

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

relative

UTAH

fixed

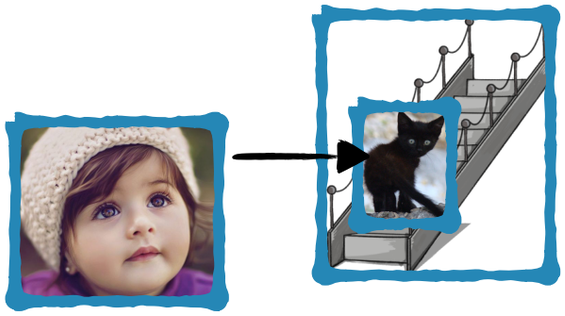
2. Exploring how a linking theory could be derived from children's input

relative

fixed

The Plan

The little girl *blicked* the kitten on the stairs.



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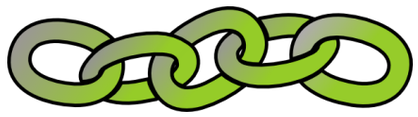


rUTAH

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

relative

UTAH

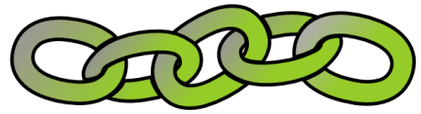
fixed

2. Exploring how a linking theory could be derived from children's input

relative

fixed

Evaluating different linking theory proposals using developmental modeling



rUTAH

UTAH

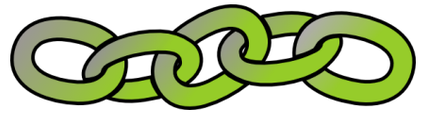
Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

relative

fixed

Goal:
Build a modeled learner who learns close enough to how real children learn to tell us something informative about these linking theory proposals

Evaluating different linking theory proposals using developmental modeling



rUTAH

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

relative

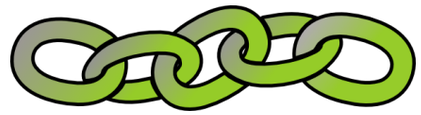
UTAH

fixed

Goal:
Build a modeled learner who learns close enough to how real children learn to tell us something informative about these linking theory proposals

What's close enough?

Evaluating different linking theory proposals using developmental modeling



rUTAH

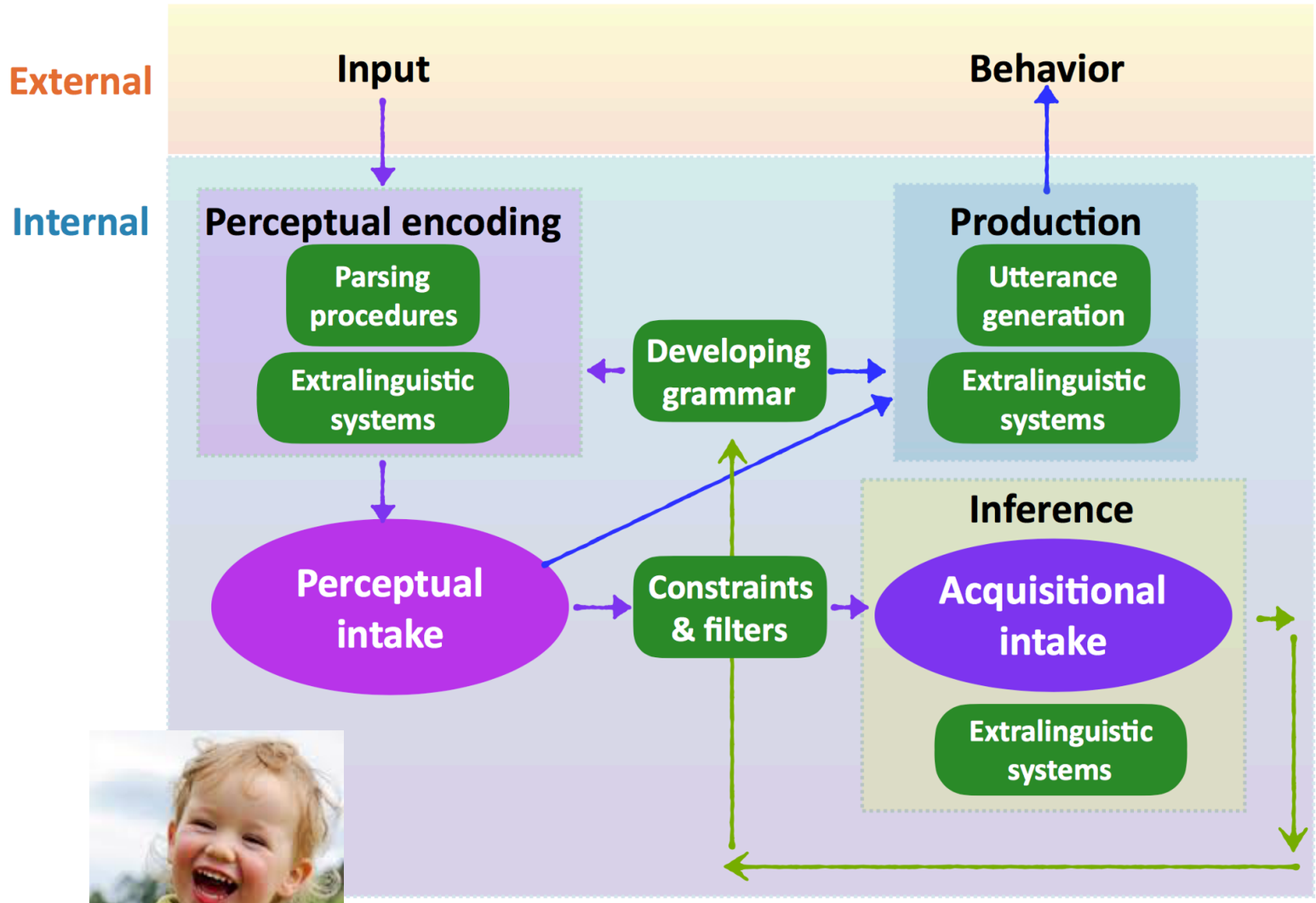
Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

relative

UTAH

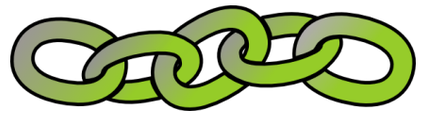
fixed

Close enough to this process



Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



rUTAH

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

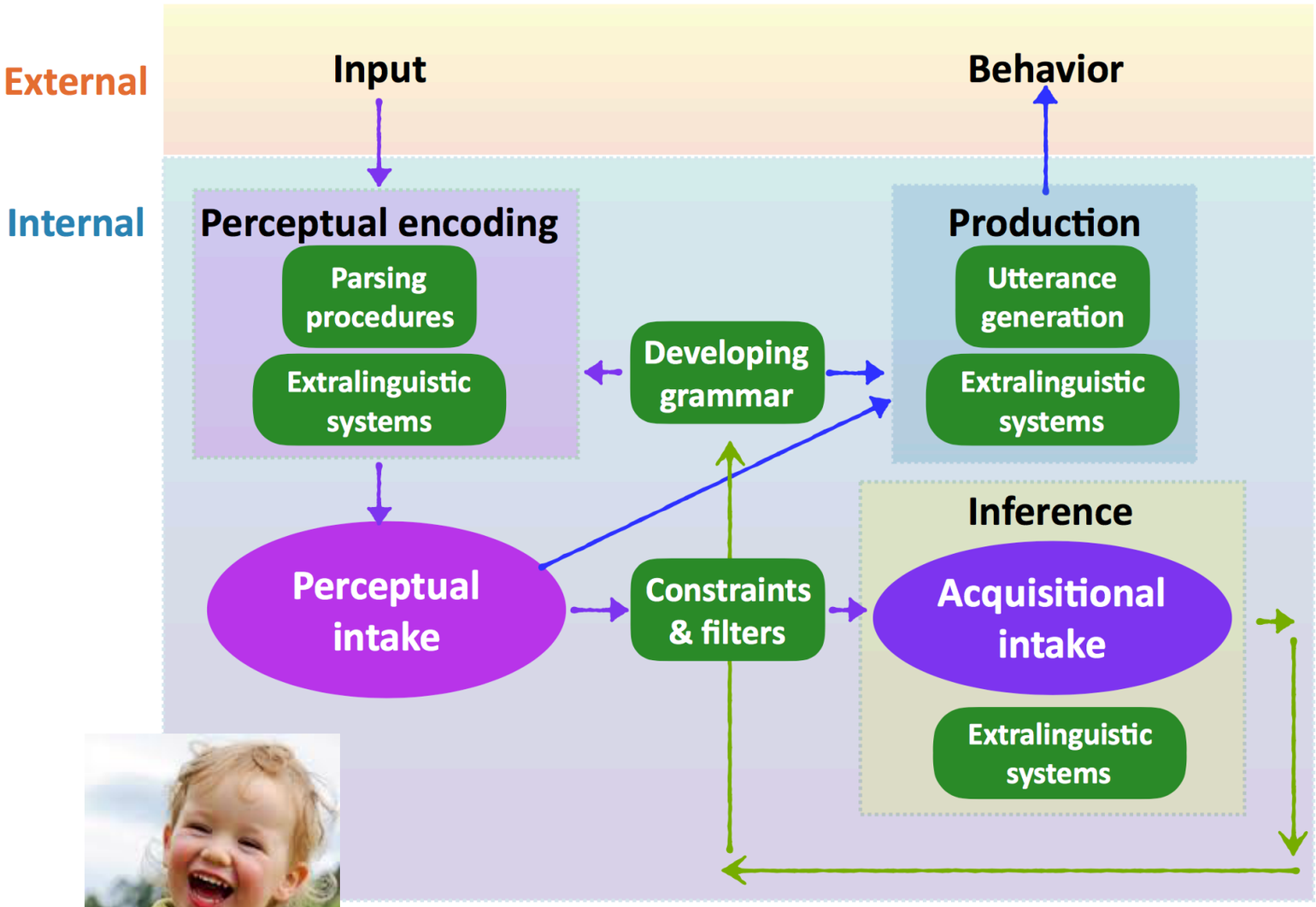
relative

UTAH

fixed

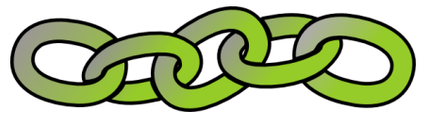
Close enough to this process

…which has a lot going on. It can be helpful when developmental modeling to think about five main parts.



Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



rUTAH

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

relative

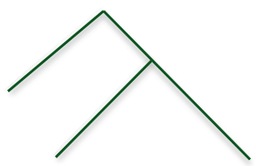
UTAH

fixed

five main parts

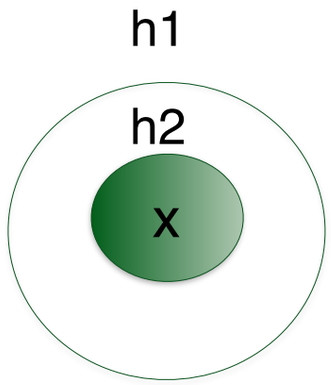
initial state

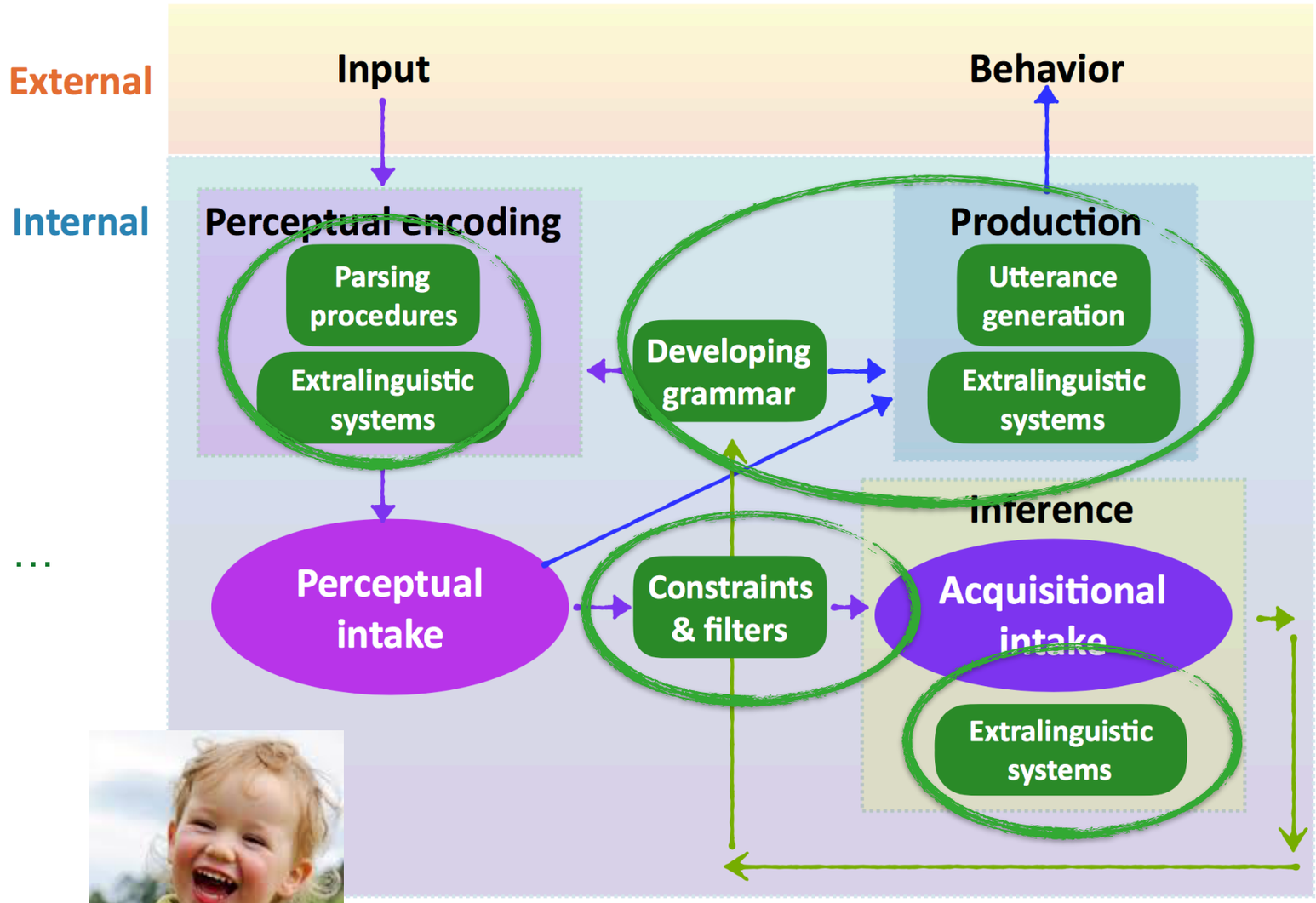
What does the child **start with**?
What knowledge, abilities, and learning biases does the child already have?



N, V, Adj, P, …

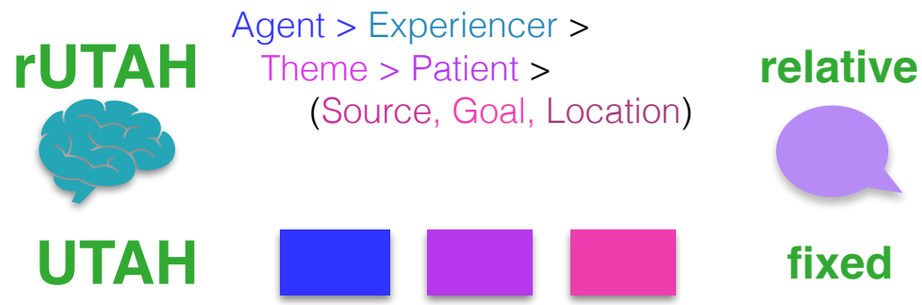
Agent, Patient, Goal, …





Pearl *in press*

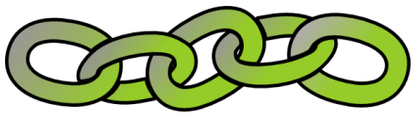
Evaluating different linking theory proposals using developmental modeling



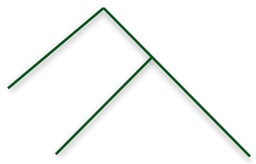
five main parts

initial state

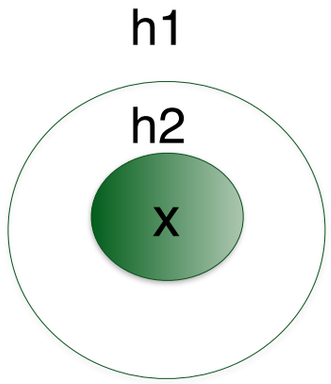
What does the child **start with**?
What knowledge, abilities, and learning biases does the child already have?

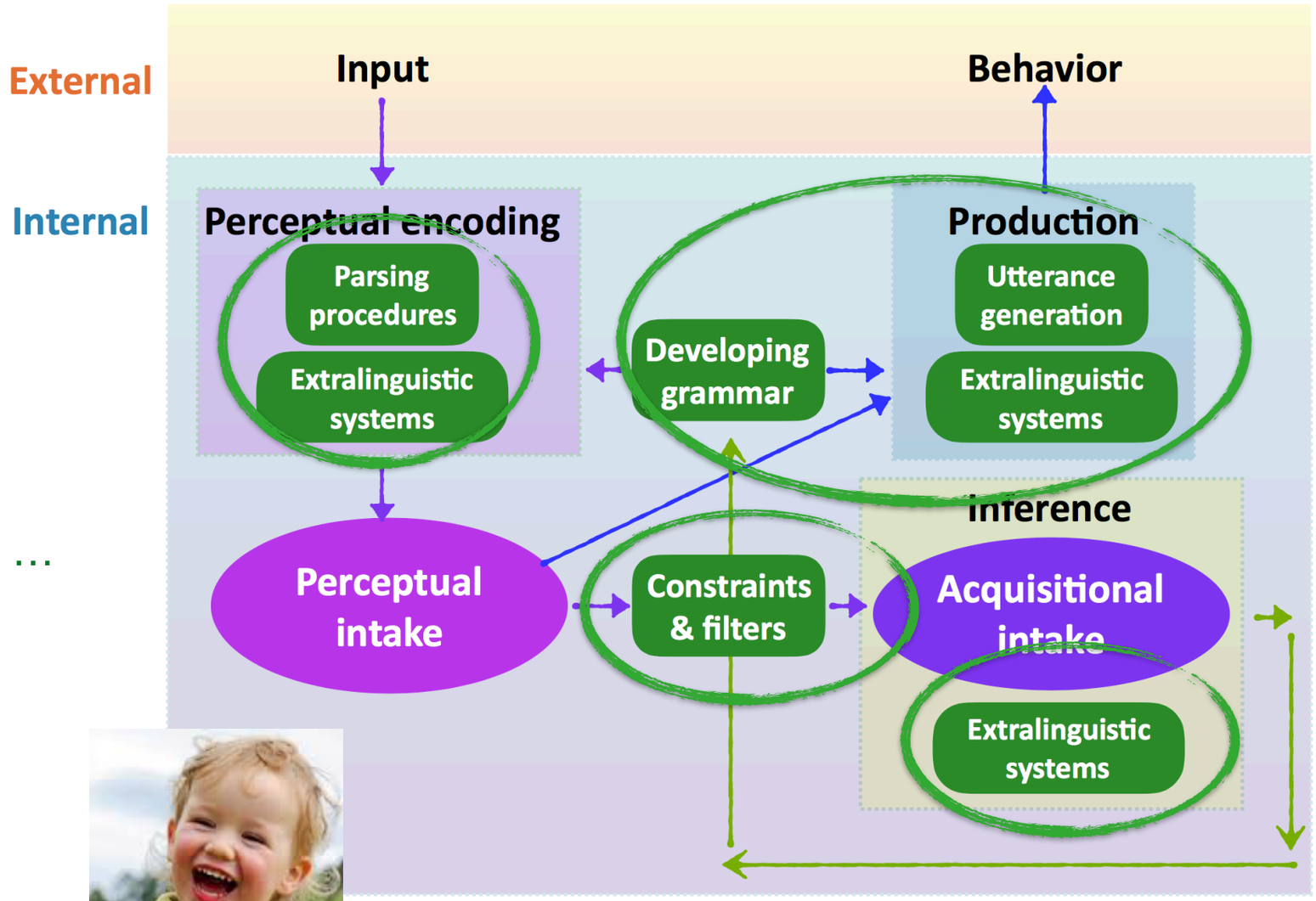


N, V, Adj, P, …



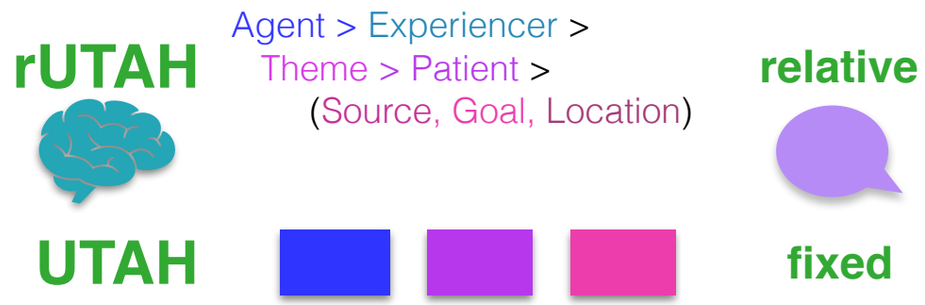
Agent, Patient, Goal, …





Pearl *in press*

Evaluating different linking theory proposals using developmental modeling

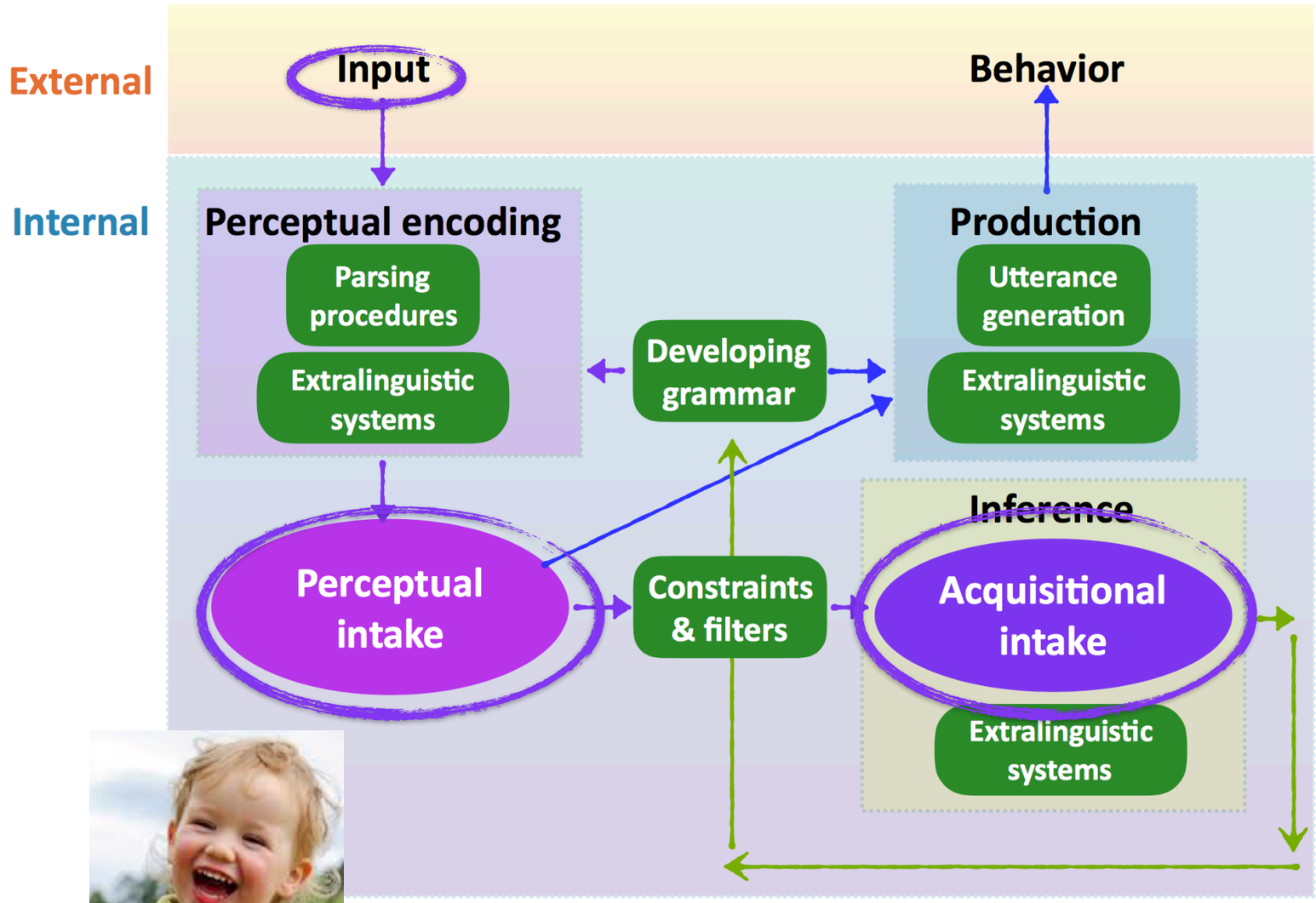


five main parts

initial state 

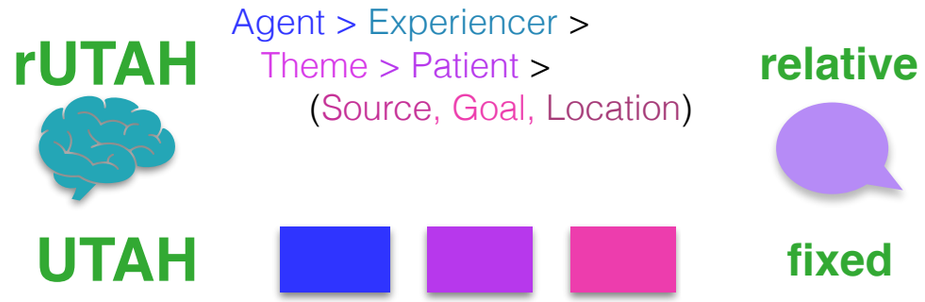
data intake

How does the modeled child perceive the input (= perceptual intake)? What part of the perceived data is used for acquisition (= **acquisitional intake**)?



Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



five main parts

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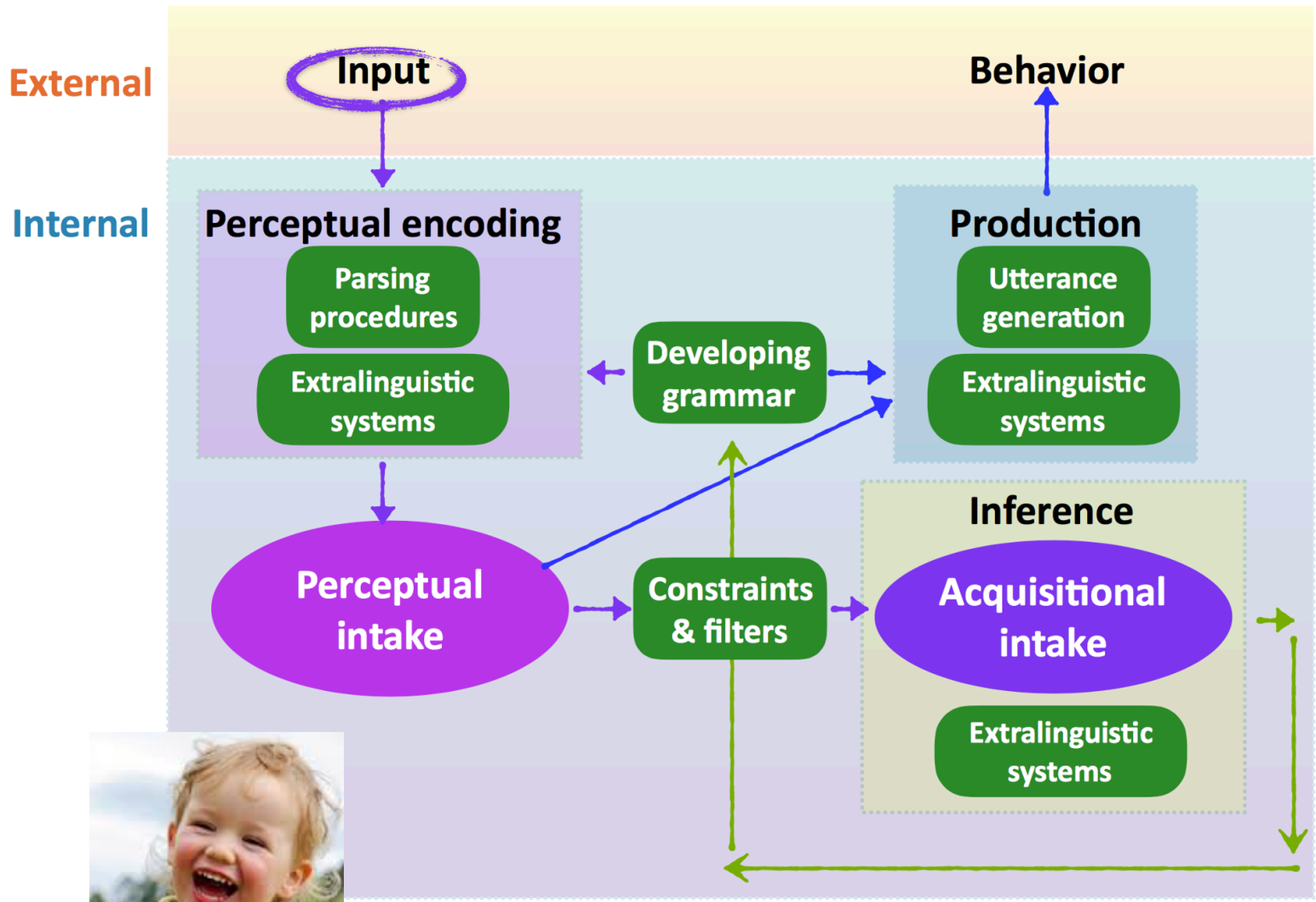
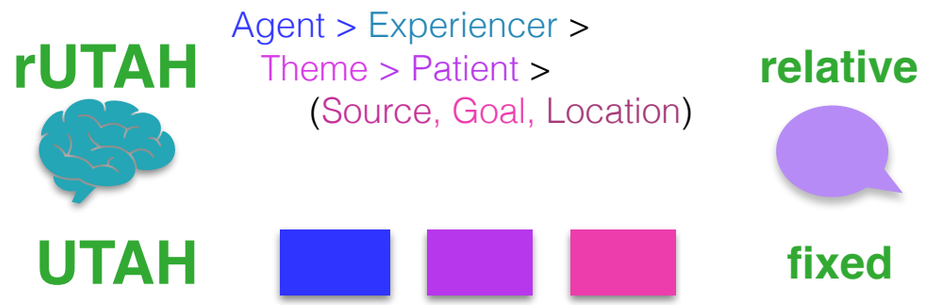
How does the modeled child perceive the input (= perceptual intake)? What part of the perceived data is used for acquisition (= **acquisitional intake**)?

The kitten was *blicked* by the little girl.



Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



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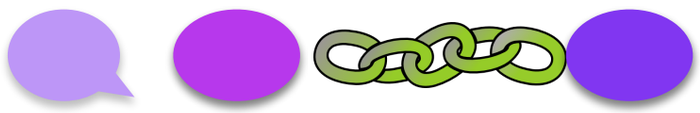

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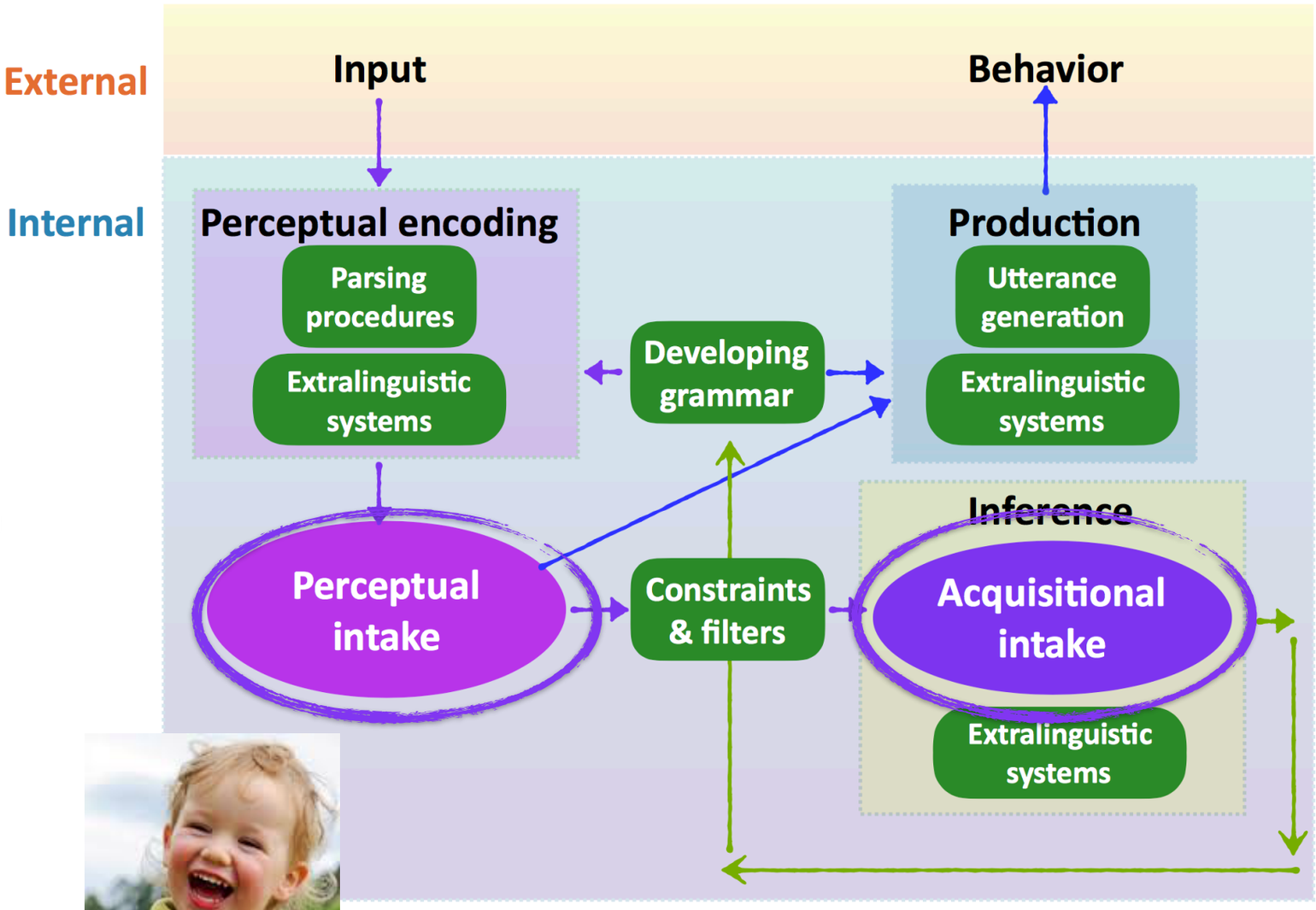
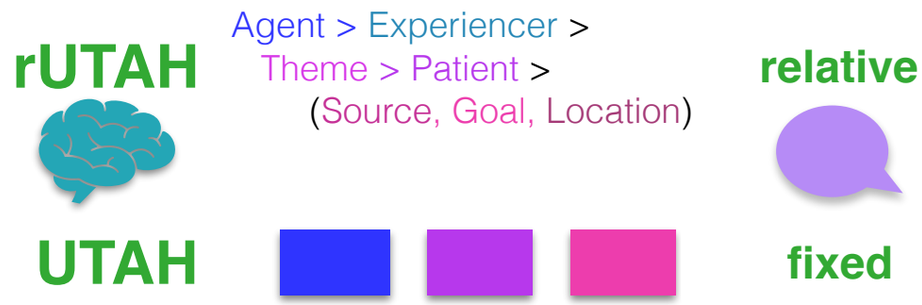


Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



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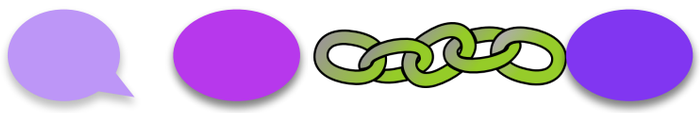
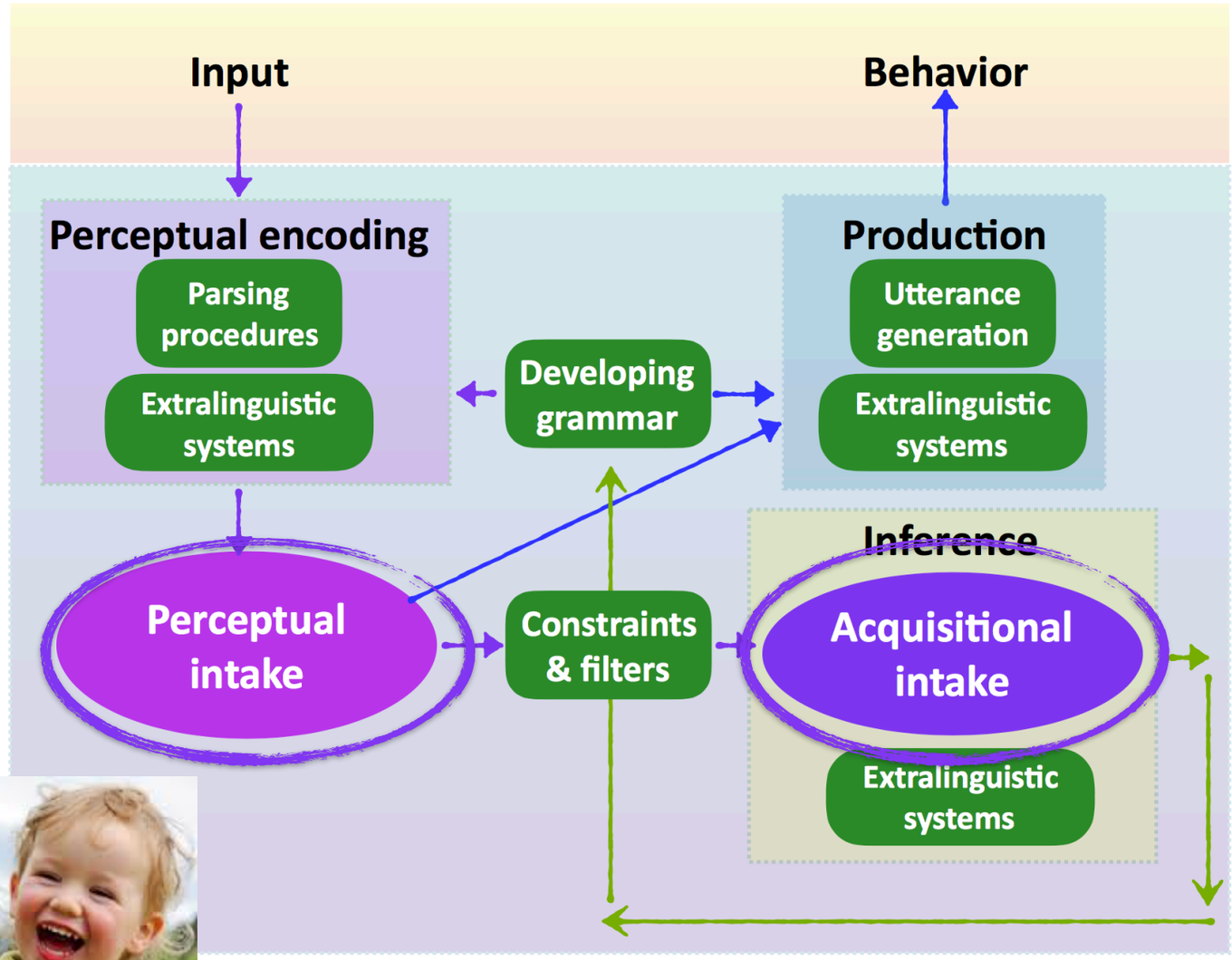


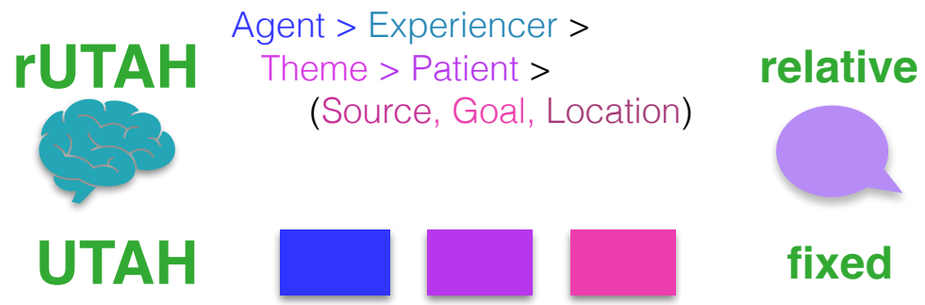
The kitten was *blicked* by the little girl.

blick:
proto-Patient = Subject
proto-Agent = Oblique



Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



five main parts

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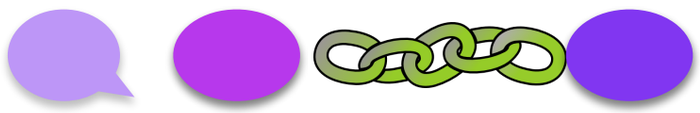

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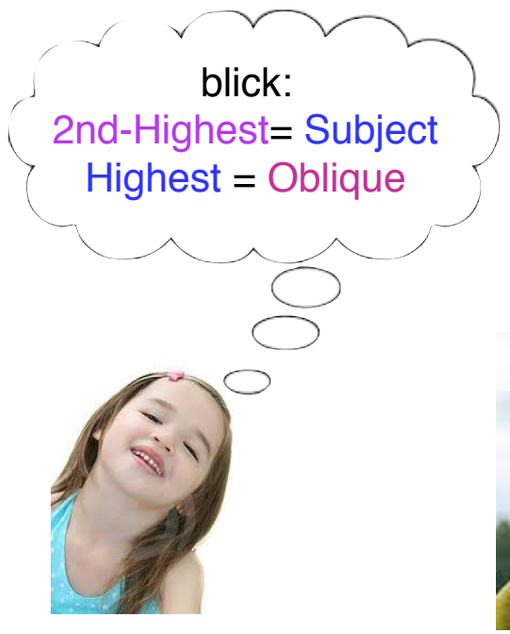
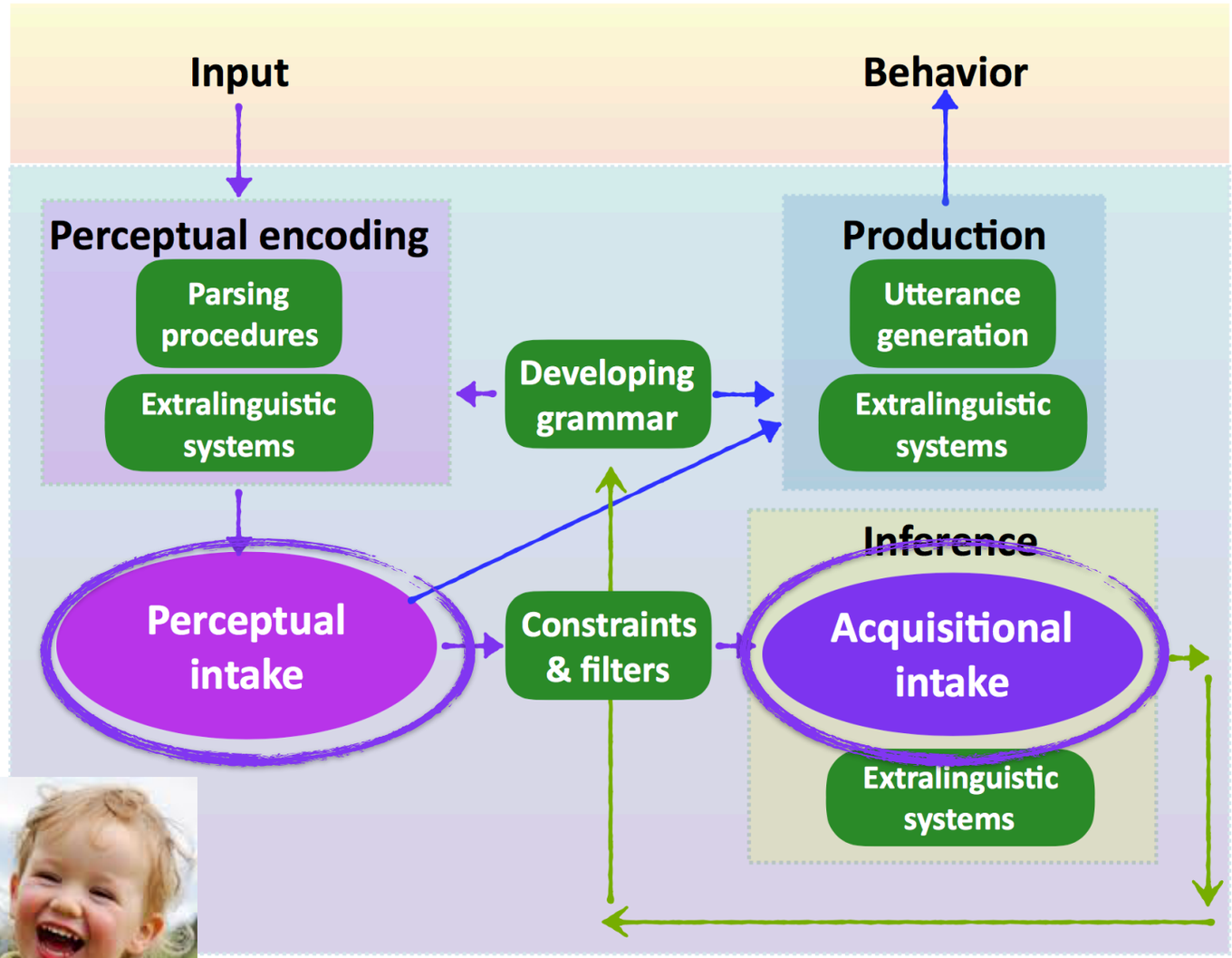
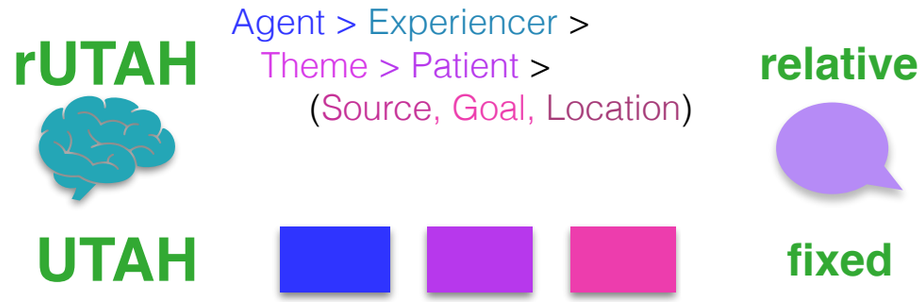




Pearl *in press*

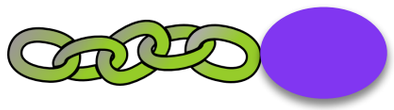
Evaluating different linking theory proposals using developmental modeling



five main parts

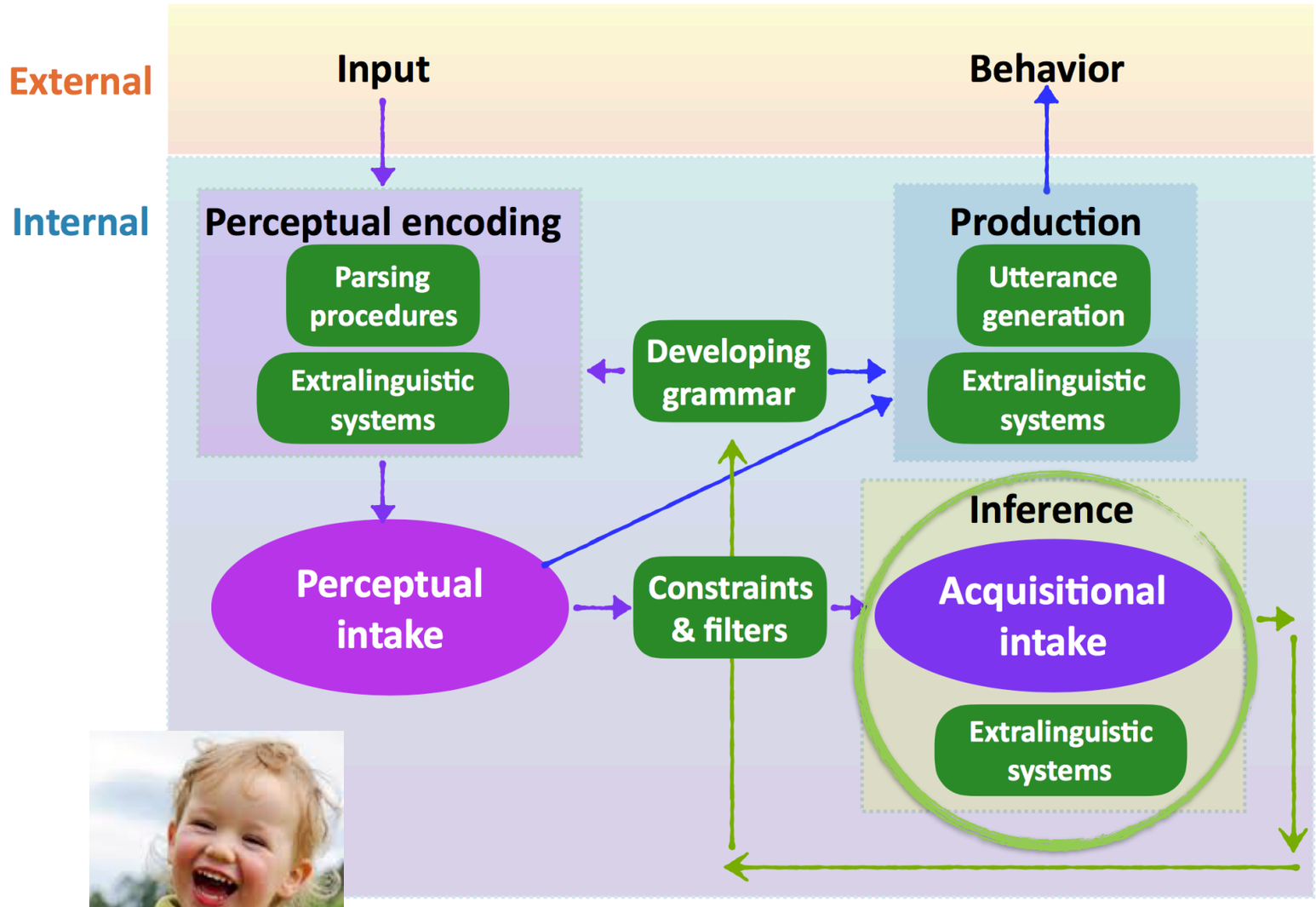
initial state

data intake



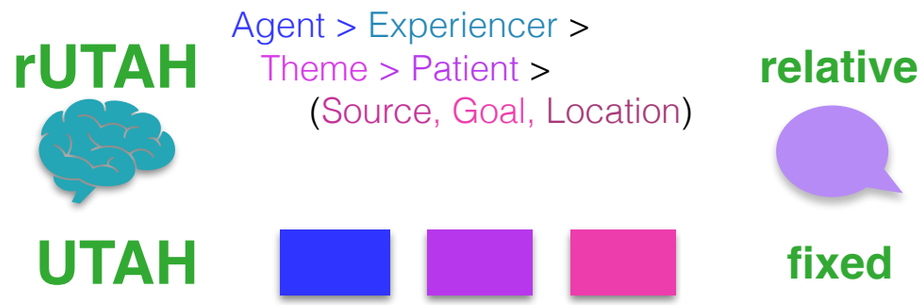
inference

How are updates made to the modeled child's internal representations?



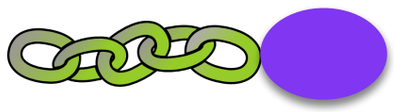
Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



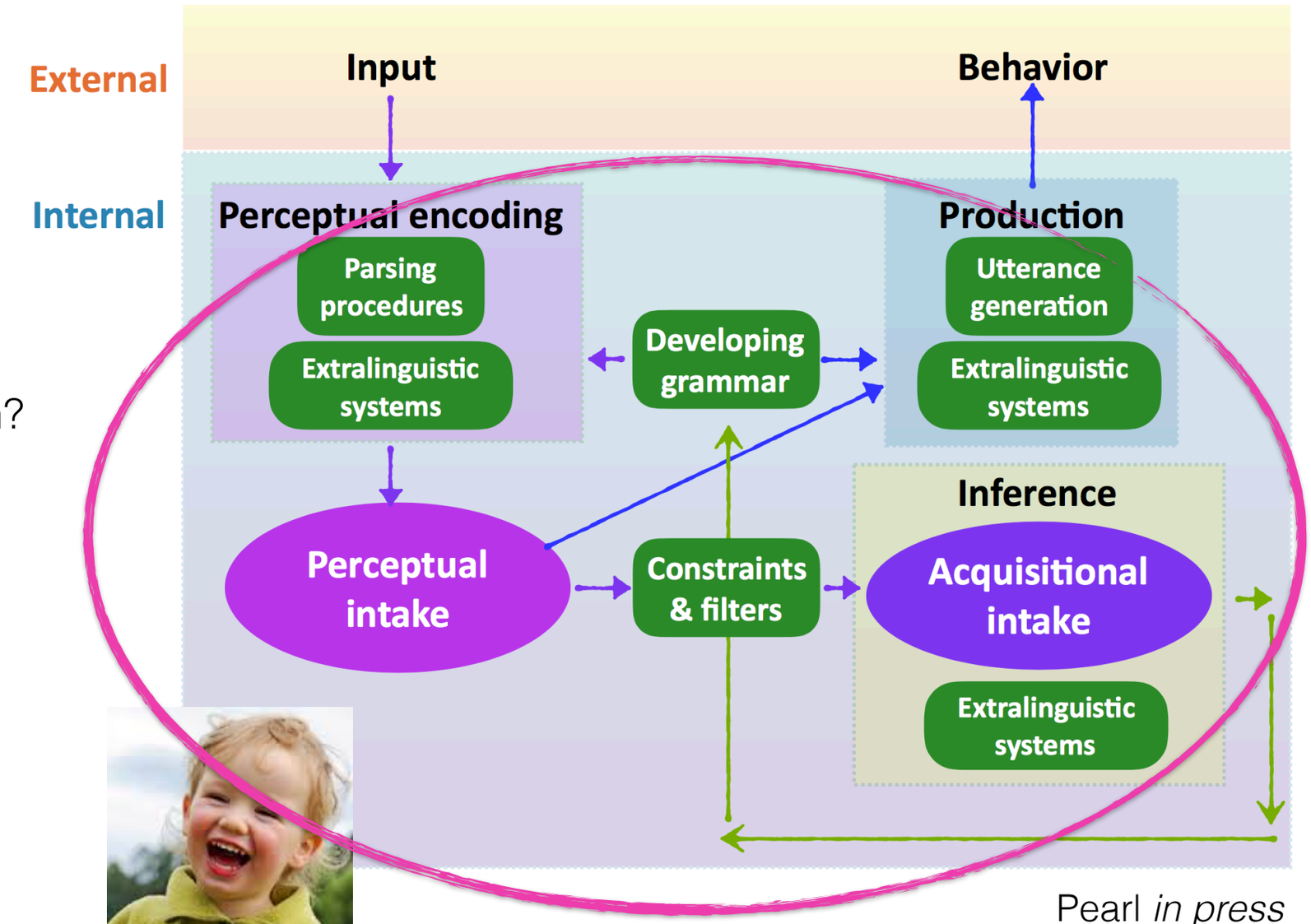
five main parts

initial state



data intake

inference



Pearl *in press*

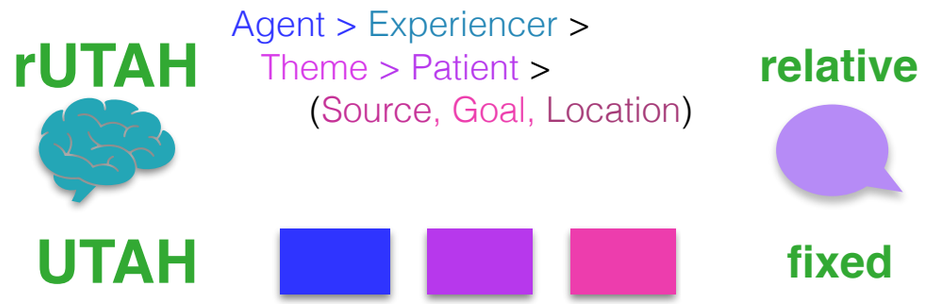
learning period

How long does the child have to learn?

ex: 3 years, ~1,000,000 data points

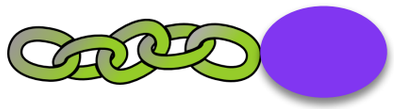
ex: 4 months, ~36,500 data points

Evaluating different linking theory proposals using developmental modeling



five main parts

initial state



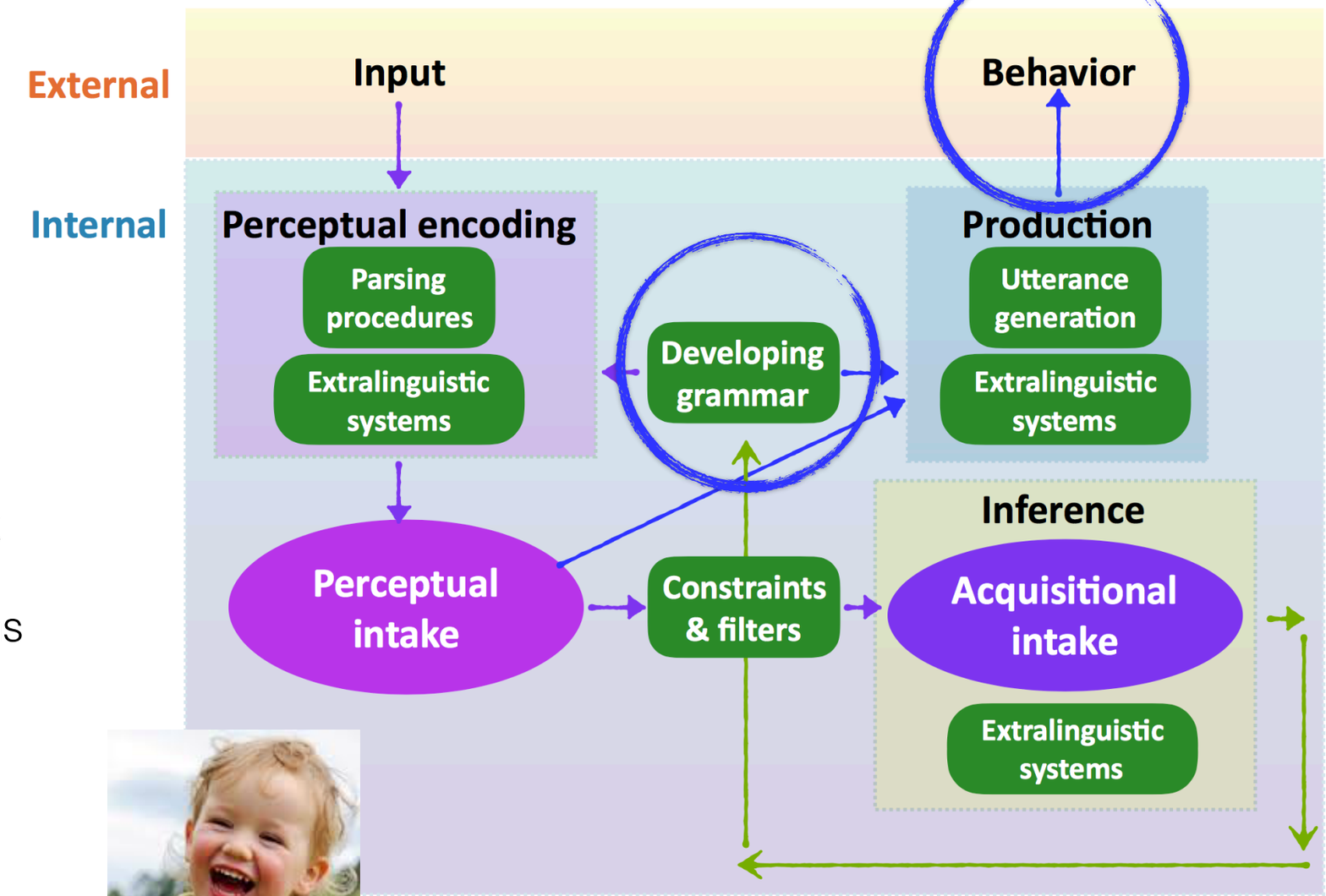
data intake

inference

learning period

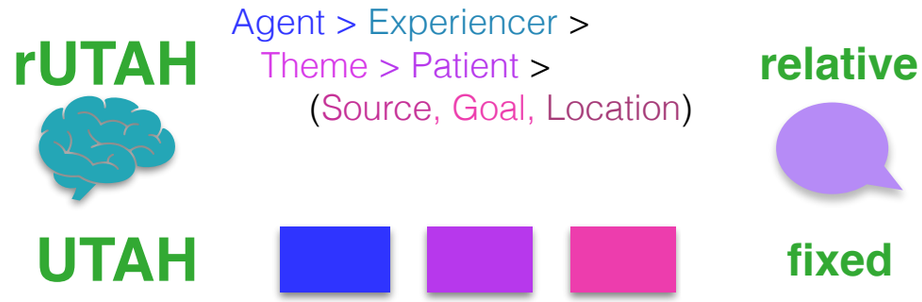
target state

What does successful acquisition look like? What knowledge is the child trying to attain (often assessed in terms of observable behavior)?



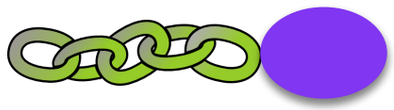
Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



five main parts

initial state



data intake

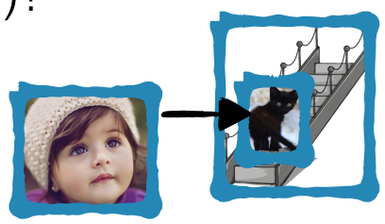
inference

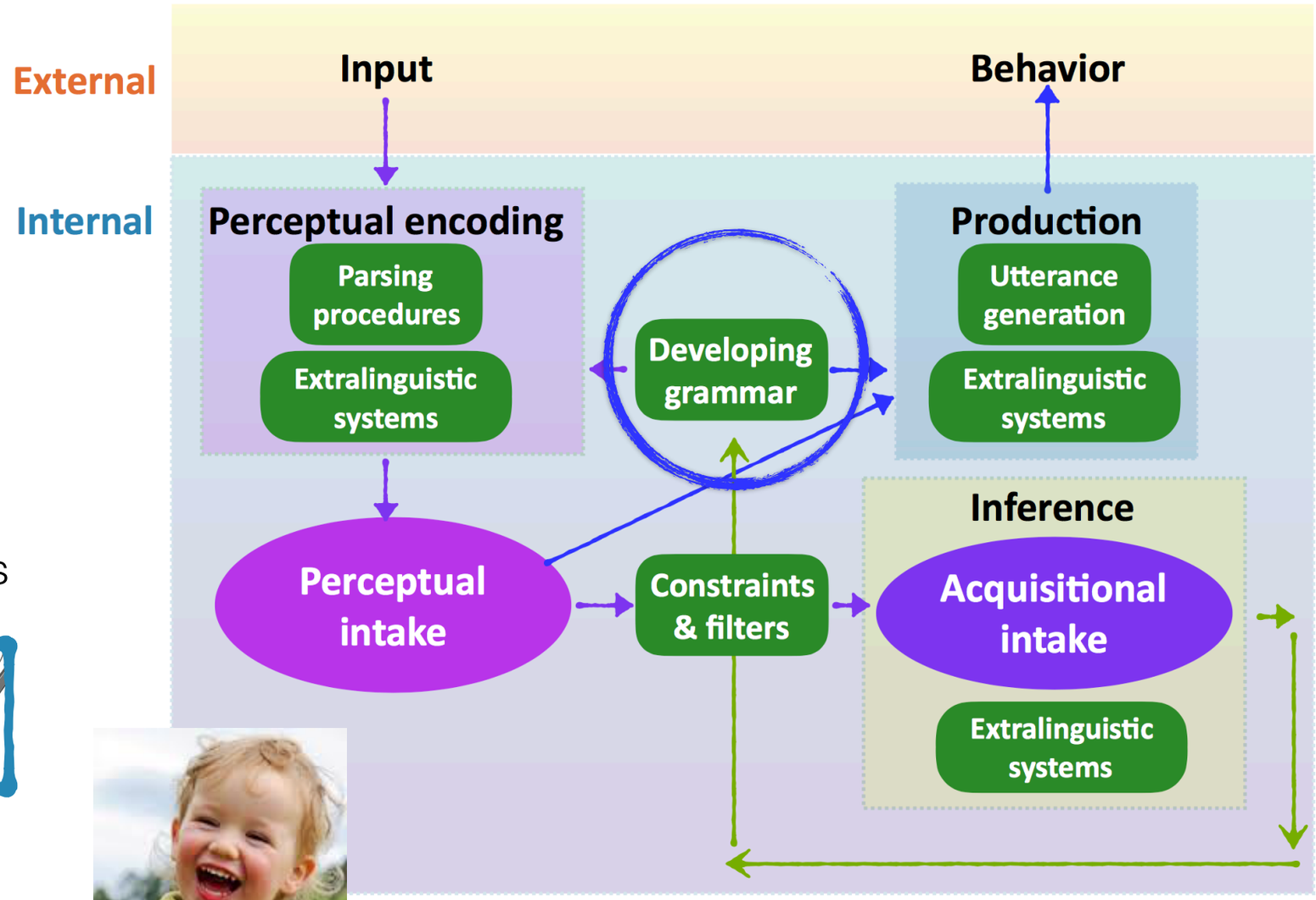
learning period

target state

What does successful acquisition look like? What **knowledge** is the child trying to attain (often assessed in terms of observable behavior)?

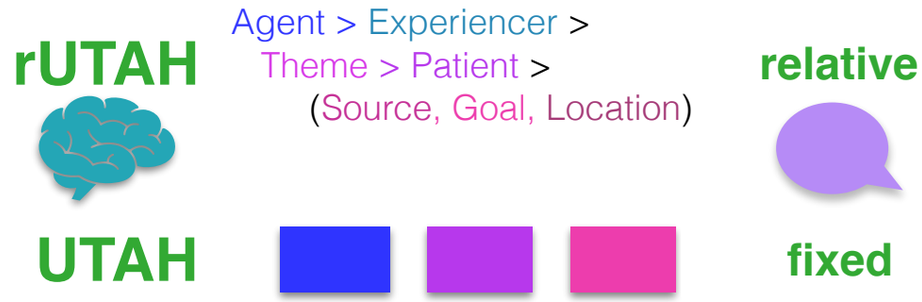
The little girl *blicked* the kitten on the stairs.





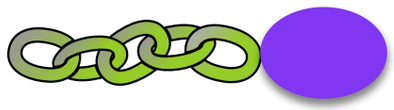
Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



five main parts

initial state



data intake

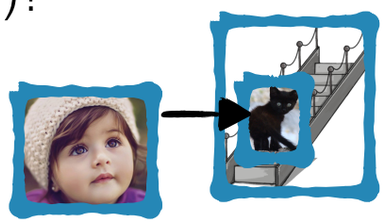
inference

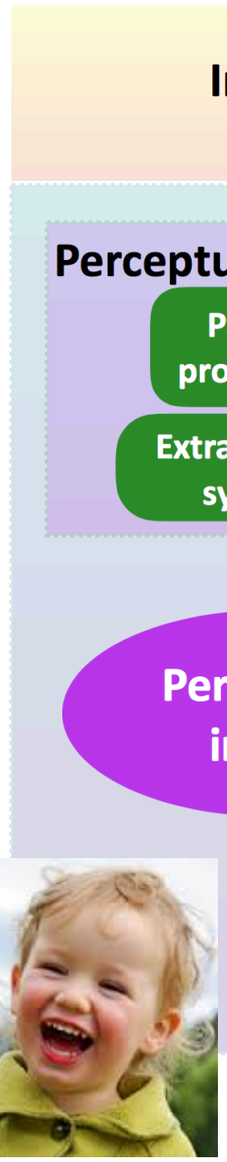
learning period

target state

What does successful acquisition look like? What **knowledge** is the child trying to attain (often assessed in terms of observable behavior)?

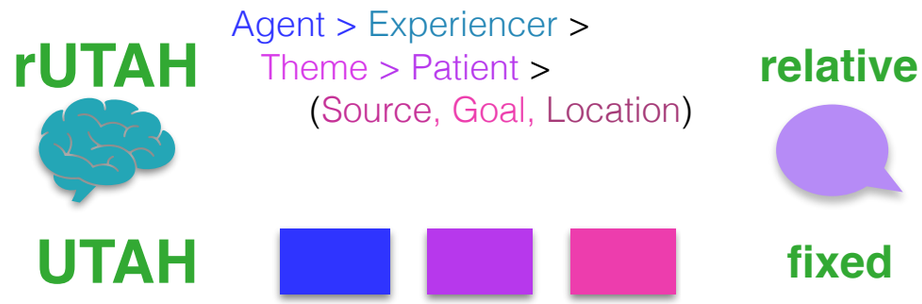
blick pet touch kiss hug





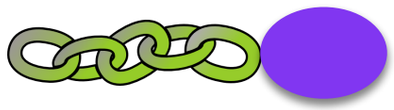
Pearl *in press*

Evaluating different linking theory proposals using developmental modeling



five main parts

initial state



data intake

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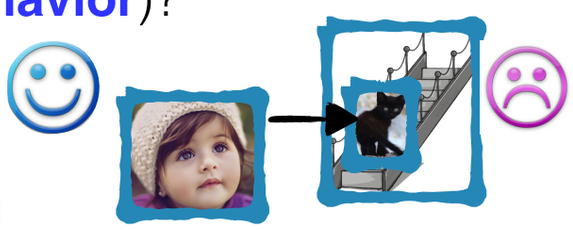
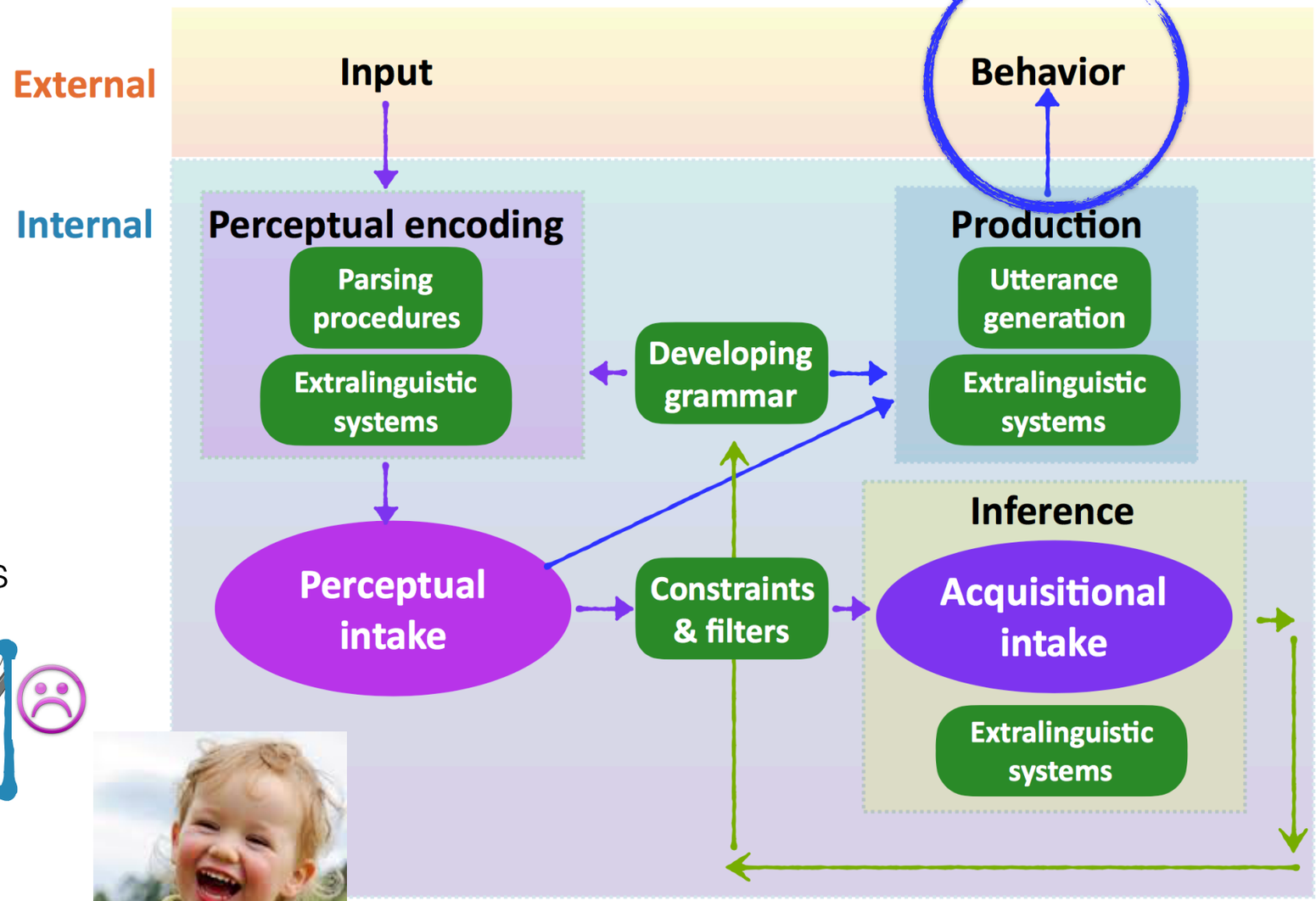
What does successful acquisition look like? What knowledge is the child trying to attain (often assessed in terms of **observable behavior**)?

blick pet touch kiss hug



interpretations or productions in context



Pearl *in press*

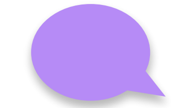
Evaluating different linking theory proposals
using developmental modeling

rUTAH

UTAH

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

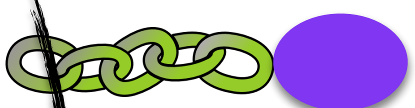
relative



fixed

five main parts

initial state

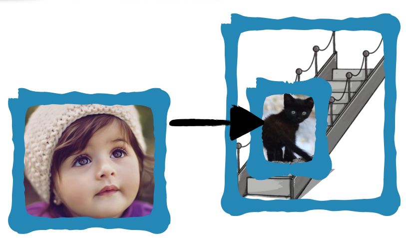


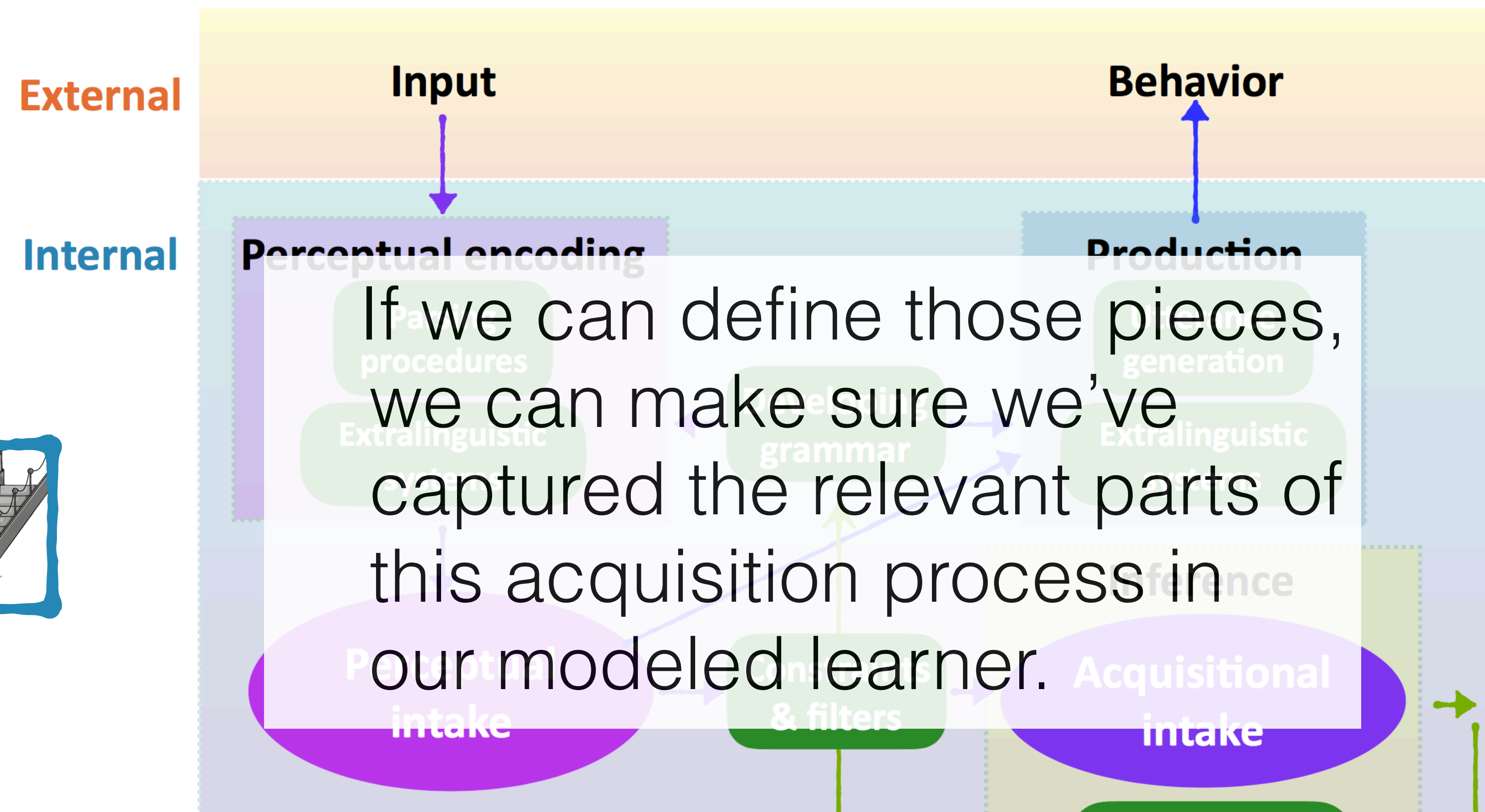
data intake

inference

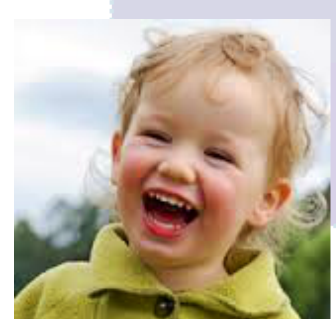
learning period

target state



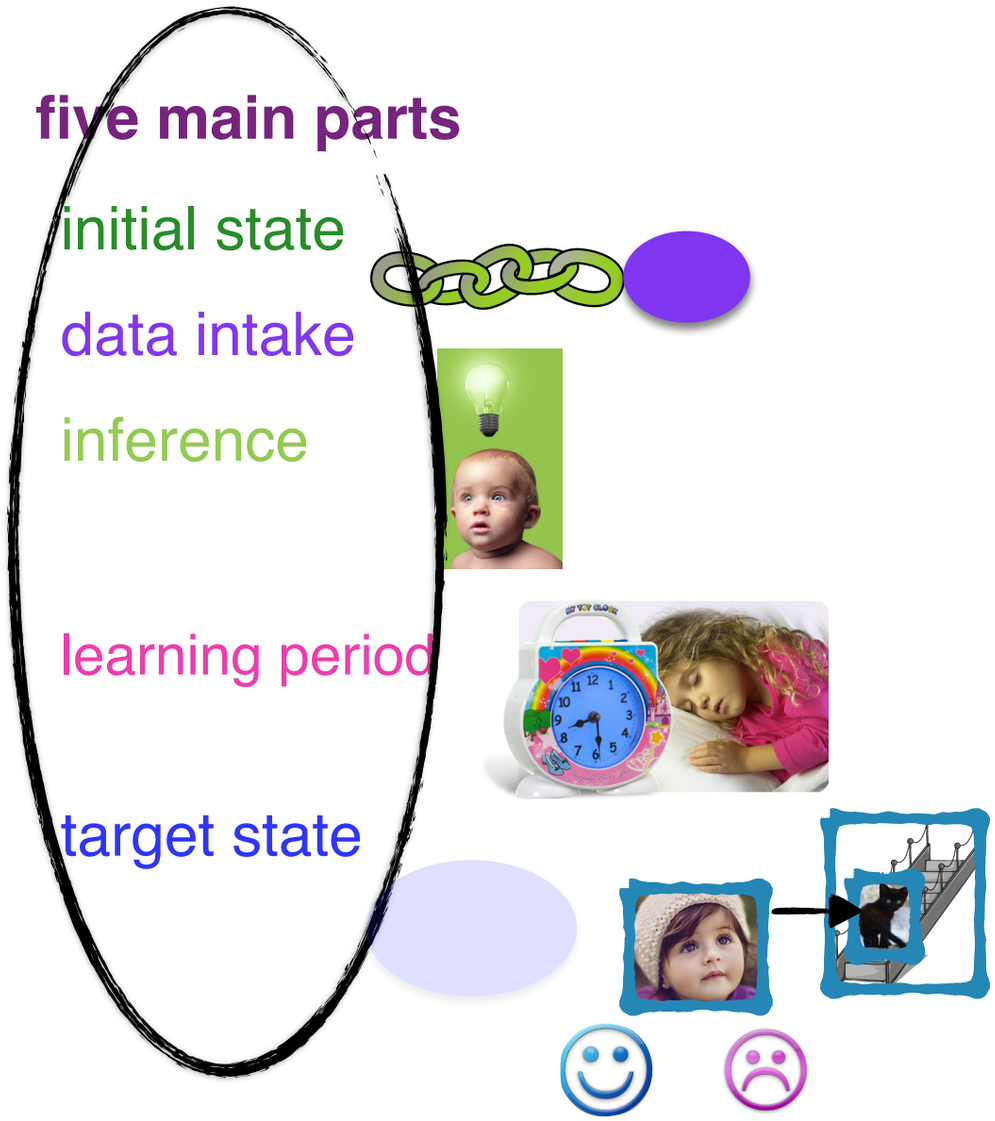


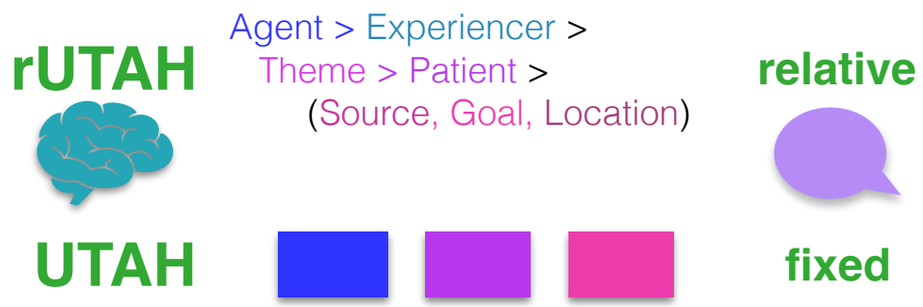
If we can define those pieces, we can make sure we've captured the relevant parts of this acquisition process in our modeled learner.



Pearl *in press*

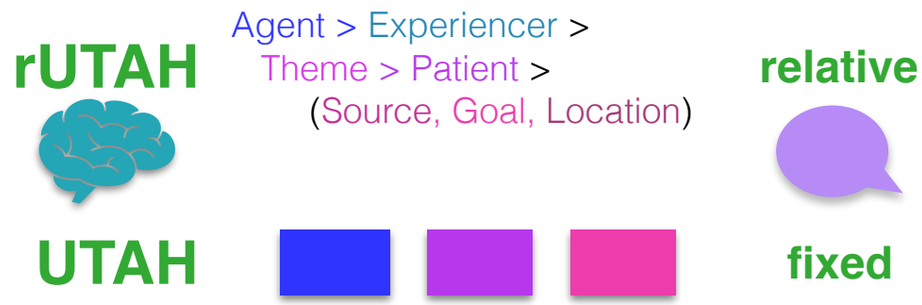
Evaluating different linking theory proposals using developmental modeling

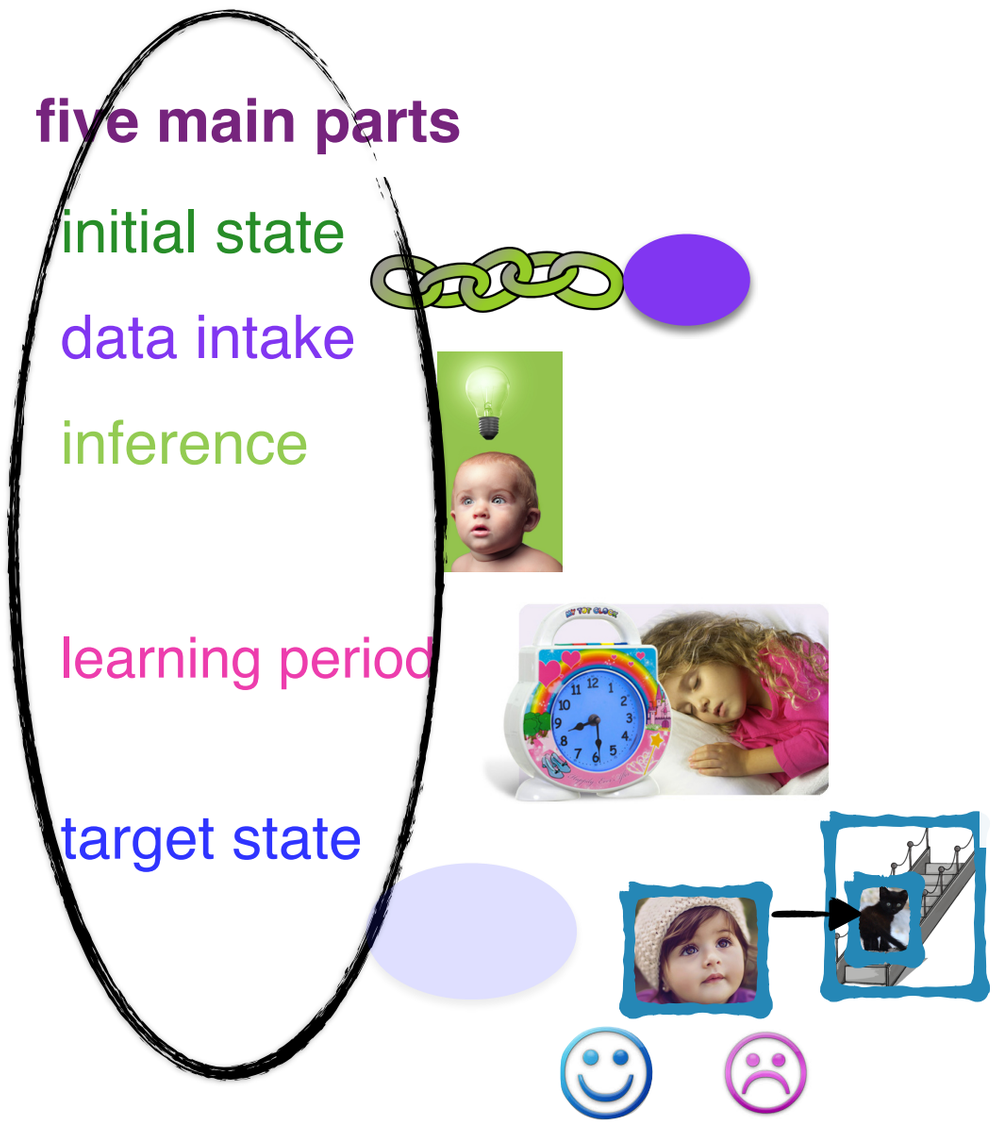




So let's do this for modeled learners who implement different linking theory proposals.

Evaluating different linking theory proposals using developmental modeling





Goal: Model the developmental trajectory of verb class knowledge from 3 to 4 to 5 years old in English

Pearl & Sprouse 2018a

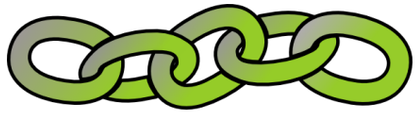
Evaluating different linking theory proposals using developmental modeling

data intake

inference
learning period

target state

initial state



rUTAH

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

relative

UTAH

fixed

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

data intake

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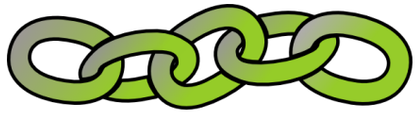

Cognitive plausibility check?

rUTAH

Agent > Experiencer >
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(Source, Goal, Location)

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fixed

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

data intake

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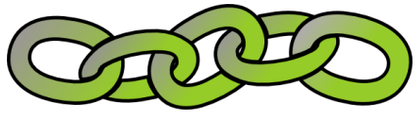


rUTAH

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

relative

UTAH

fixed

Cognitive plausibility check?

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)

Pearl & Sprouse 2018a

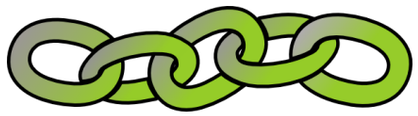
Evaluating different linking theory proposals using developmental modeling

data intake

inference
learning period

target state

initial state



rUTAH

UTAH

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

relative

fixed

Children are also sensitive to the animacy of verb arguments.

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

The little girl *blicked* the kitten on the stairs.

+animate

+animate

-animate

Pearl & Sprouse 2018a

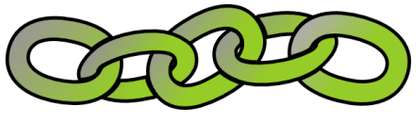
Evaluating different linking theory proposals using developmental modeling

data intake

inference
learning period

target state

initial state



rUTAH

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

relative

UTAH

fixed

+animate

-animate

Children pay attention to the linguistic context of a verb (its syntactic frame) to figure out how it behaves (e.g., Fisher et al. 2010, Gutman et al. 2015, Harrigan et al. 2016).

The little girl *blicked* the kitten on the stairs.

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

data intake

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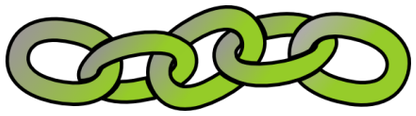

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Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

UTAH

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The little girl *blicked* the kitten on the stairs.

NP ___ NP PP

Pearl & Sprouse 2018a

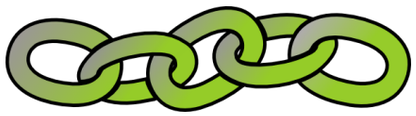
Evaluating different linking theory proposals using developmental modeling

data intake

inference
learning period

target state

initial state



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

rUTAH

UTAH

relative

fixed

+animate

-animate

NP ___ NP PP

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state

inference
learning period

target state

input that yields data intake



The little girl *blicked* the kitten on the stairs.

Samples of child-directed speech

CHILDES Treebank

Pearl & Sprouse 2013

<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

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state

inference
learning period

target state

data intake

The little girl *blicked* the kitten on the stairs.
NP ___ NP PP

NP ___ NP PP -surface morphology

NP ___$_{+past}$ NP PP +surface morphology

Children may either ignore verb surface morphology (like the past tense marker -ed) or pay attention to it when encoding the syntactic frame information.

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state

inference
learning period

target state

data intake

+animate **+animate** **-animate**

The little girl *blicked* the kitten on the stairs.

NP ___ NP PP -surface morphology

NP ___**+past** NP PP +surface morphology

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state inference learning period target state

data intake



+animate **+animate** **-animate**

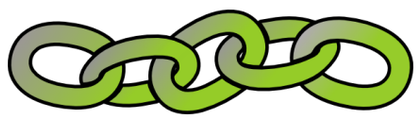
The little girl *blicked* the kitten on the stairs.

NP ___ NP PP -surface morphology

NP ___**+past** NP PP +surface morphology

rUTAH

UTAH



relative

fixed

blick:
3 no-movement

+expect-mapping

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state

inference
learning period

target state

data intake



+animate **+animate** **-animate**

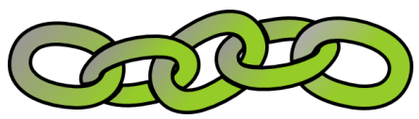
The little girl *blicked* the kitten on the stairs.

NP ___ NP PP -surface morphology

NP ___**+past** NP PP +surface morphology

rUTAH

UTAH



relative

fixed

blick:
Subject = proto-Agent
Object = proto-Patient
Oblique = Other

-expect-mapping

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state

inference
learning period

target state

data intake



+animate **+animate** **-animate**

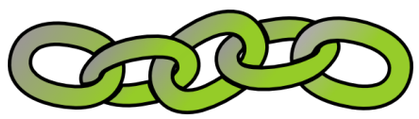
The little girl *blicked* the kitten on the stairs.

NP ___ NP PP -surface morphology

NP ___**+past** NP PP +surface morphology

rUTAH

UTAH



relative

fixed

blick:
Subject = Highest
Object = 2nd-Highest
Oblique = 3rd-Highest

-expect-mapping

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference
learning period

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

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference

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

learning period

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.

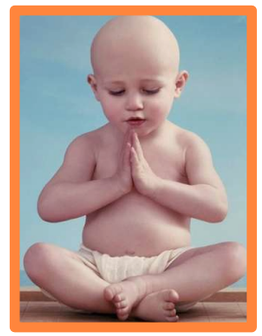
Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference

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



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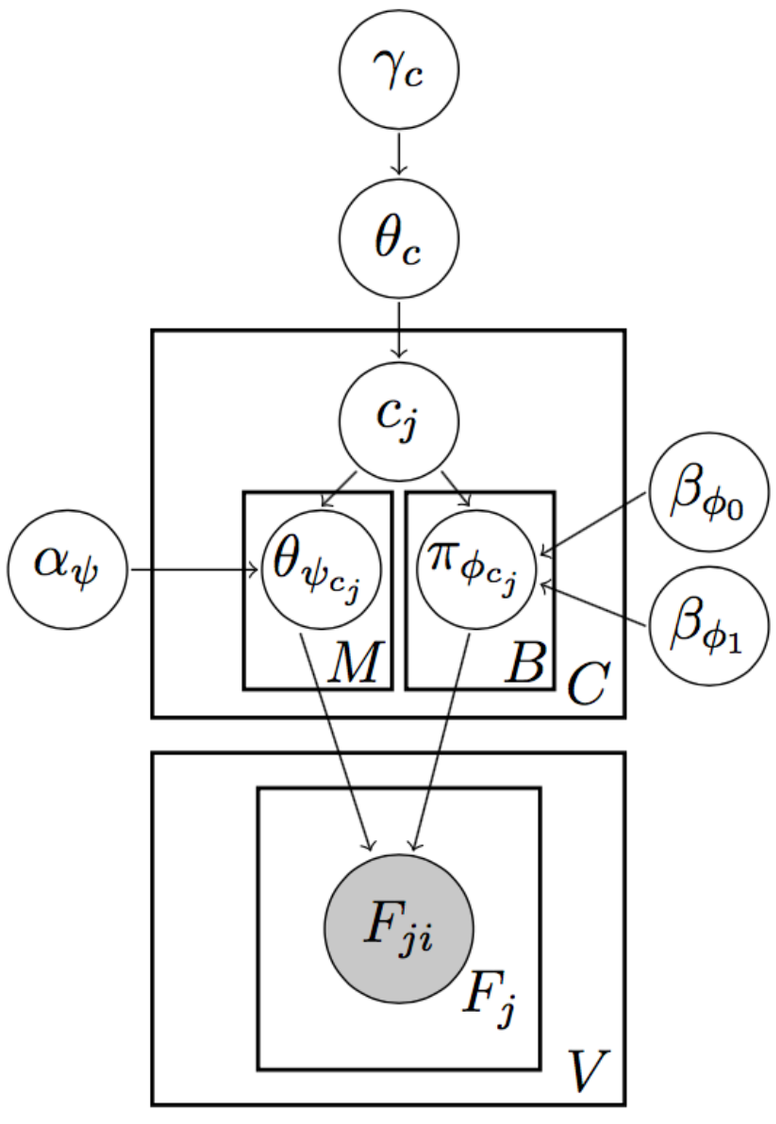
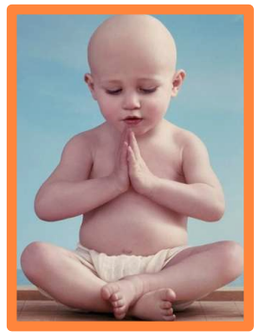


Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

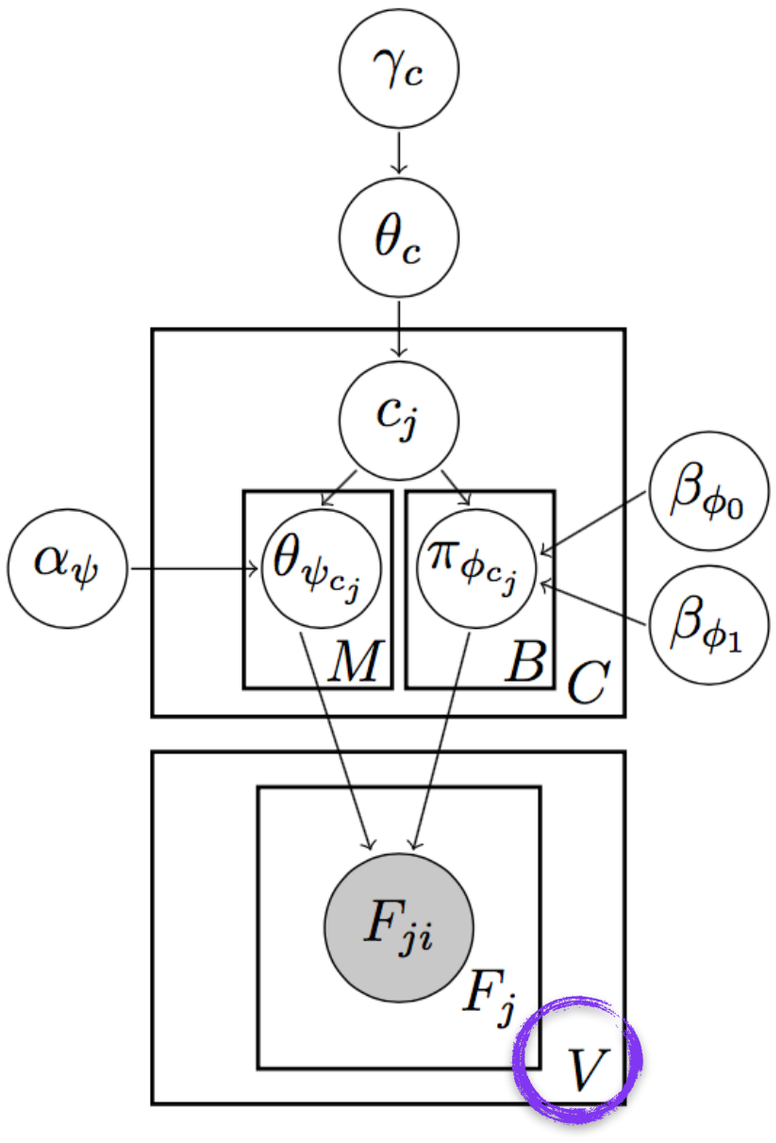


Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

inference

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

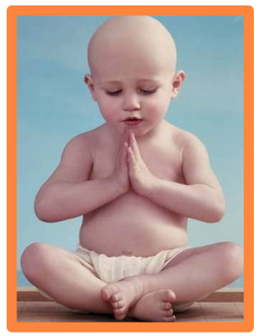
FALL



Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

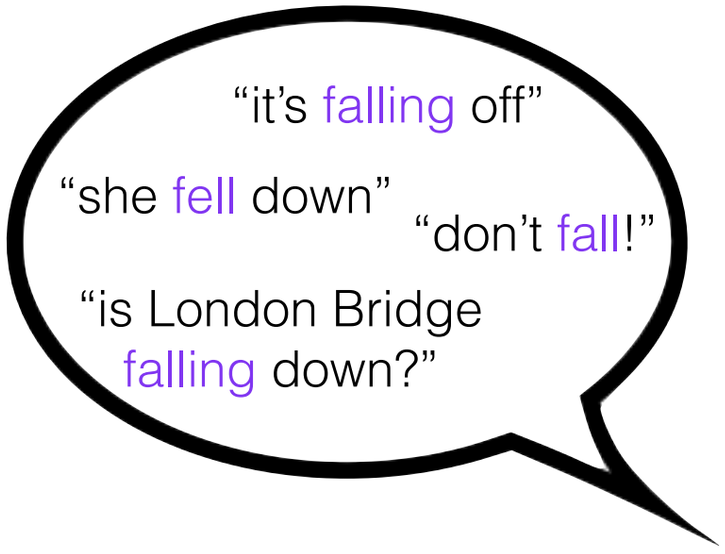


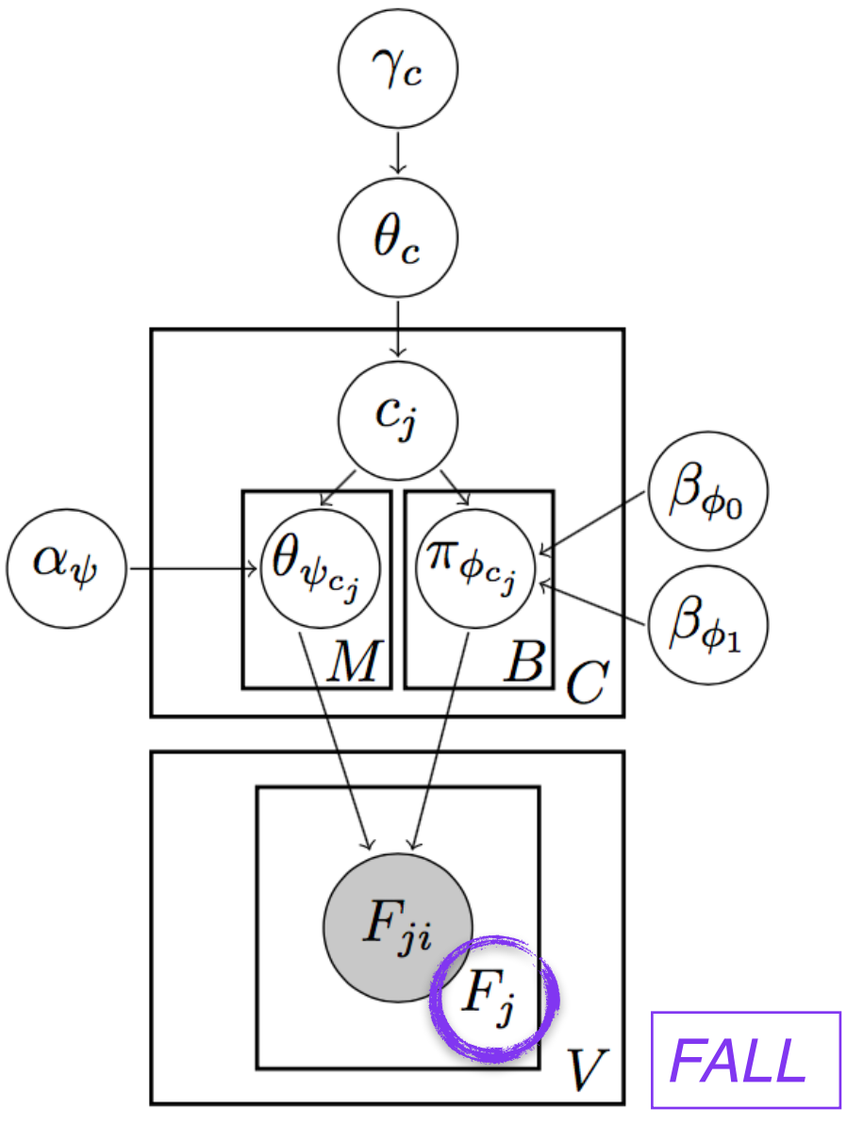
Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

inference

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

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





Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference

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

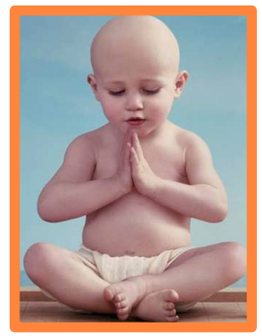
Each instance is observed **some number of times**.

(3x) "it's falling off"

"she fell down"

"don't fall!"

"is London Bridge falling down?"



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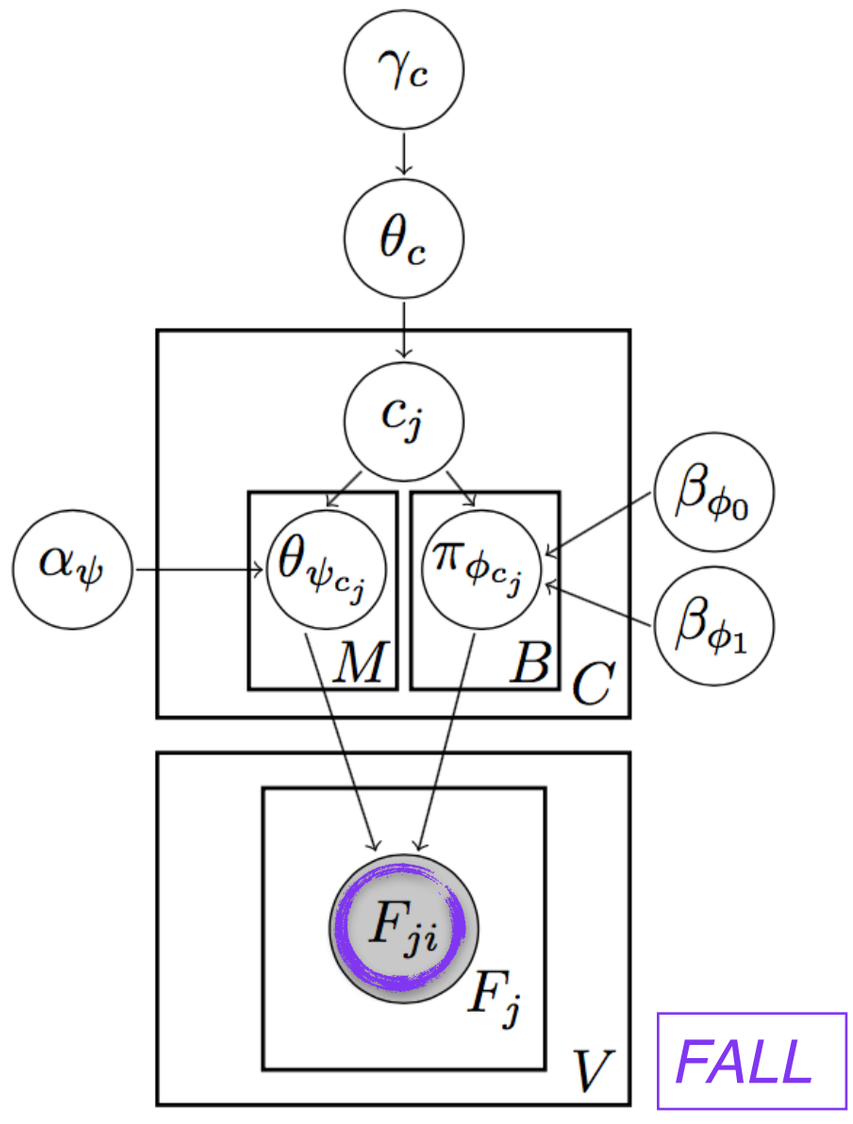
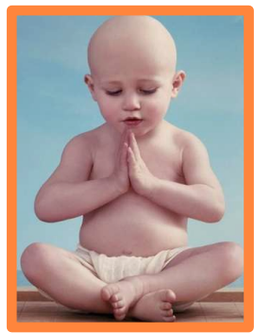


Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

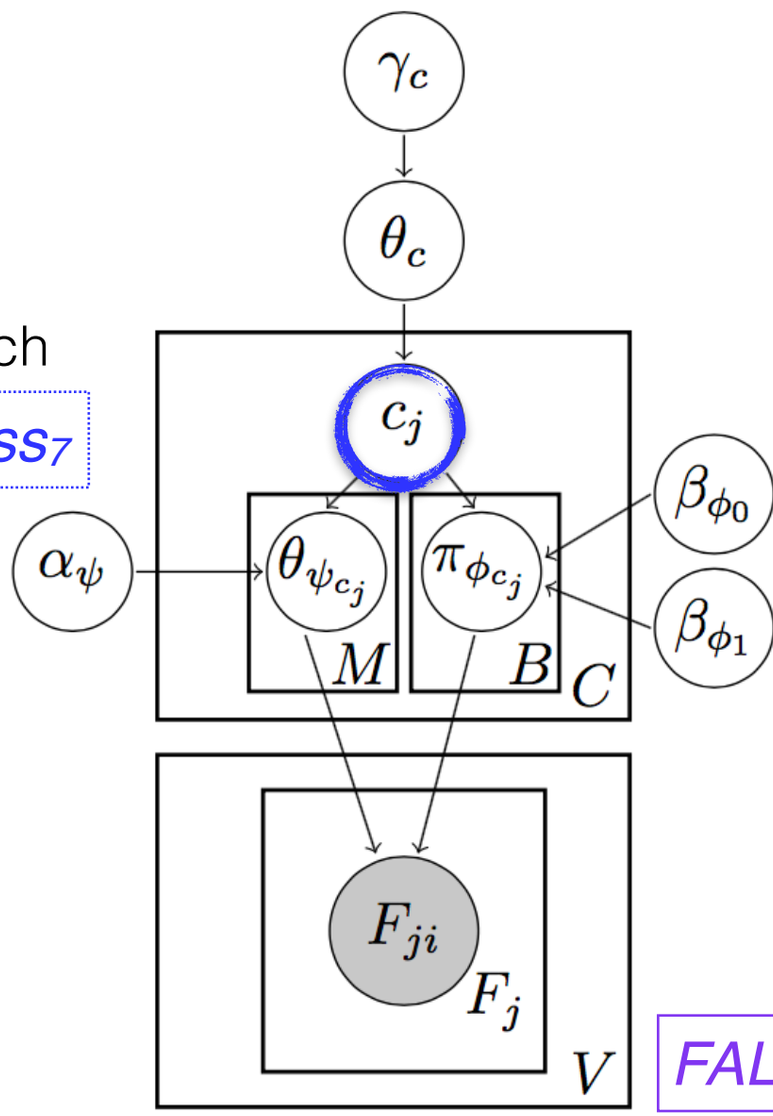
inference



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

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

class7



FALL

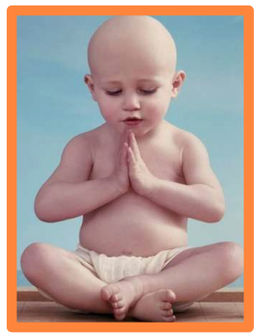
(3x)
"it's falling off"
"she fell down" "don't fall!"
"is London Bridge falling down?"

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference



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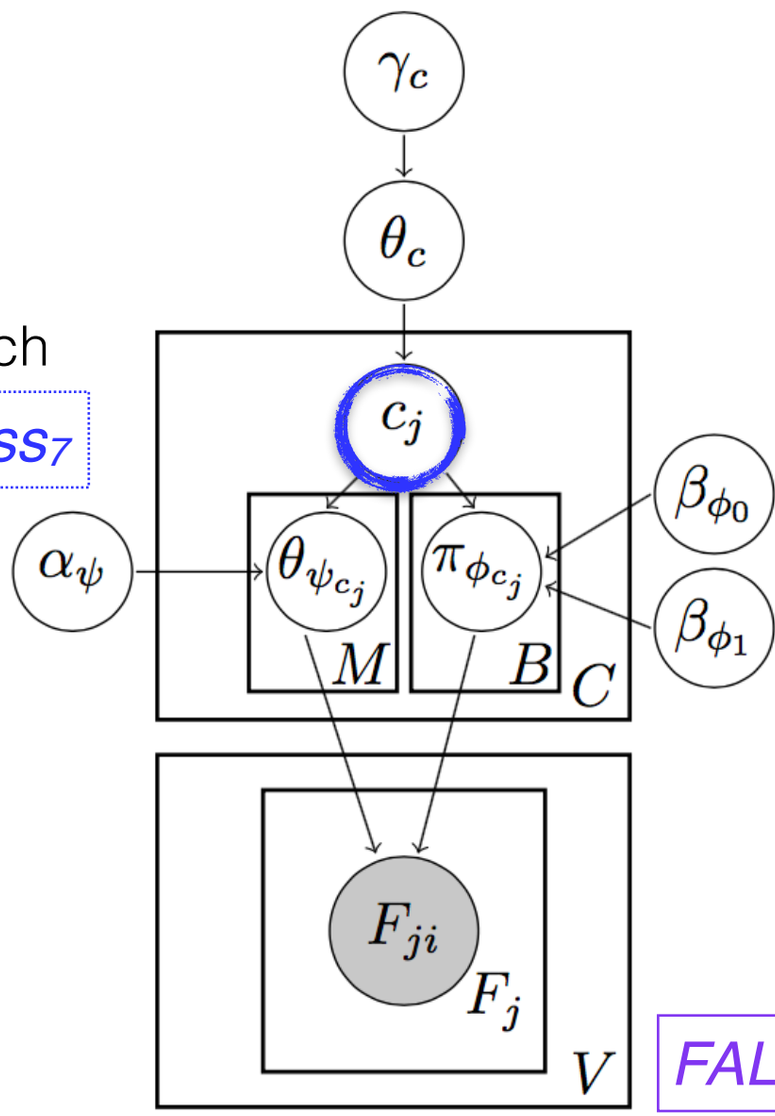
Each verb belongs to some class which determines its linguistic behavior.

class7

Objective: Infer verb class



(3x)
"it's falling off"
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"is London Bridge falling down?"

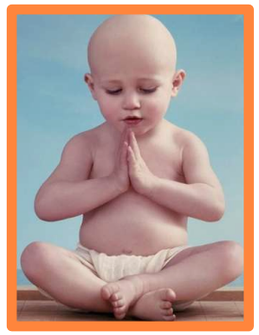
FALL

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference



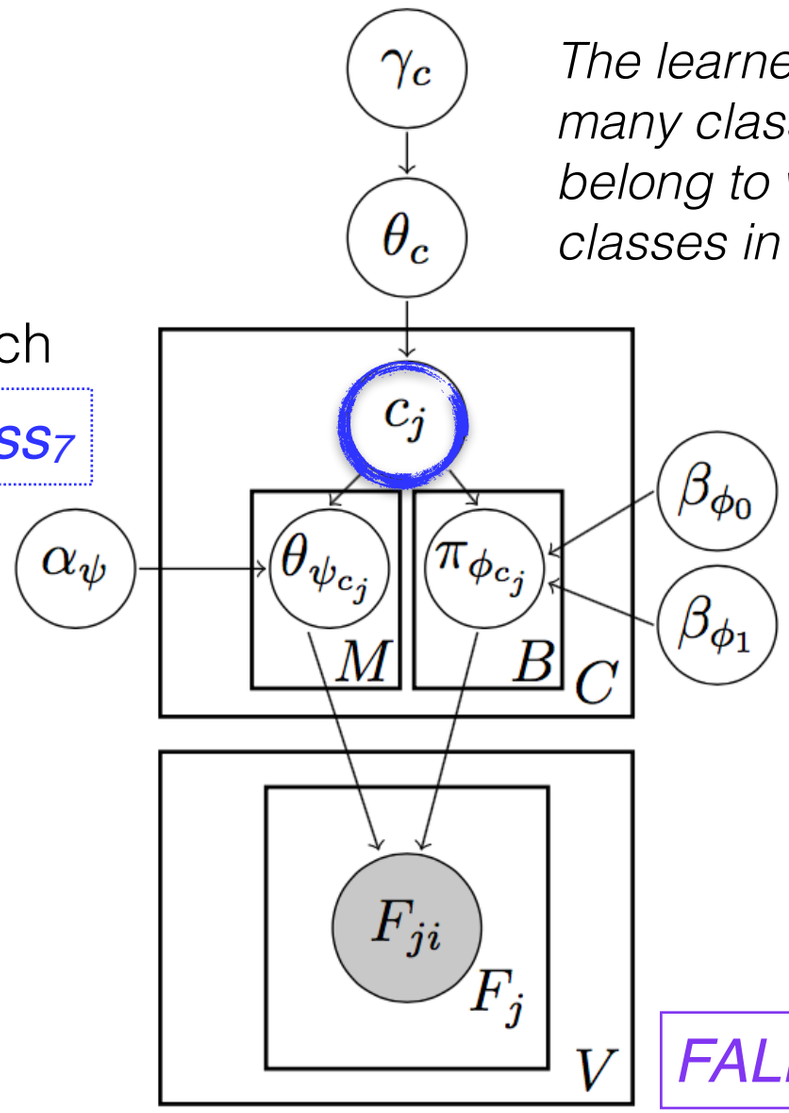
Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

The learner doesn't know beforehand how many classes there are or which verbs belong to which. There's a bias for classes in a power law distribution.

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

class7

Objective: Infer verb class



FALL

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Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

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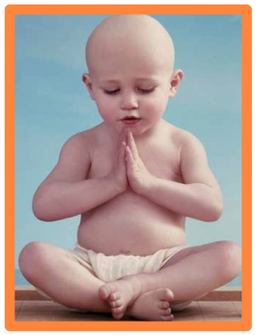
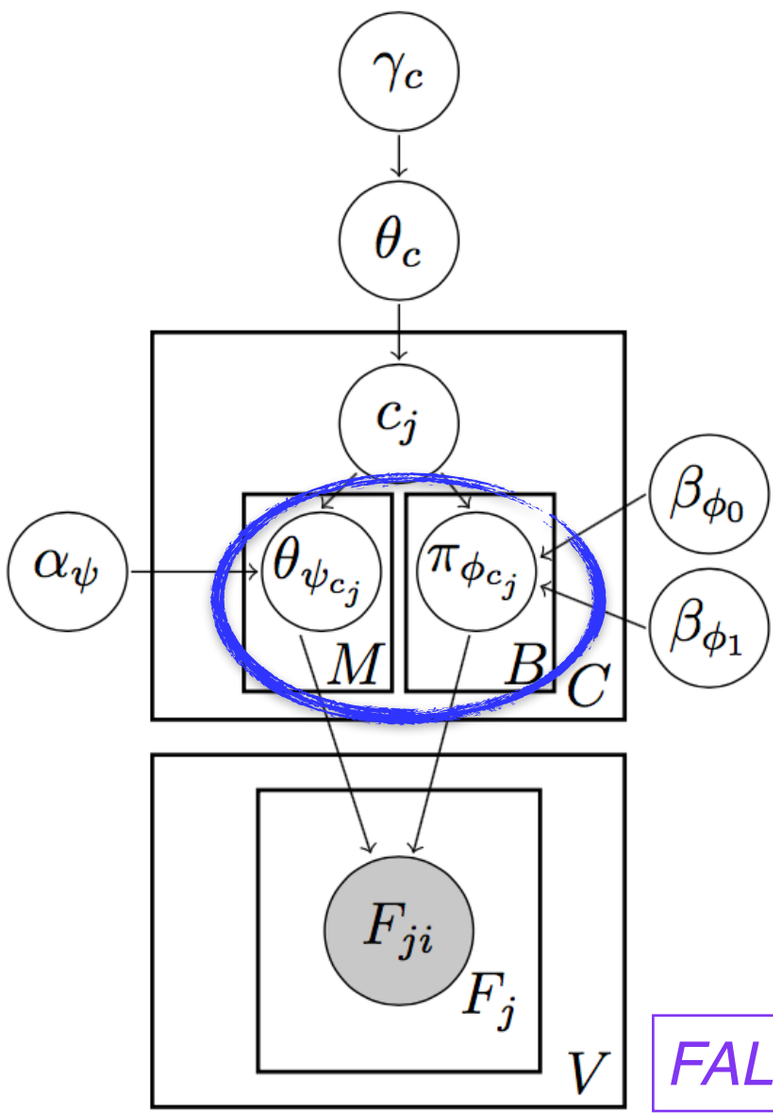


Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

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



class7

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Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

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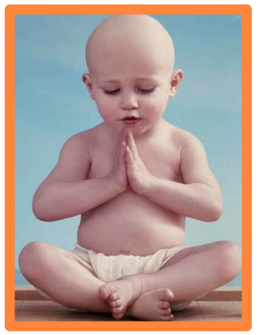
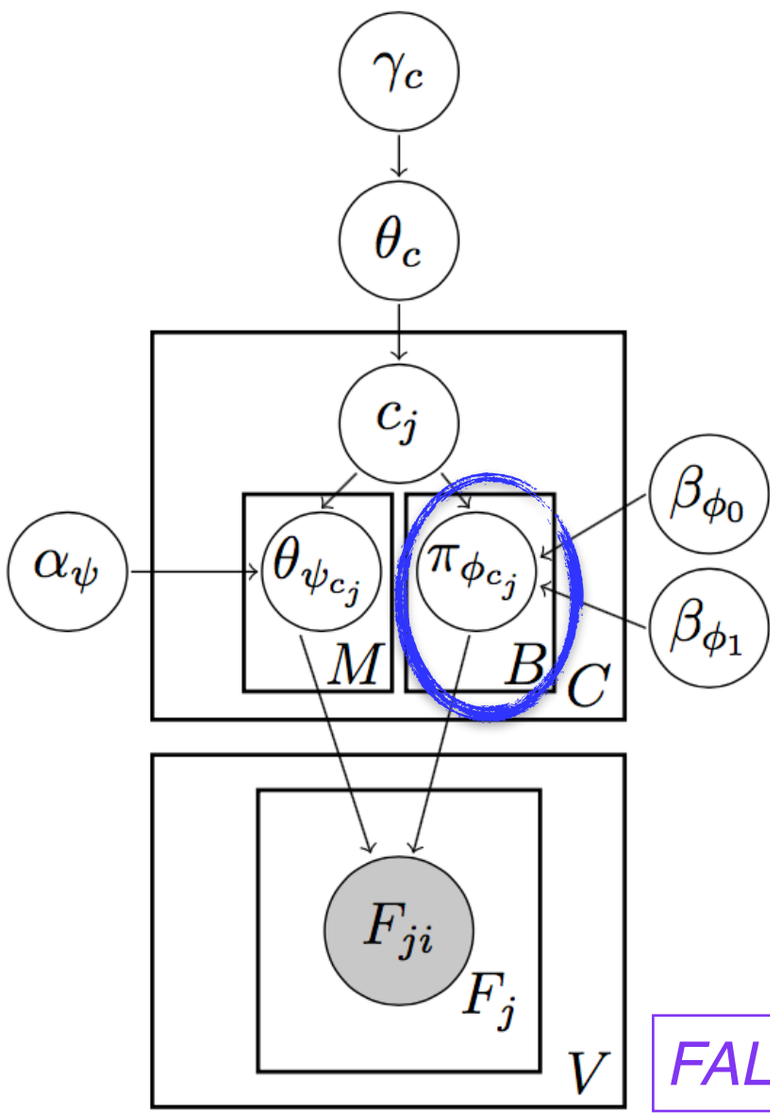


Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

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



class7

(3x)
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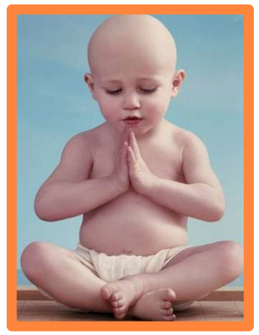
FALL

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference



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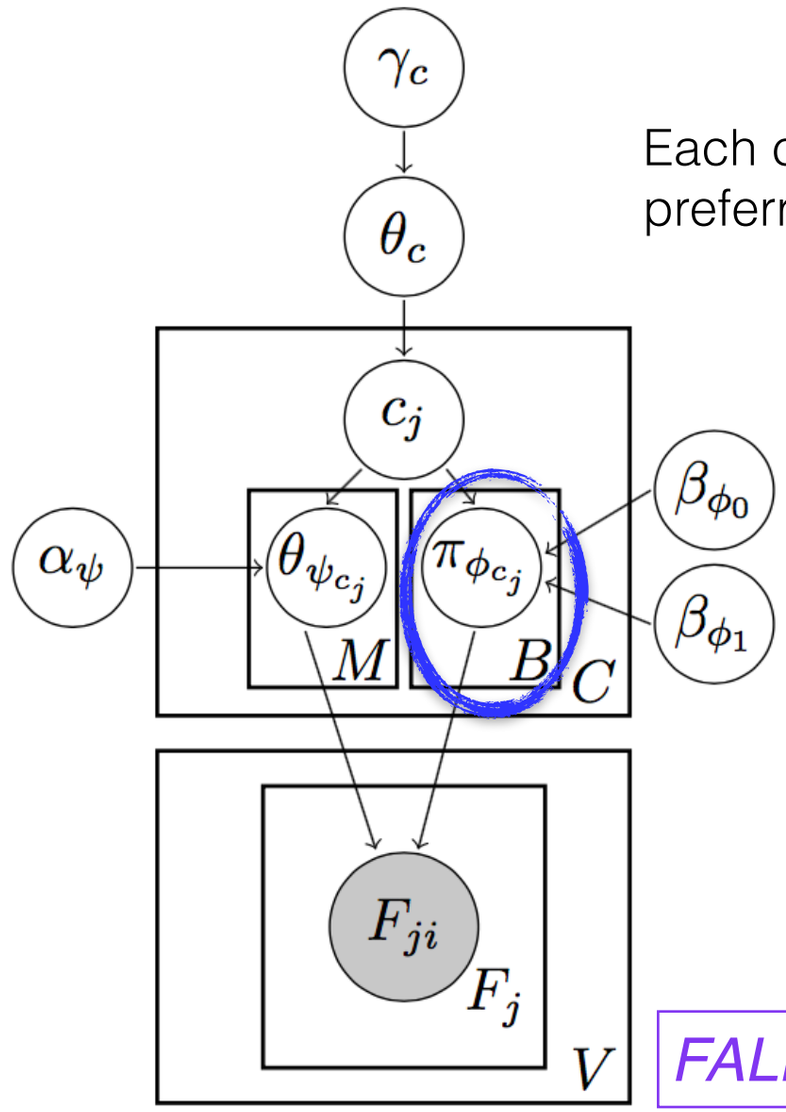


Each class has a probability of preferring each option.

class$_7$

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

0.3 ***0.7***

-anim (3x)

"it's falling off"

"she fell down" "don't fall!"

"is London Bridge falling down?"

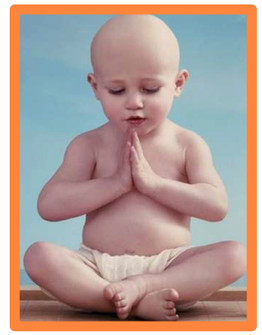
FALL

Pearl & Sprouse 2018a

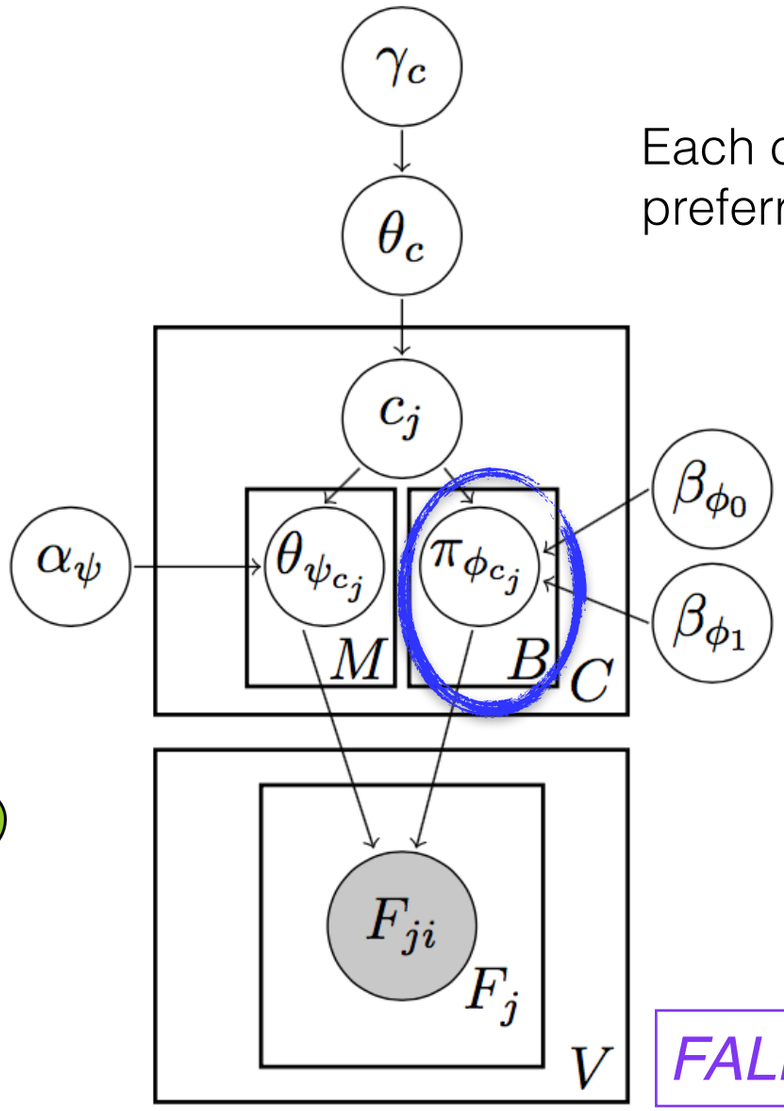
Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference



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



Each class has a probability of preferring each option.

class$_7$

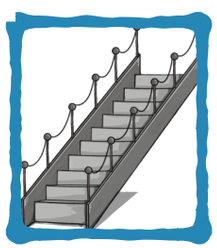
+anim *Subject* ***-anim***

0.3 ***0.7***

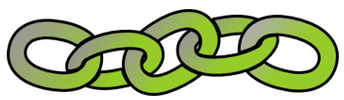
Binary choices:

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

+animate



-animate



-anim (3x)
"it's falling off"
"she fell down" "don't fall!"
"is London Bridge falling down?"

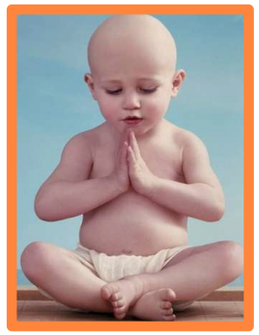
FALL

Pearl & Sprouse 2018a

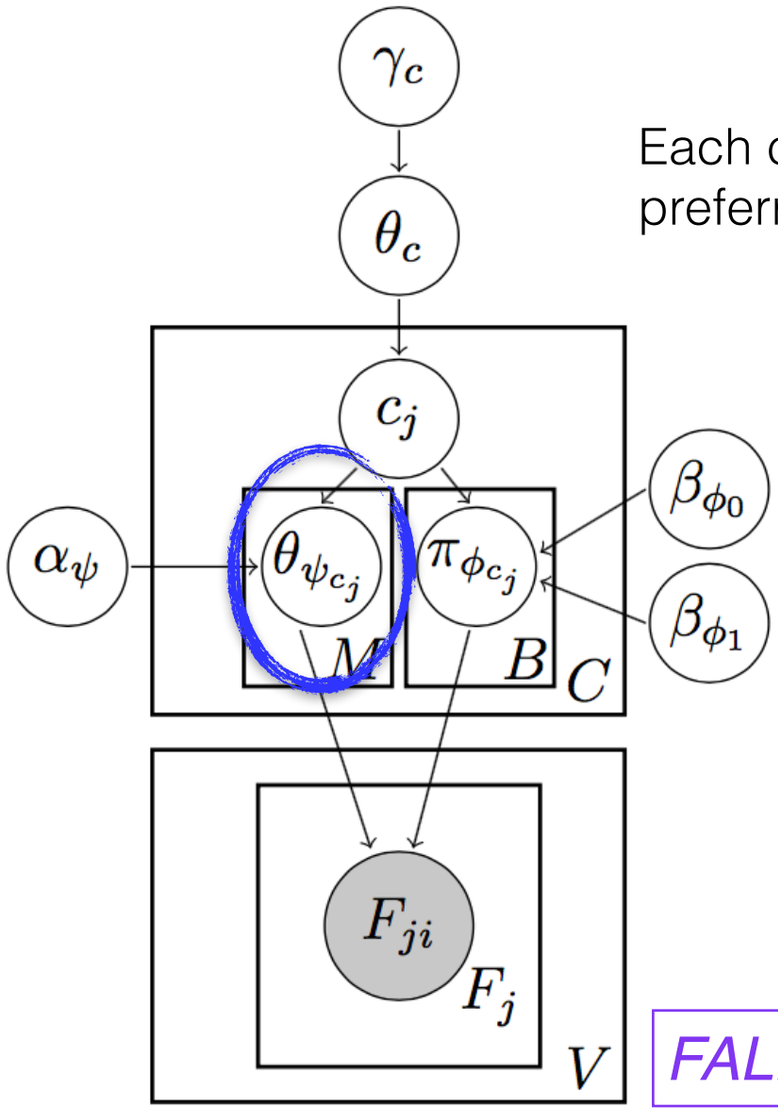
Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference



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



Each class has a probability of preferring each option.

class$_7$

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

FALL

-anim (3x)

"it's falling off"

"she fell down" "don't fall!"

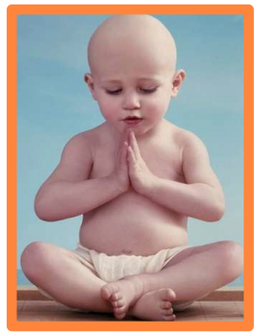
"is London Bridge falling down?"

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference



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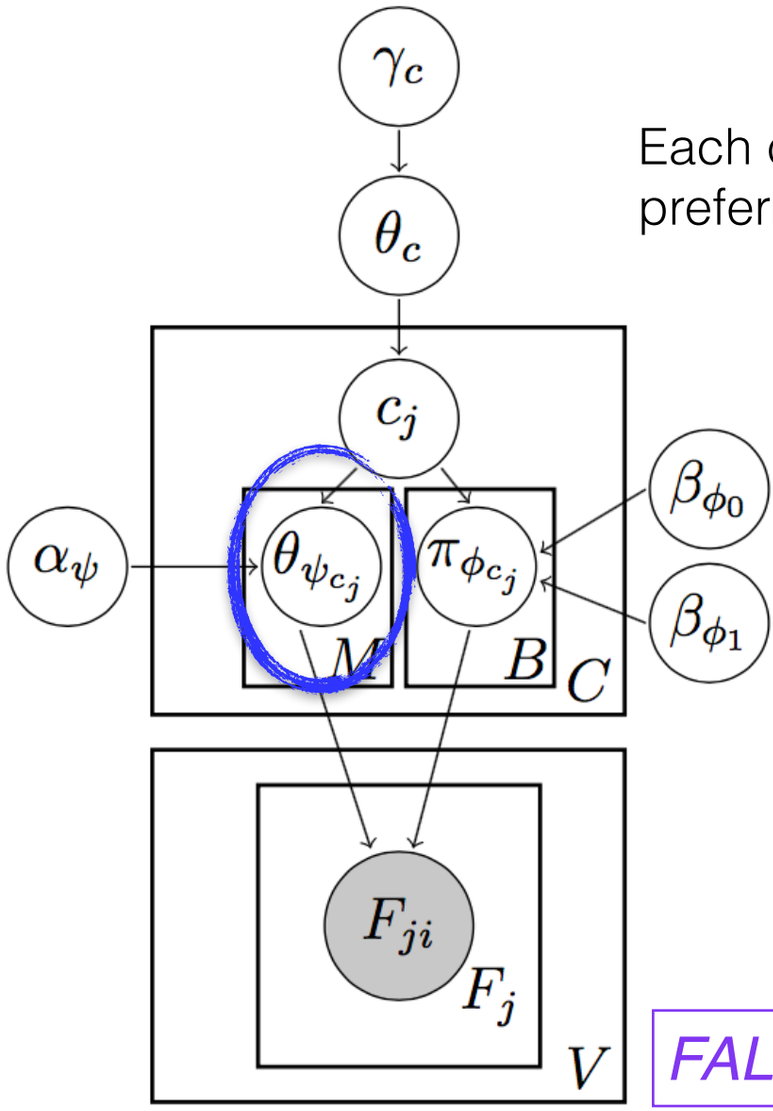

Each class has a probability of preferring each option.

class$_7$

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

NP V PRT

NP V

…

NP V S

FALL

-anim (3x)

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Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

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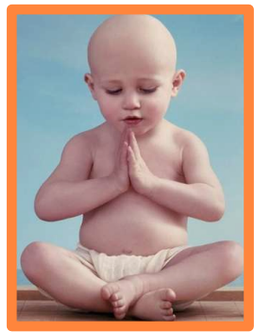


Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

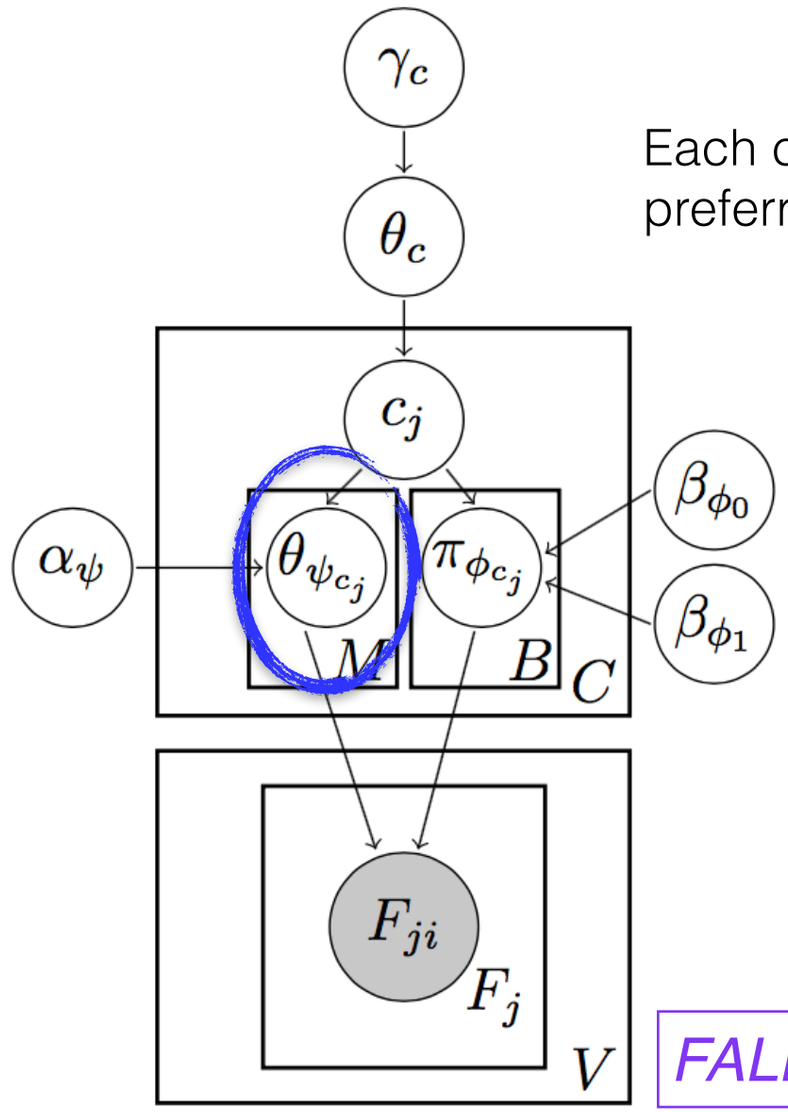
Each class has a probability of preferring each option.

NP V PRT ***0.3***

NP V ***0.25***

…

NP V S ***0***



Each class has a probability of preferring each option.

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"is London Bridge falling down?"

FALL

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

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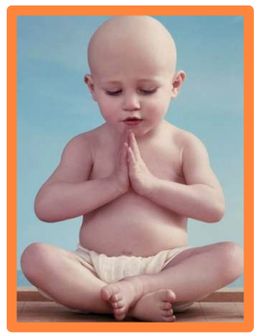


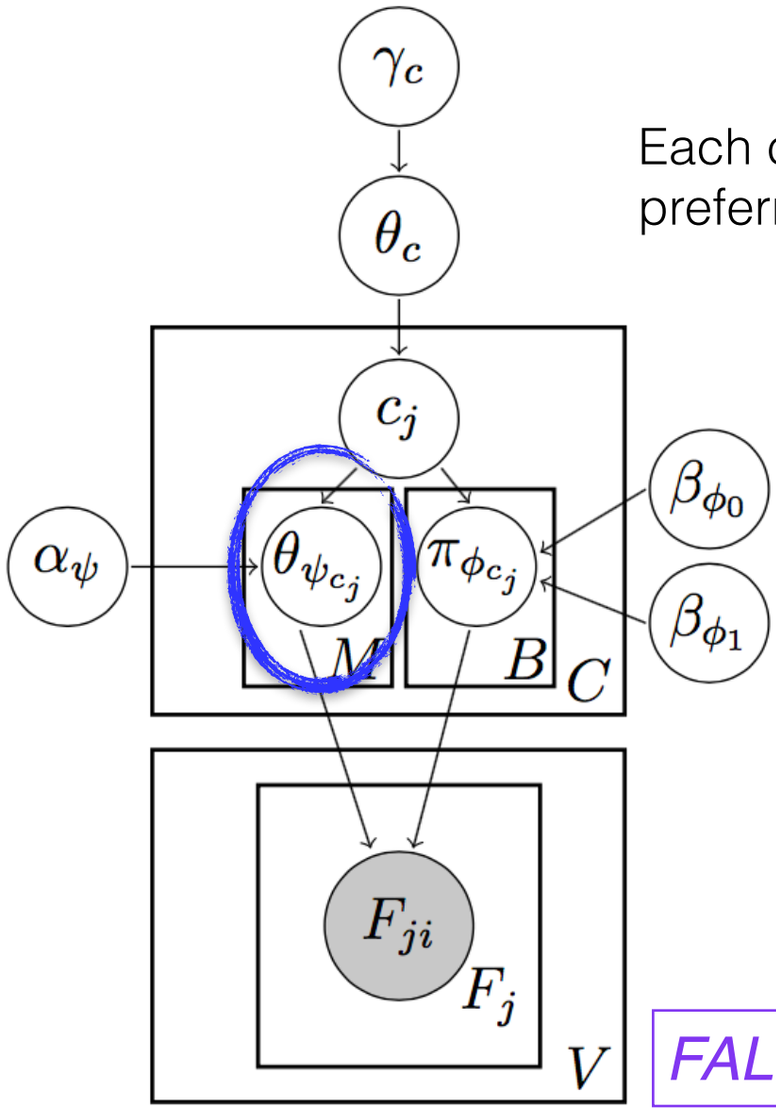
Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

Multinomial choices:

syntactic frame *NP V PRT*

(when -exp-mapping)
position of proto-Agent/Highest
position of proto-Patient/2nd-Highest
position of Other/3rd-Highest

Subject Object Oblique Object



class$_7$

FALL

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Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

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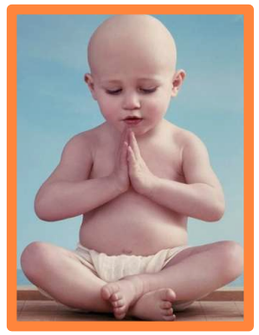
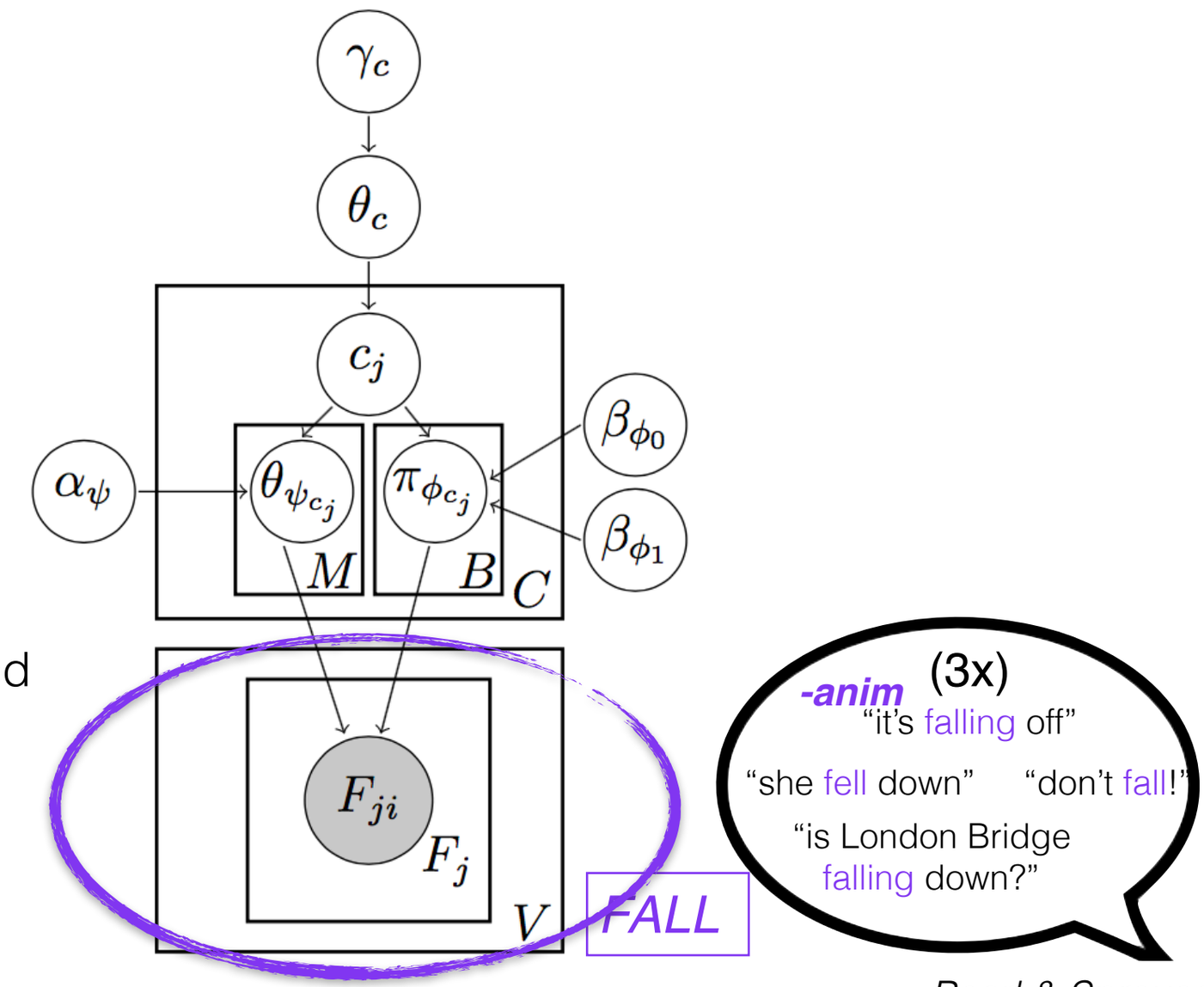


Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

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



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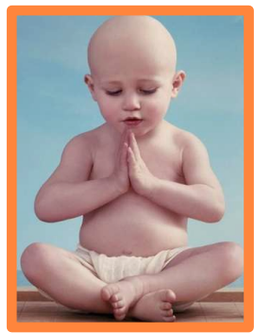
Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

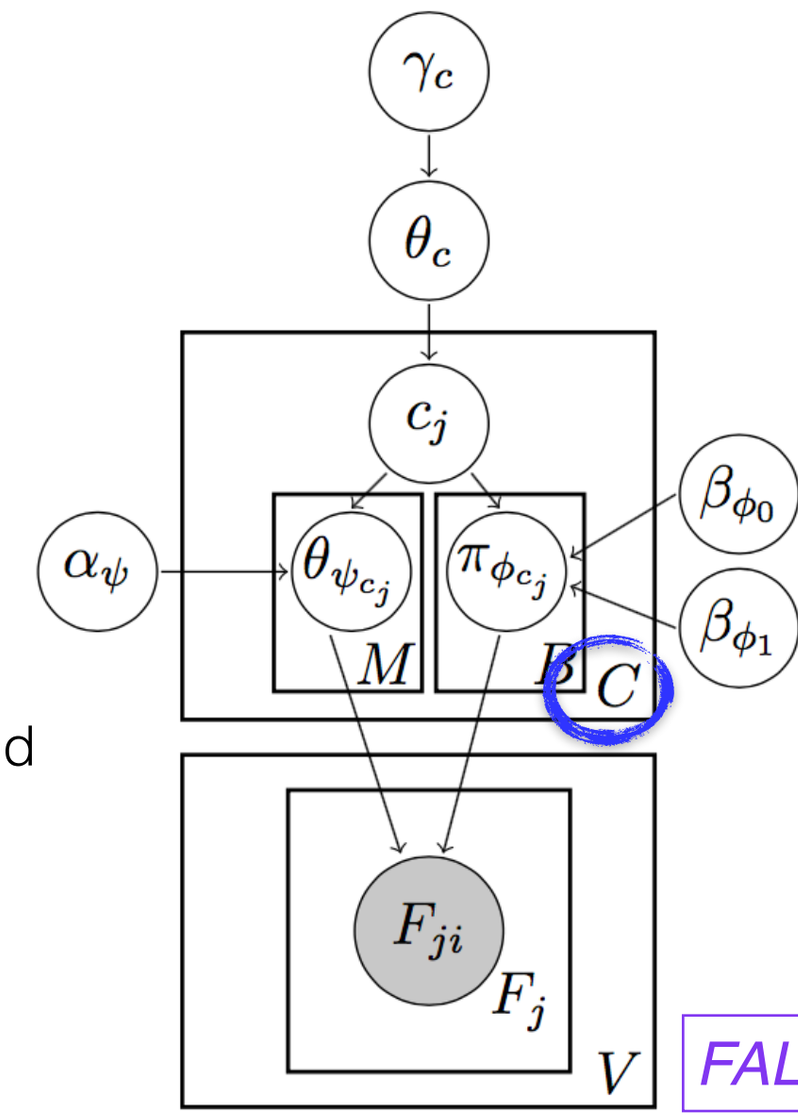
inference



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

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

- how many classes there are



FALL

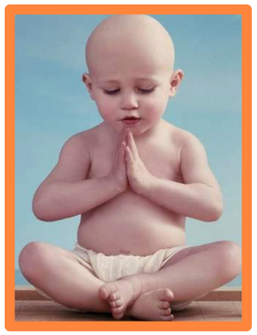
-anim (3x)
"it's falling off"
"she fell down" "don't fall!"
"is London Bridge falling down?"

Pearl & Sprouse 2018a

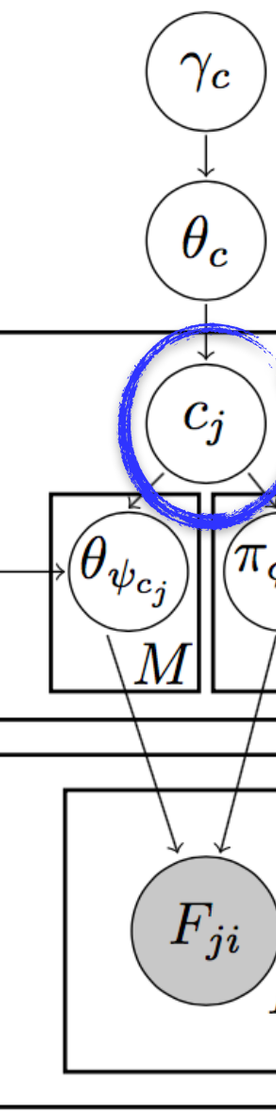
Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference



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



class7

FALL

-anim (3x)

"it's falling off"

"she fell down" "don't fall!"

"is London Bridge falling down?"

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

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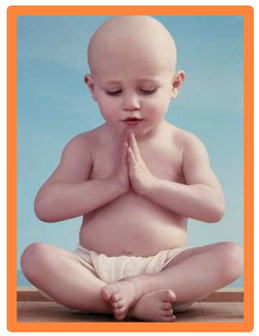
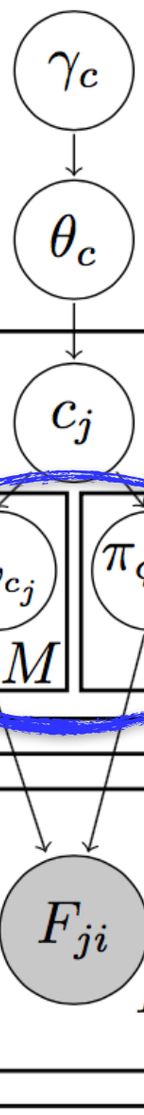
Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference



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



NP V PRT ***0.3***

NP V ***0.25***

NP V S ***0***

class7

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

0.3 ***0.7***

-anim (3x)
"it's falling off"
"she fell down" "don't fall!"
"is London Bridge falling down?"

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
- what the characteristics are of each class

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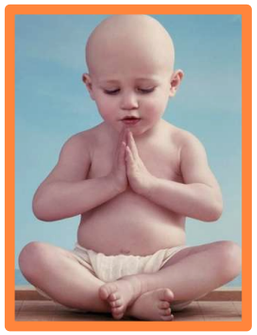
Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference

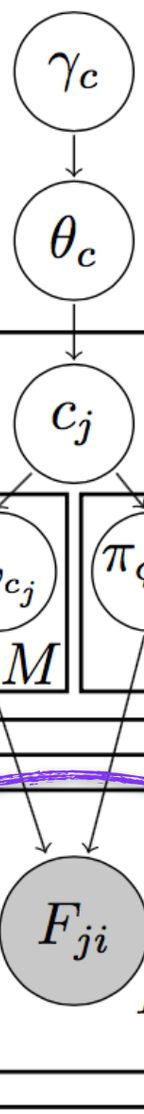


Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

Best answer: maximizes the probability of the observed data.

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



FALL

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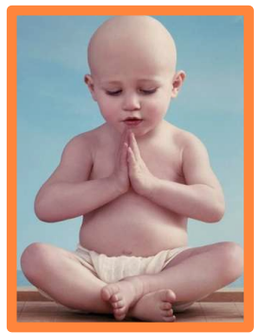
Evaluating different linking theory proposals using developmental modeling

initial state data intake target state

inference



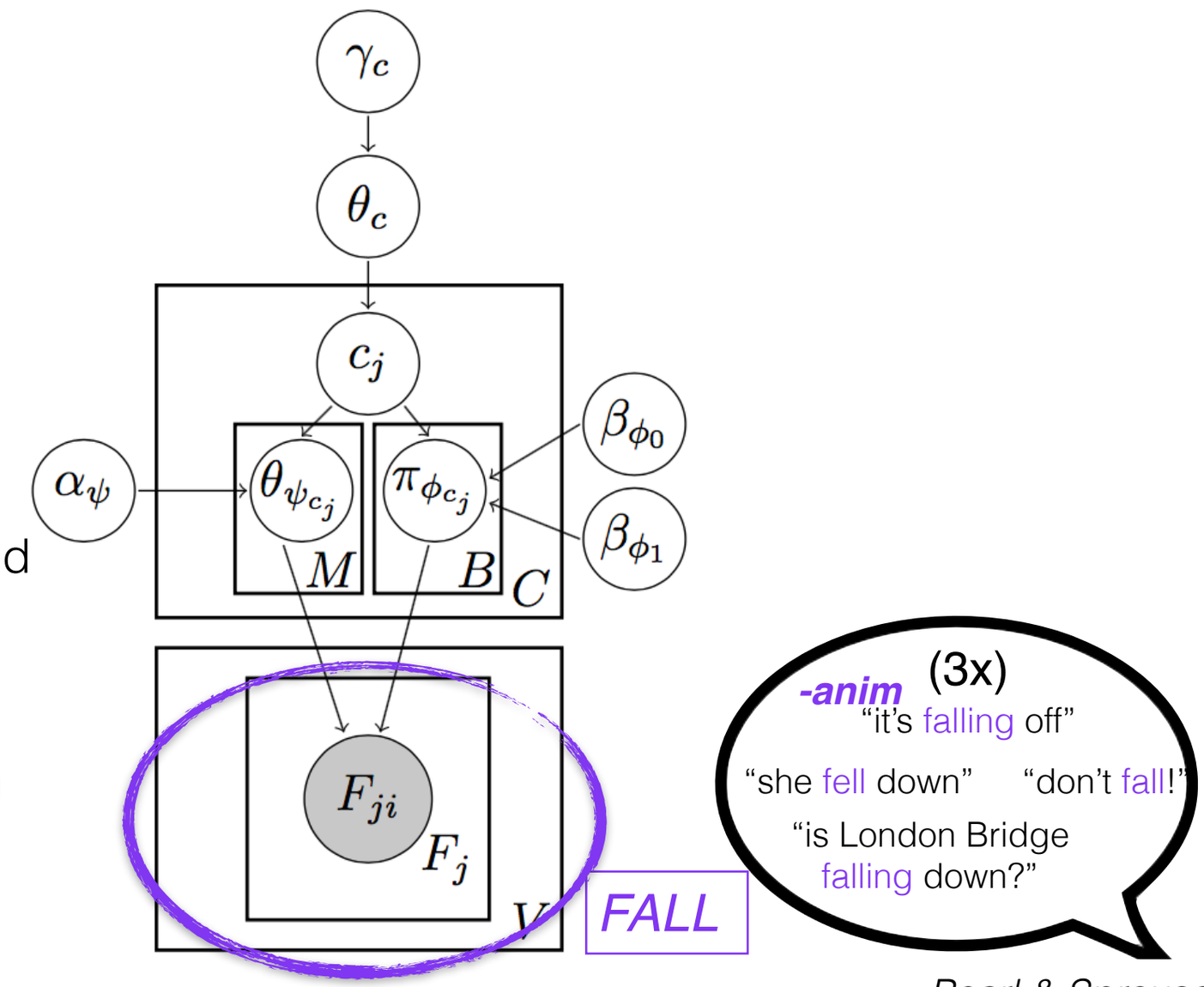
Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior?

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

+ Gibbs sampling

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



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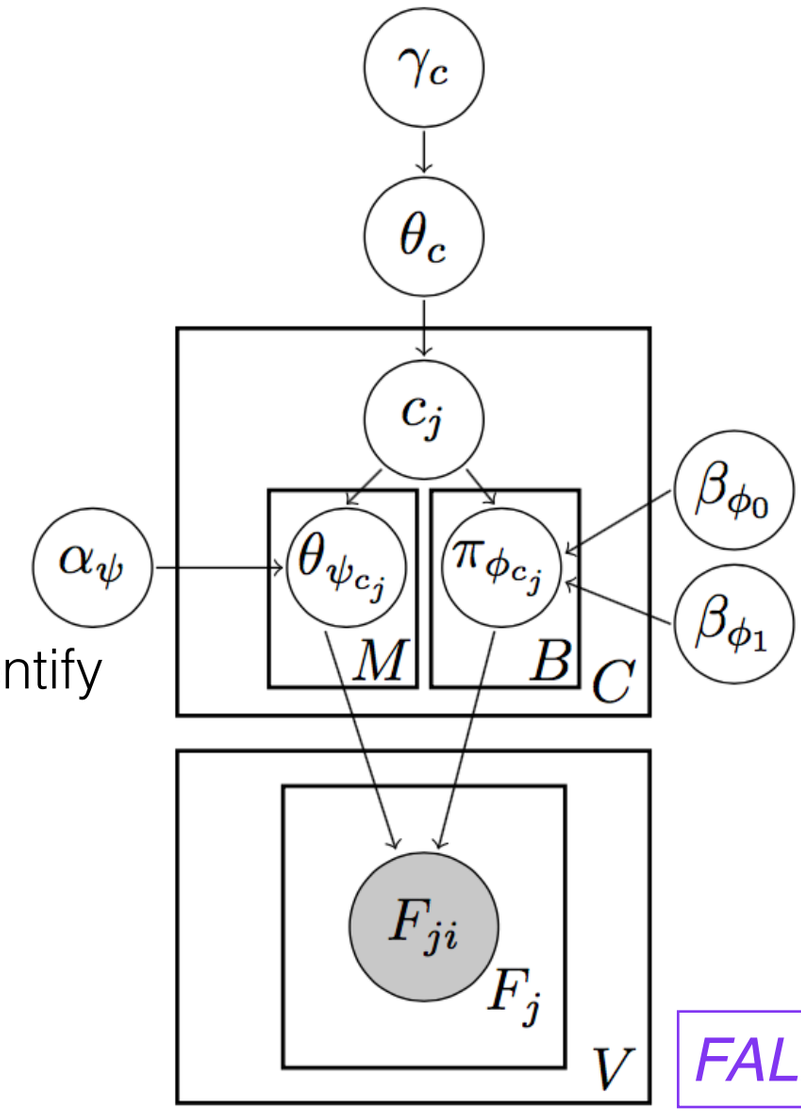
Evaluating different linking theory proposals using developmental modeling

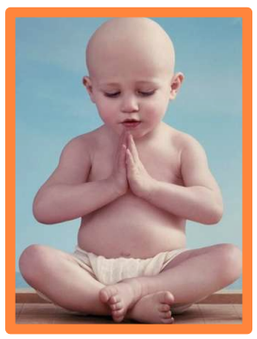
initial state data intake target state

inference

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



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



-anim (3x)
"it's falling off"
"she fell down" "don't fall!"
"is London Bridge falling down?"

FALL

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Evaluating different linking theory proposals using developmental modeling

initial state data intake inference

target state

So what does the target knowledge/behavior look like?

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Evaluating different linking theory proposals using developmental modeling

initial state data intake inference

target state

Goal: Model the developmental trajectory of verb class knowledge from 3 to 4 to 5 years old in English

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Evaluating different linking theory proposals using developmental modeling

initial state data intake inference

target state

verb class knowledge

Survey of 38 experimental studies on children's production and comprehension of specific verbs

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Evaluating different linking theory proposals using developmental modeling

initial state data intake inference

target state

verb class knowledge

Survey of 38 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

+non-finite *to*-comp

+object-experiencer

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Evaluating different linking theory proposals using developmental modeling

initial state data intake inference

target state

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

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Evaluating different linking theory proposals using developmental modeling

initial state data intake inference

target state

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

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Evaluating different linking theory proposals using developmental modeling

initial state data intake inference

target state

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

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

<4yrs

[+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

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Evaluating different linking theory proposals using developmental modeling

initial state data intake inference

target state

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

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

<5yrs

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Evaluating different linking theory proposals using developmental modeling

initial state data intake inference

target state

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

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Evaluating different linking theory proposals using developmental modeling

<3yrs

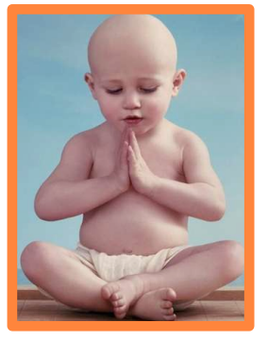
15 classes

<4yrs

23 classes

<5yrs

25 classes



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

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Evaluating different linking theory proposals using developmental modeling

<3yrs

15 classes

<4yrs

23 classes

<5yrs

25 classes

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

Implementation:
Rand Index

0.0 <= RI <= 1.0

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Evaluating different linking theory proposals using developmental modeling

<3yrs

15 classes

<4yrs

23 classes

<5yrs

25 classes

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

Implementation:
Rand Index

0.0 <= RI <= 1.0

Intuition: Get credit for putting things together that belong together and keeping things apart that should be apart.

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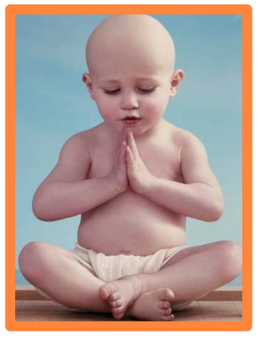
Evaluating different linking theory proposals using developmental modeling



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

<3yrs

15 classes

<4yrs

23 classes

<5yrs

25 classes

0.0 <= RI <= 1.0

Rand Index

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

Inferred Class

Same class *Different class*

Child Class

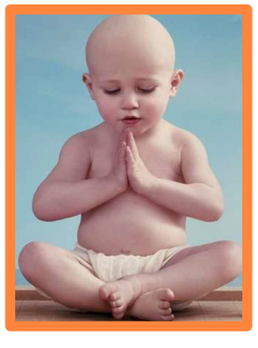
Same class

Different class

Intuition: Get credit for putting things together that belong together and keeping things apart that should be apart.

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling



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

<3yrs

15 classes

<4yrs

23 classes

<5yrs

25 classes

0.0 <= RI <= 1.0

Rand Index

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

		Inferred Class	
		Same class	*Different class*
Child Class	*Same class*	True Positive	
	Different class		True Negative

Intuition: Get credit for putting things together that belong together and keeping things apart that should be apart.

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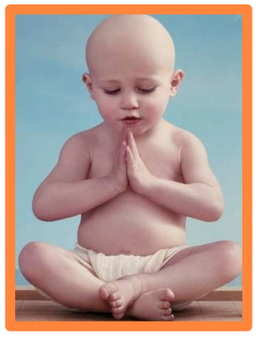
Evaluating different linking theory proposals using developmental modeling



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<3yrs

15 classes

<4yrs

23 classes

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25 classes

0.0 <= RI <= 1.0

Rand Index

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

		Inferred Class	
		Same class	*Different class*
Child Class	*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 should be apart.

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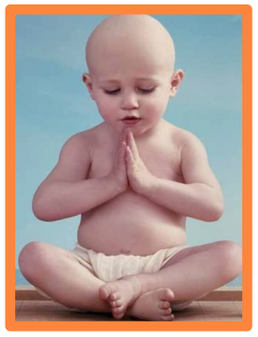
Evaluating different linking theory proposals using developmental modeling



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

<3yrs

15 classes

<4yrs

23 classes

<5yrs

25 classes

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

Rand Index

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

Child Class \ Inferred Class	*Same class*	*Different class*
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 should be apart.

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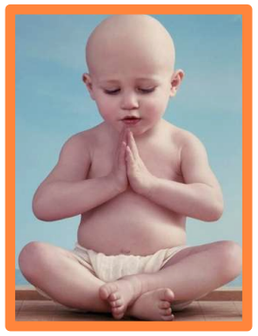
Evaluating different linking theory proposals using developmental modeling



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

<3yrs

15 classes

<4yrs

23 classes

<5yrs

25 classes

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

Rand Index

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

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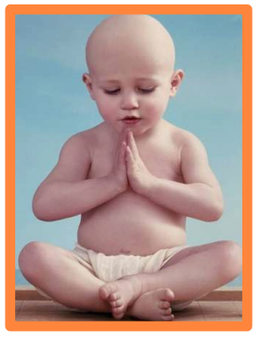
Evaluating different linking theory proposals using developmental modeling



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

<3yrs

15 classes

<4yrs

23 classes

<5yrs

25 classes

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

Rand Index

Bootstrapped confidence intervals for RI, with randomly generated classes of random size and random verb assignment

RI > 99% = better than chance

RI < 1% = worse than chance

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Evaluating different linking theory proposals using developmental modeling

<3yrs

<4yrs

<5yrs

Thematic systems

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Evaluating different linking theory proposals using developmental modeling

<3yrs

<4yrs

<5yrs

Thematic systems

relative

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

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Evaluating different linking theory proposals using developmental modeling

<3yrs

<4yrs

<5yrs

Thematic systems

relative

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

fixed

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

<3yrs

<4yrs

<5yrs

Thematic systems

relative Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

fixed 

Expected mapping

yes 

Subject

Object

no 

Oblique Object

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

<3yrs

<4yrs

<5yrs

Thematic systems

relative Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

fixed 

Expected mapping

yes 

Subject

Object

no 

Oblique Object

Surface morphology

yes *NP V_{past} PRT*

no *NP V PRT*

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

<3yrs

<4yrs

<5yrs

Thematic systems

relative Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

fixed 

Expected mapping

yes 

Subject

Object

no 

Oblique Object

Surface morphology

yes *NP V_{past} PRT*

no *NP V PRT*

A modeled learner implements one of each (thematic system, expected mapping, and surface morphology)

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Evaluating different linking theory proposals using developmental modeling

RI > 99% = better than chance

<3yrs

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

NP V PRT

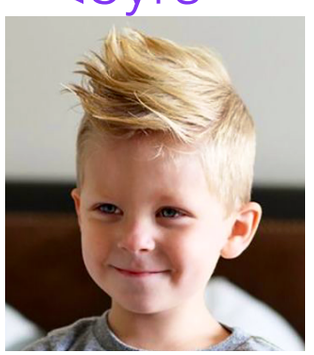
relative **no**

yes

no

<4yrs

<5yrs



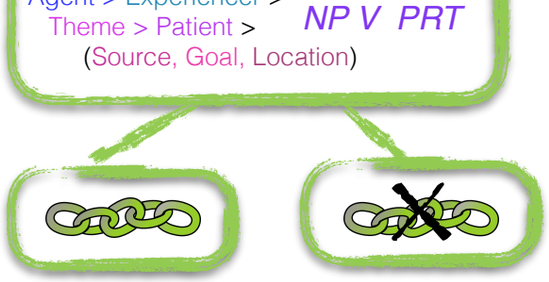
Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

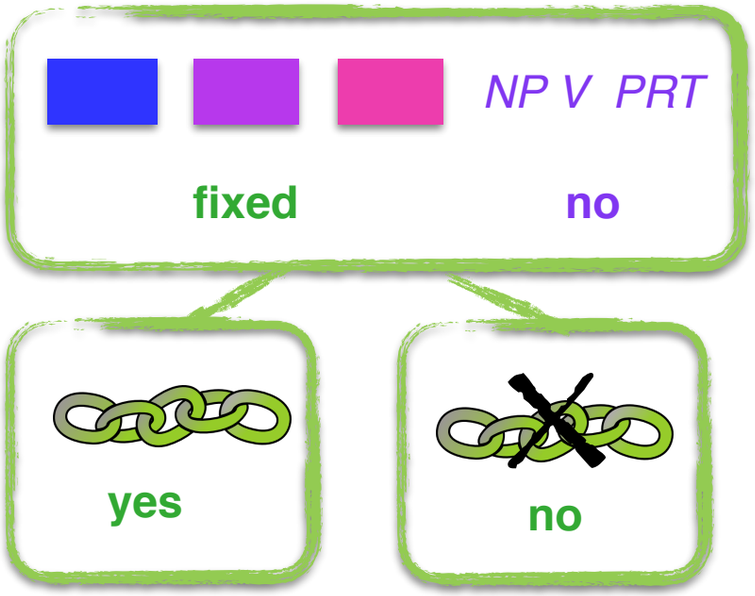
RI > 99% = better than chance

<3yrs

Agent > Experiencer > Theme > Patient > (Source, Goal, Location) *NP V PRT*



<4yrs



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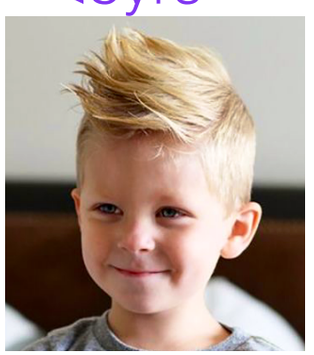


Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

RI > 99% = better than chance

<3yrs

Agent > Experiencer > Theme > Patient > (Source, Goal, Location) *NP V PRT*

<4yrs

 *NP V PRT*

no

NP V_{past} PRT

yes

fixed

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

relative

<5yrs

Pearl & Sprouse 2018a

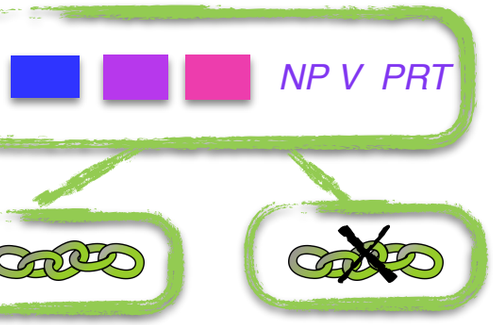
Evaluating different linking theory proposals using developmental modeling

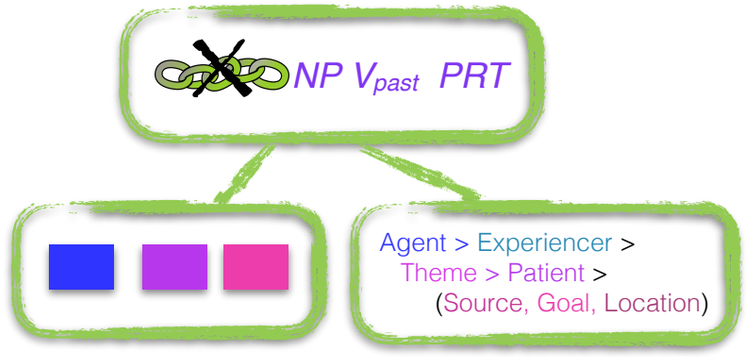
RI > 99% = better than chance

<3yrs

Agent > Experiencer > Theme > Patient > (Source, Goal, Location) *NP V PRT*

<4yrs





<5yrs

NP V PRT **no**

NP V_{past} PRT **yes**

yes

fixed

Agent > Experiencer > Theme > Patient > (Source, Goal, Location) **relative**

Pearl & Sprouse 2018a

Evaluating different linking theory proposals using developmental modeling

RI > 99% = better than chance

<3yrs

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

NP V PRT

<4yrs

NP V PRT

~~*NP V_{past} PRT*~~

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

<5yrs

NP V PRT

NP V_{past} PRT

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

~~*NP V PRT*~~ **no**

NP V PRT **no**

fixed

Agent > Experiencer > Theme > Patient > (Source, Goal, Location) **relative**

Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?

rUTAH **relative**

UTAH **fixed**

<3yrs

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

NP V PRT

<4yrs

NP V PRT

NP V_{past} PRT

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

<5yrs

NP V PRT

NP V_{past} PRT

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

NP V PRT

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

Pearl & Sprouse 2018a

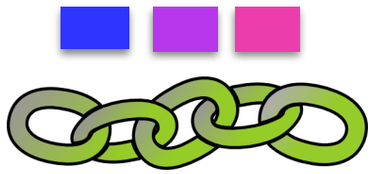
How do we interpret this with respect to our linking theory proposals?

rUTAH

relative

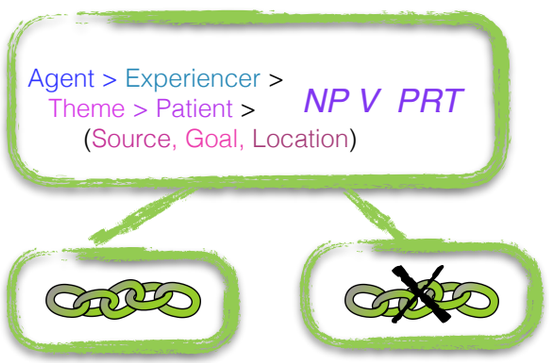
fixed

UTAH

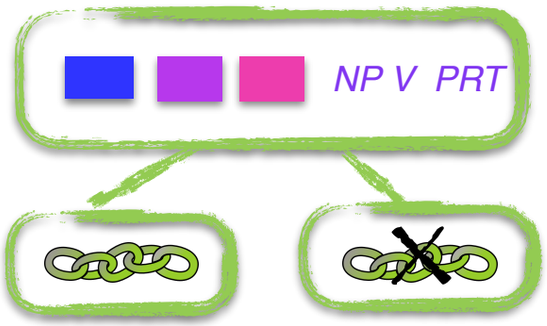


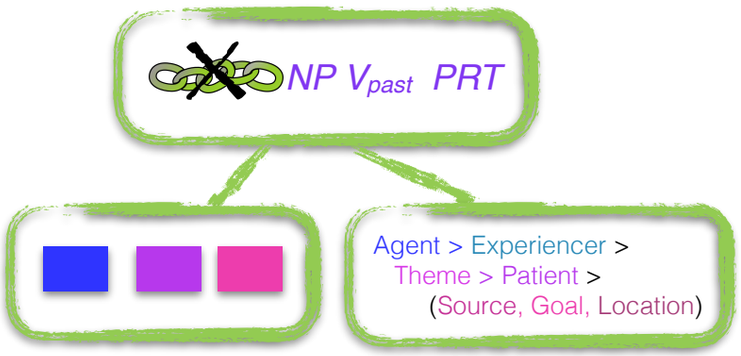
These are innately specified. Early maturation would assume they're present at all ages.

<3yrs

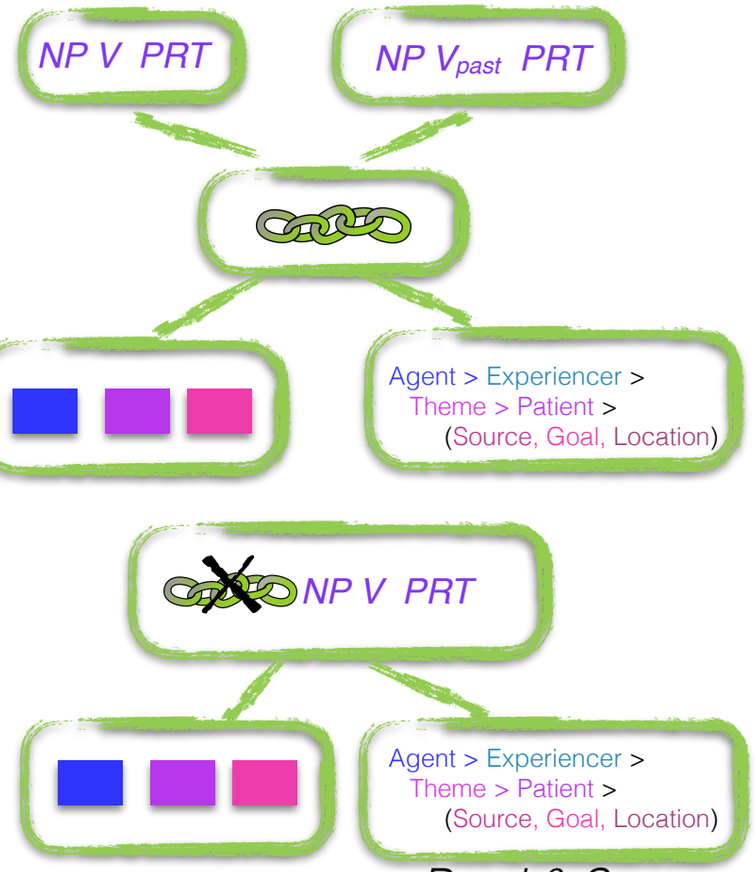


<4yrs



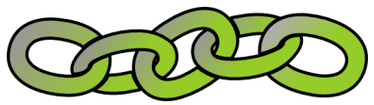


<5yrs



Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?

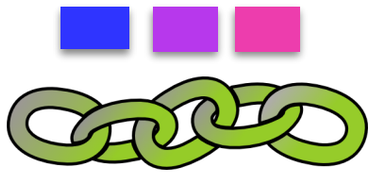


rUTAH

relative

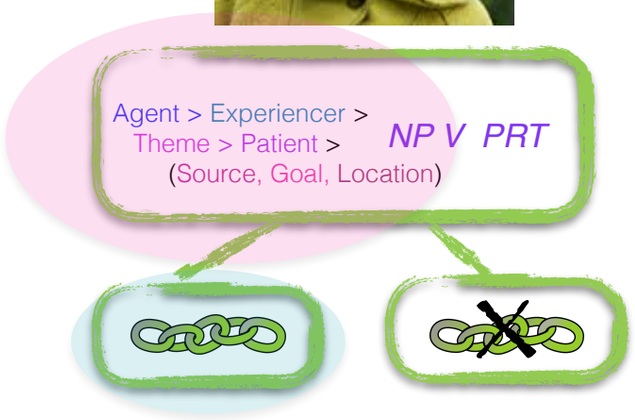
fixed

UTAH

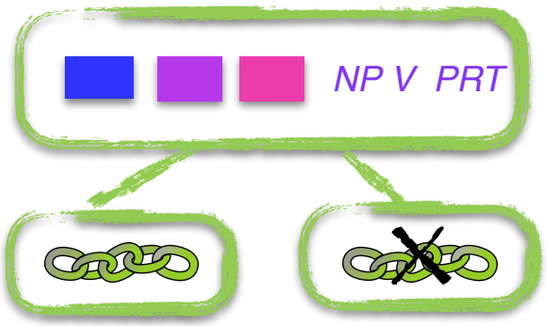


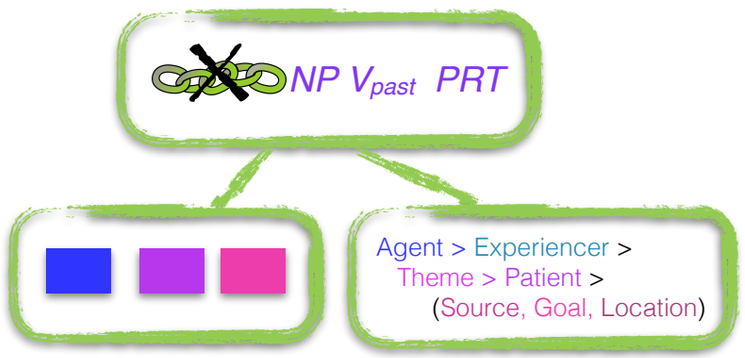
But the thematic representation isn't present at three, even though the link could be.

<3yrs

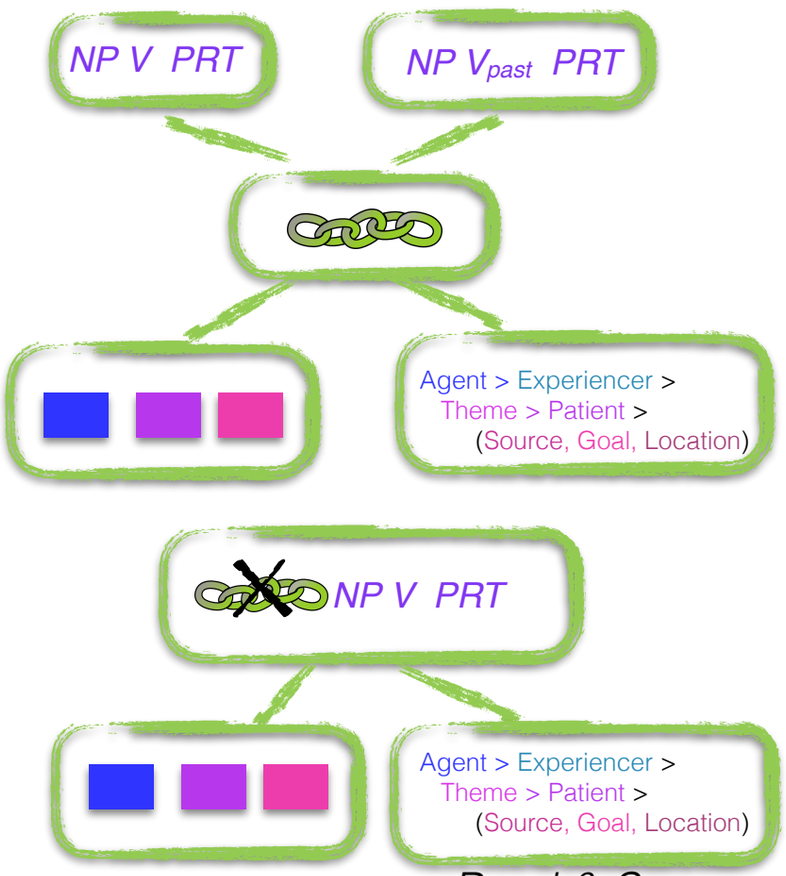


<4yrs





<5yrs



Pearl & Sprouse 2018a

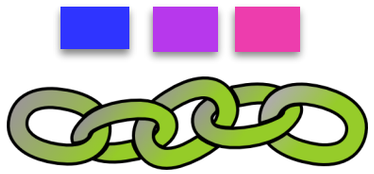
How do we interpret this with respect to our linking theory proposals?

rUTAH

relative

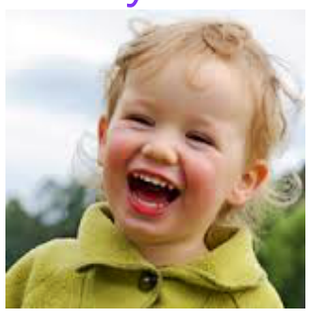
fixed

UTAH



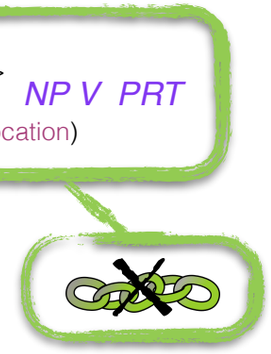
Both are present at four and five, though.

<3yrs

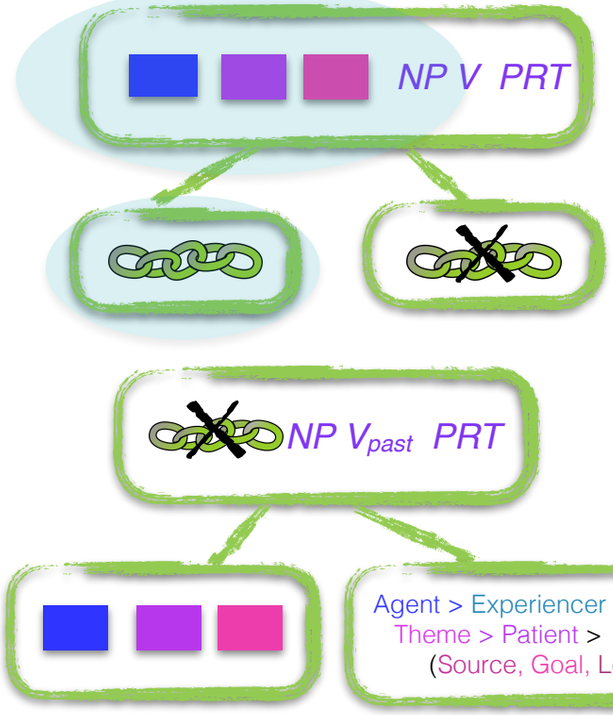


Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

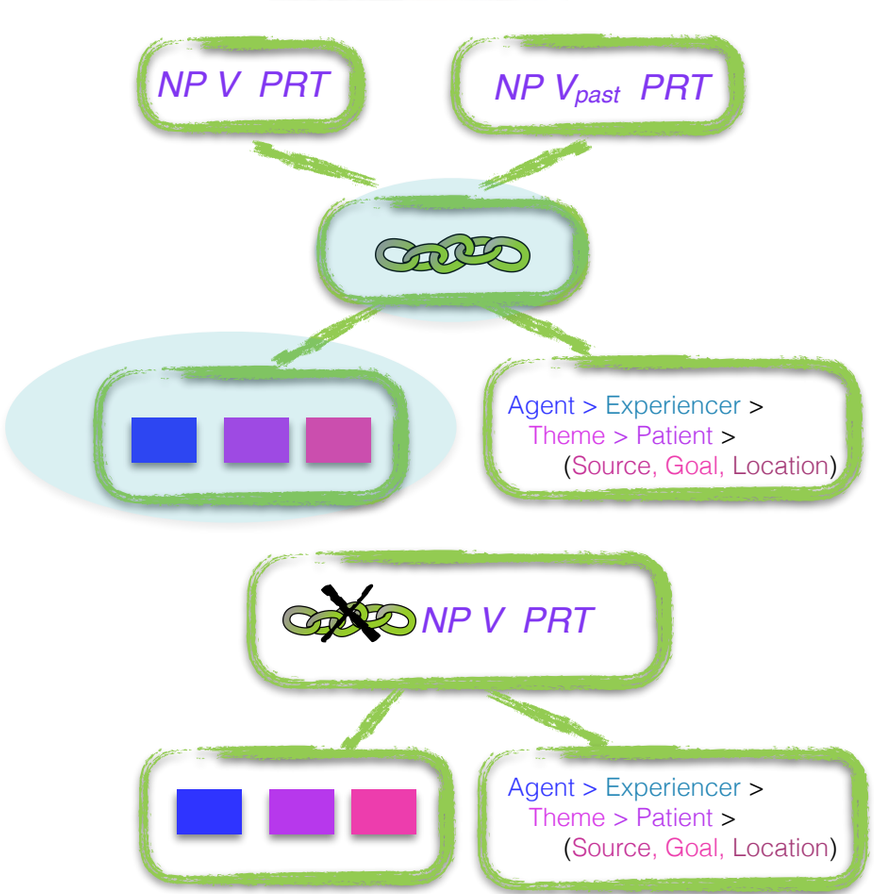
NP V PRT



<4yrs

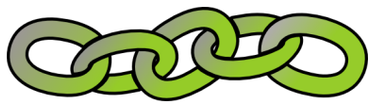


<5yrs



Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?

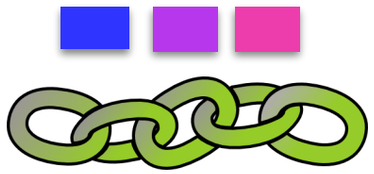


rUTAH

relative

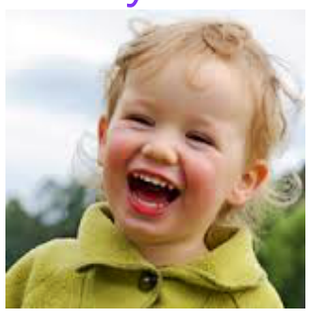
fixed

UTAH



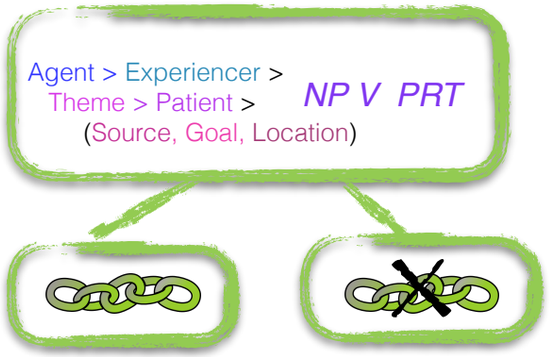
So UTAH is compatible with late maturation (at four or later).

<3yrs



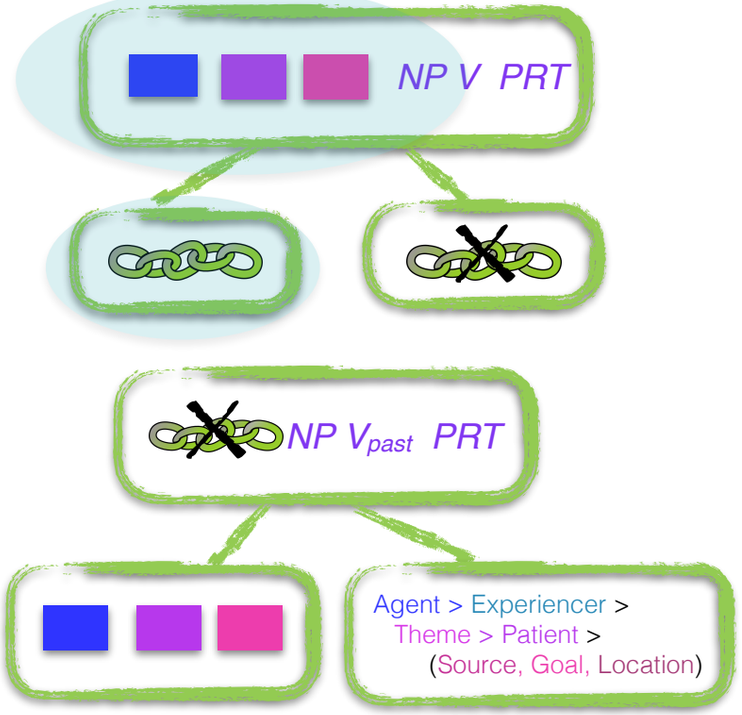
Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

NP V PRT



<4yrs

NP V PRT



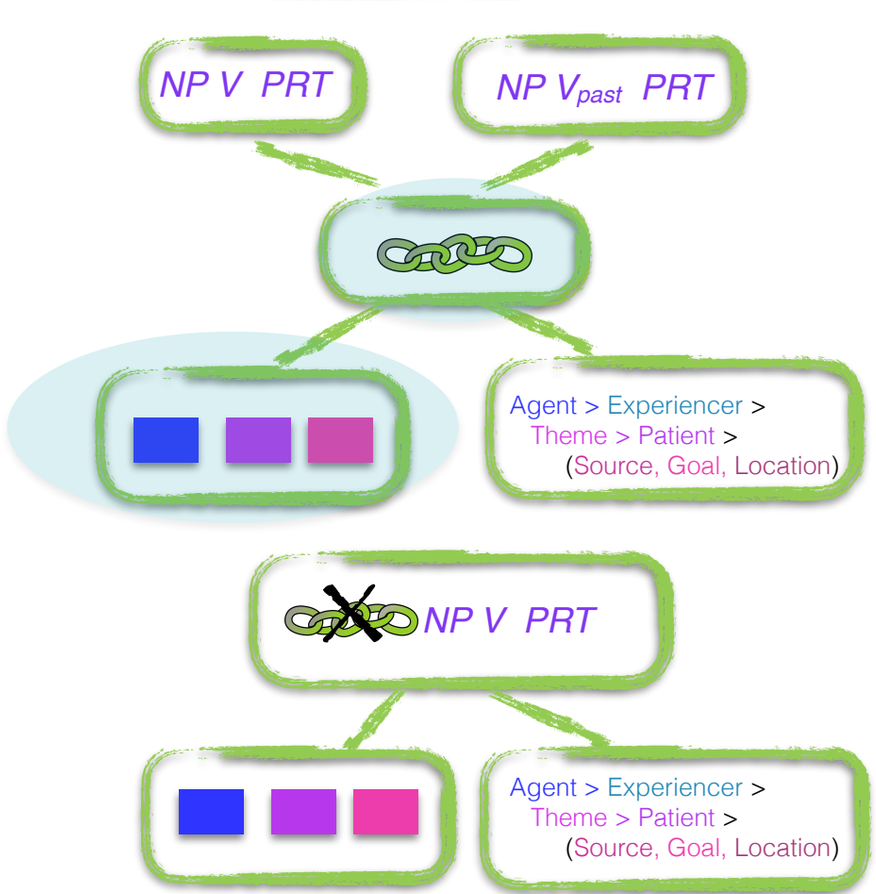
NP V_{past} PRT

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

<5yrs

NP V PRT

NP V_{past} PRT



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

NP V PRT

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

Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?

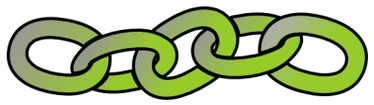
relative

late
UTAH

fixed

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

rUTAH

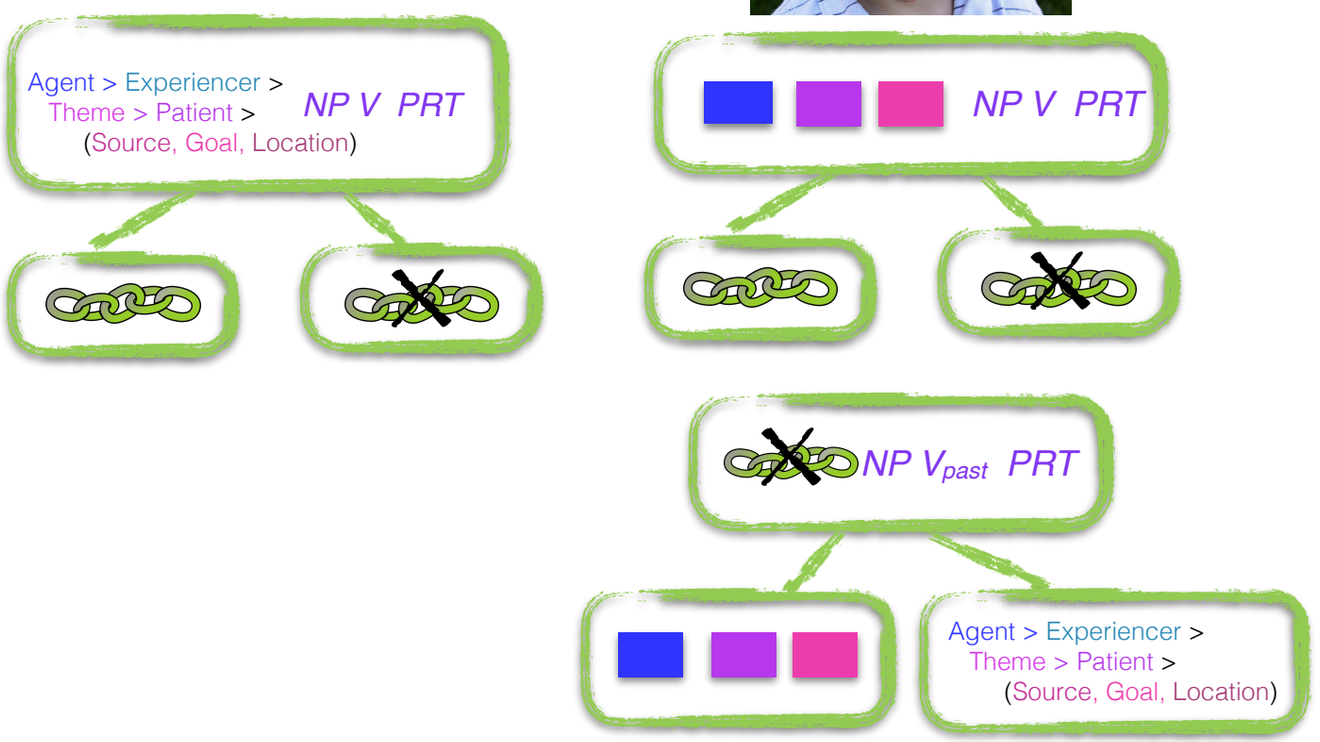


These are innately specified. Early maturation would assume they're present at all ages.

<3yrs

<4yrs

<5yrs



Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?

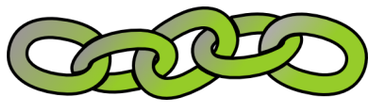
late
UTAH

relative

fixed

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

rUTAH

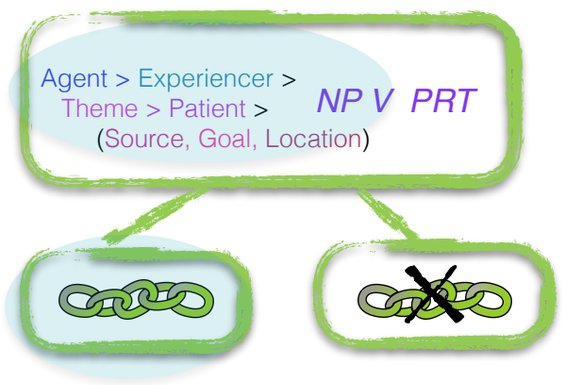


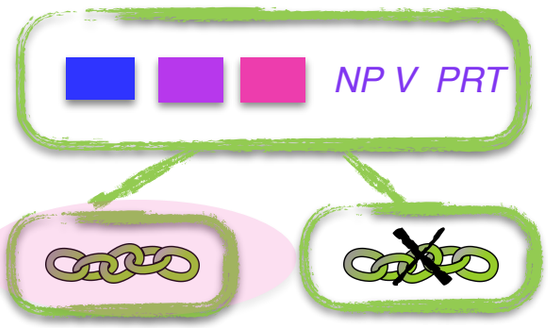
Both are present at three and five, but absent together at four.

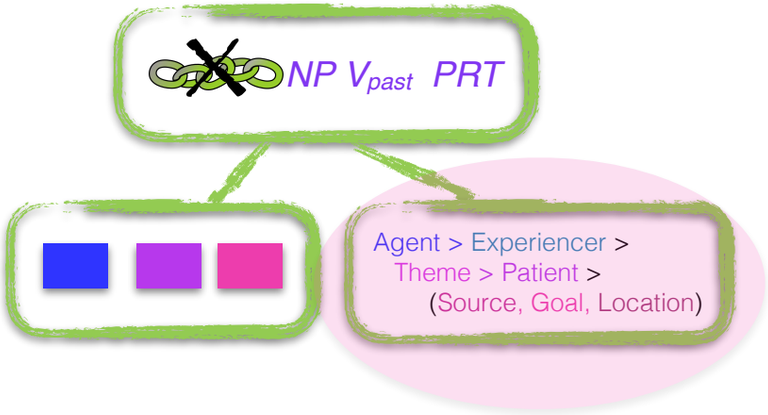
<3yrs

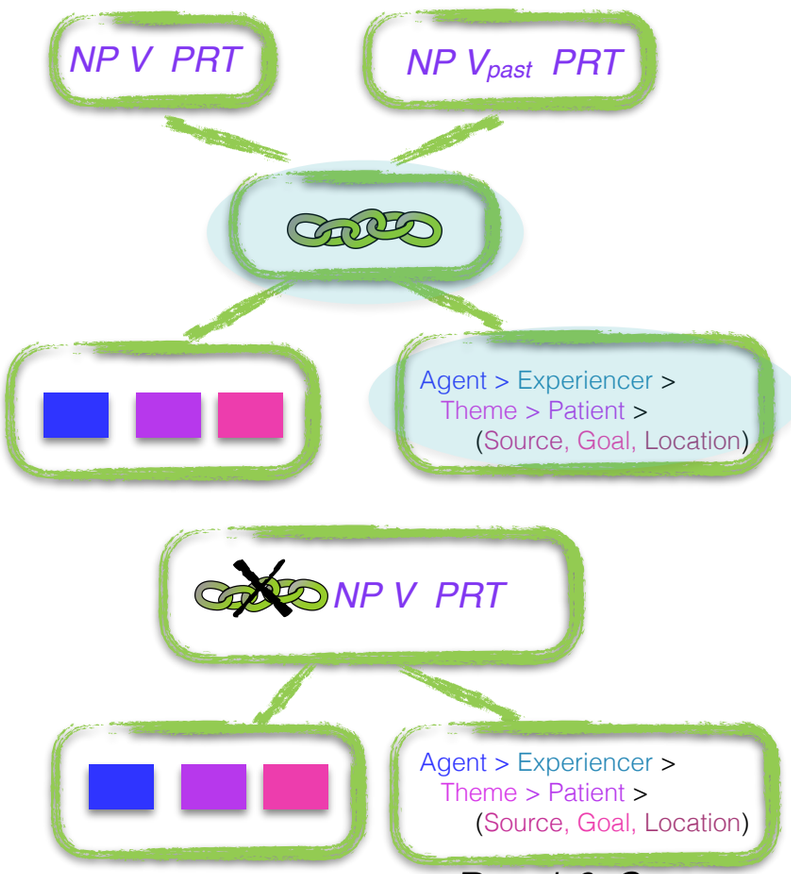
<4yrs

<5yrs









Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?

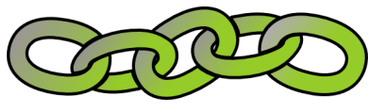
relative

late
UTAH

fixed

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

rUTAH

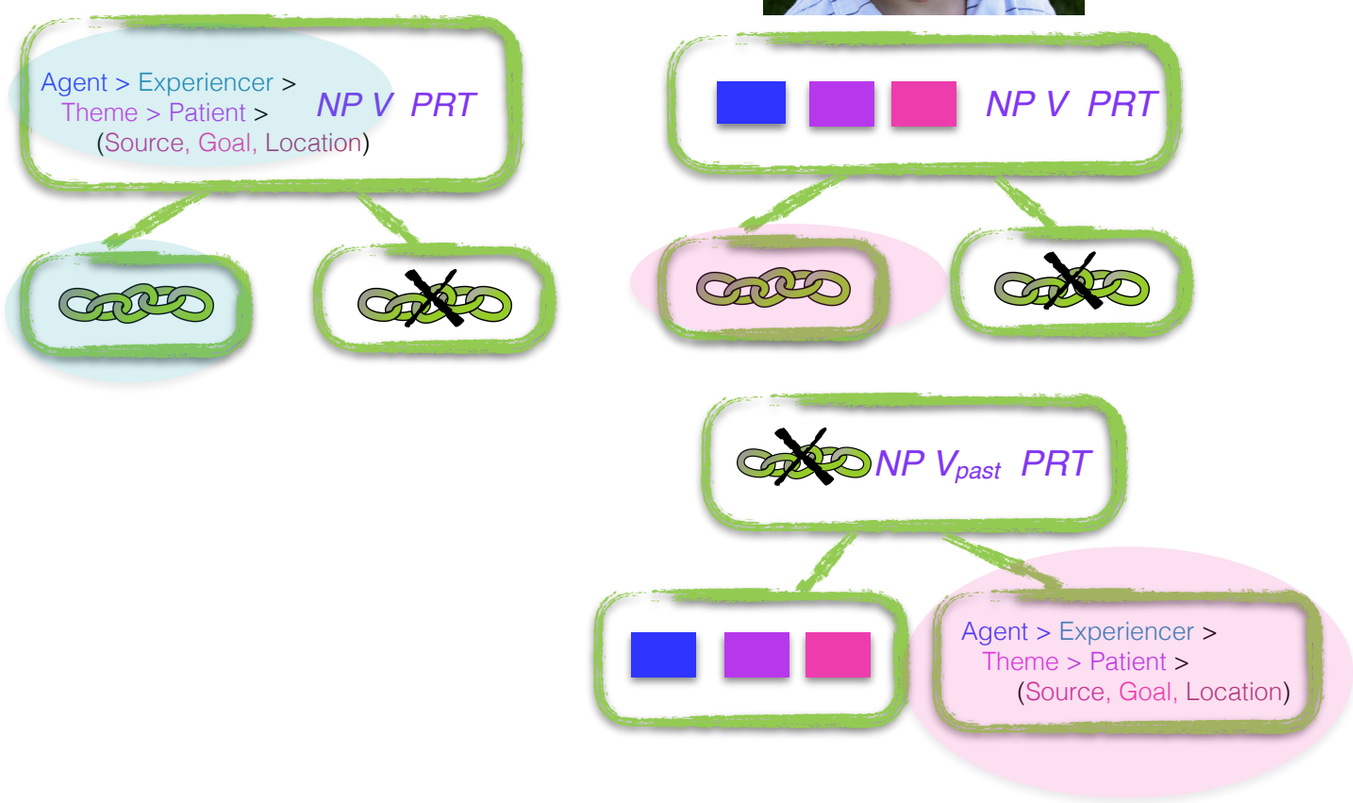


This means development is complicated for early maturation — the knowledge has to be inaccessible at four for some reason.

<3yrs

<4yrs

<5yrs



Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?

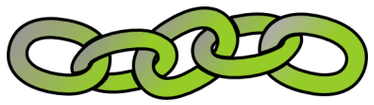
late
UTAH

relative

fixed

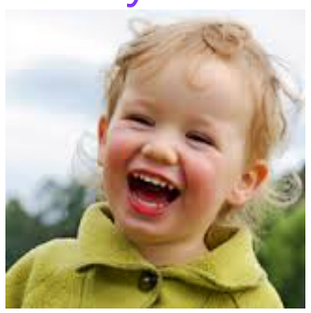
Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

rUTAH



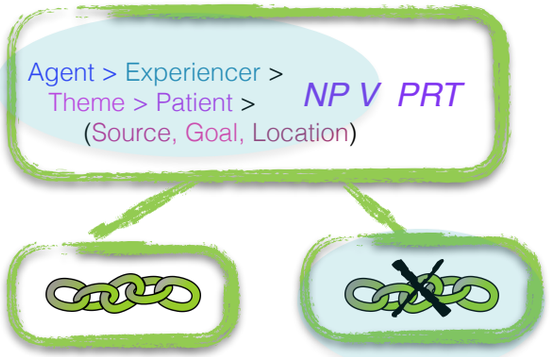
Late maturation is compatible, and would predict that the linking knowledge doesn't emerge till five.

<3yrs

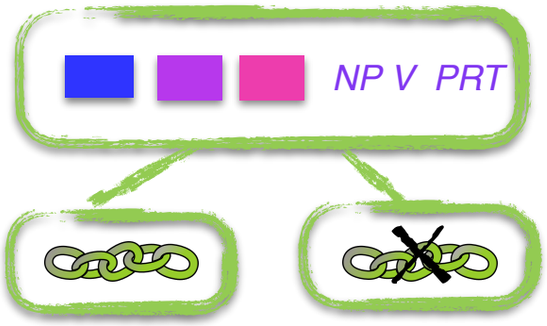


Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

NP V PRT

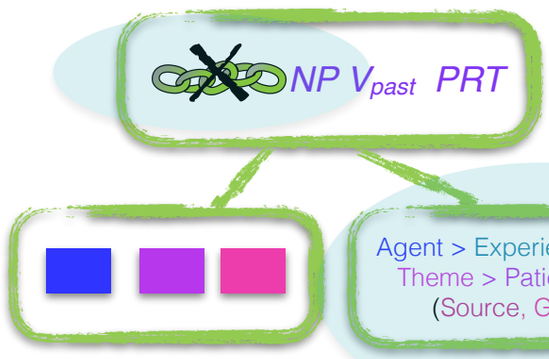


<4yrs



NP V PRT

NP V_{past} PRT

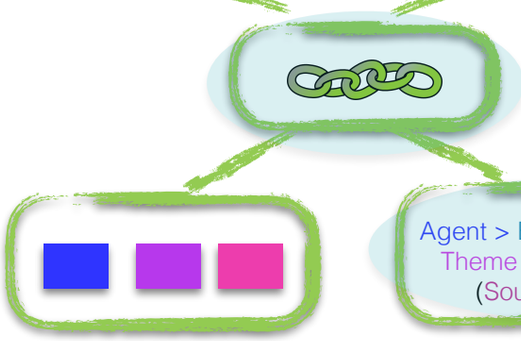


Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

<5yrs

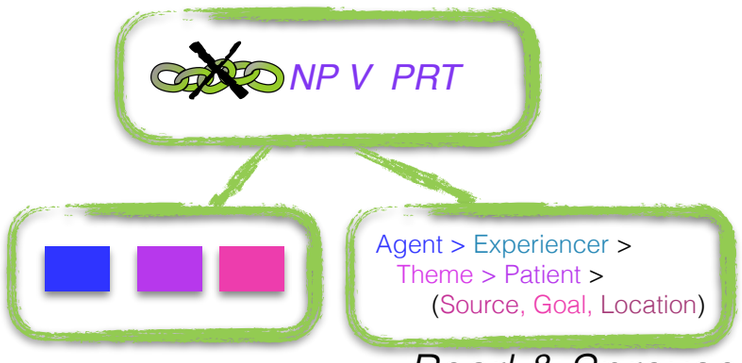
NP V PRT

NP V_{past} PRT



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

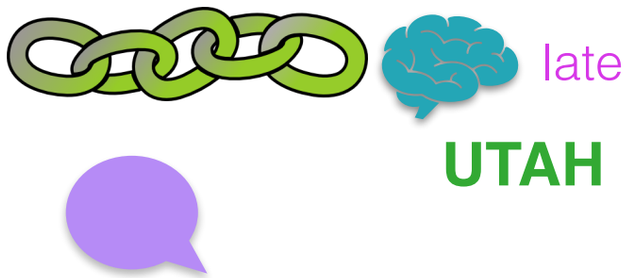
NP V PRT

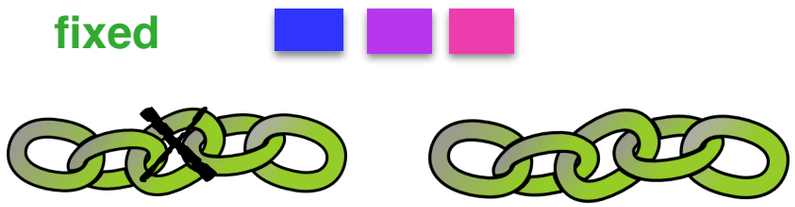


Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?





The derived-mapping variant using the fixed system would look for this knowledge to be present after the child has had sufficient language experience.

<3yrs

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

NP V PRT

<4yrs

NP V PRT

NP V_{past} PRT

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

<5yrs

NP V PRT

NP V_{past} PRT

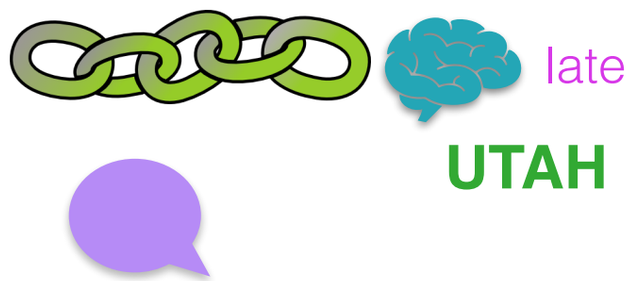
Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

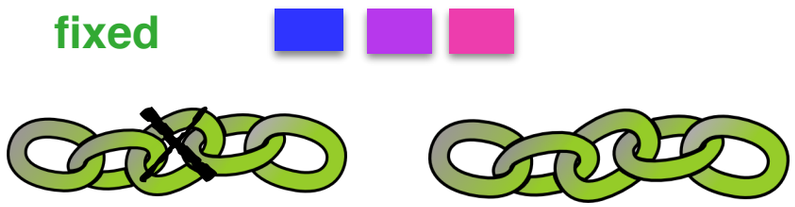
NP V PRT

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

Pearl & Sprouse 2018a

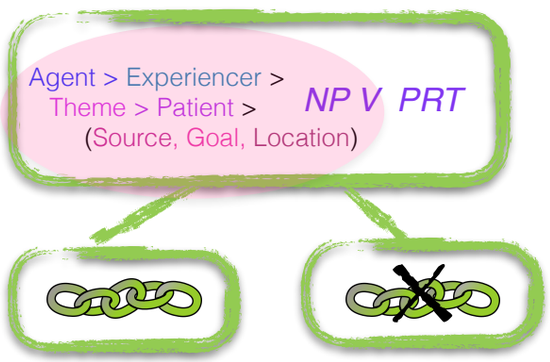
How do we interpret this with respect to our linking theory proposals?



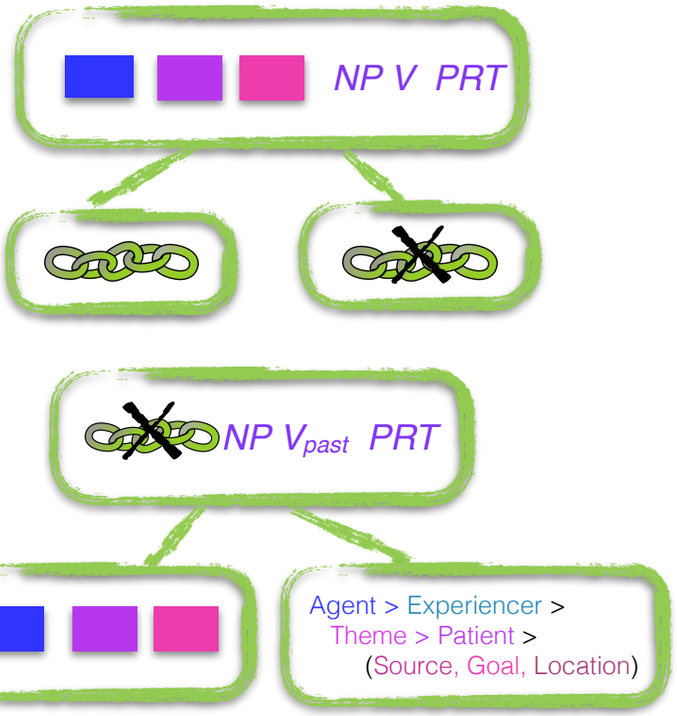


The child would need to derive the fixed system knowledge as well as the linking knowledge, since it's not present at age three.

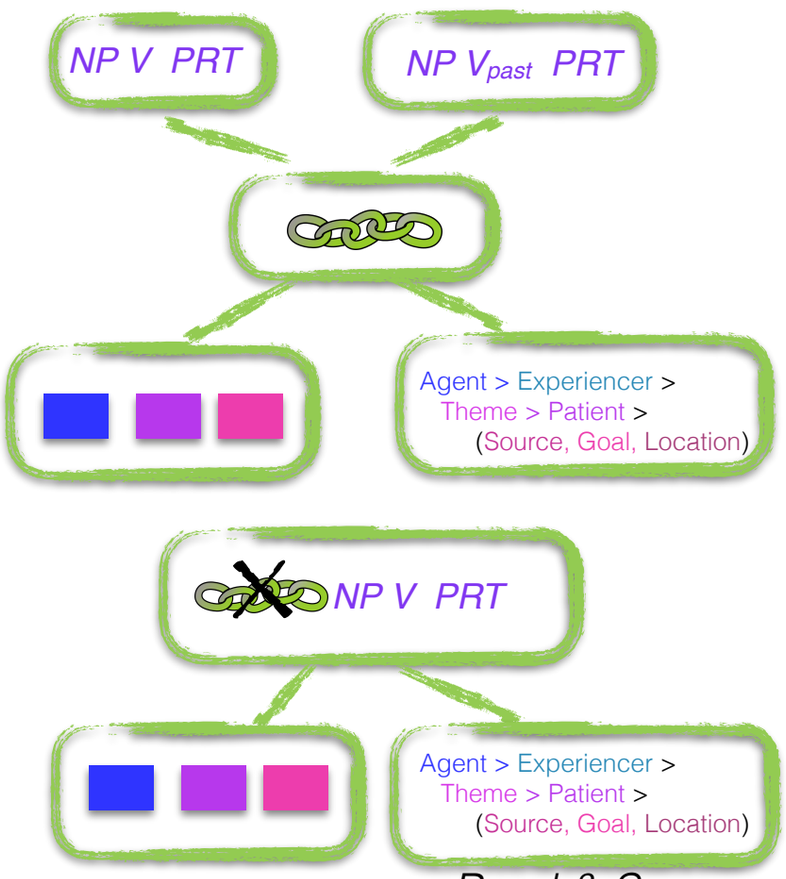
<3yrs



<4yrs

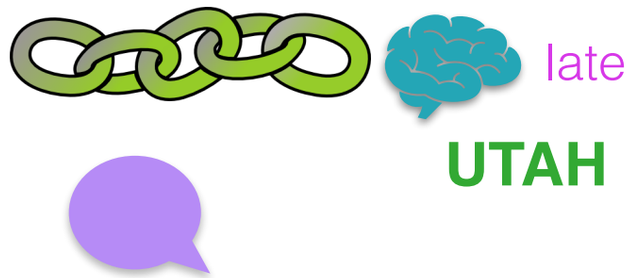


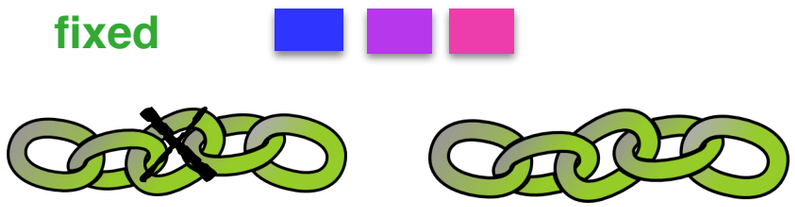
<5yrs



Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?



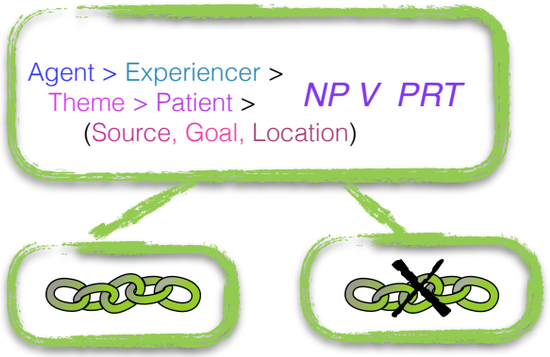


The child would need to derive the fixed system knowledge as well as the linking knowledge, since it's not present at age three.

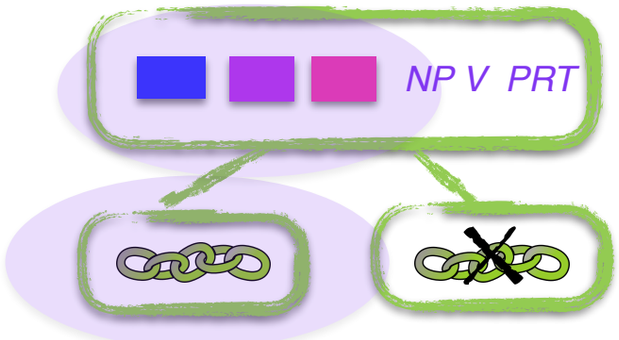
<3yrs

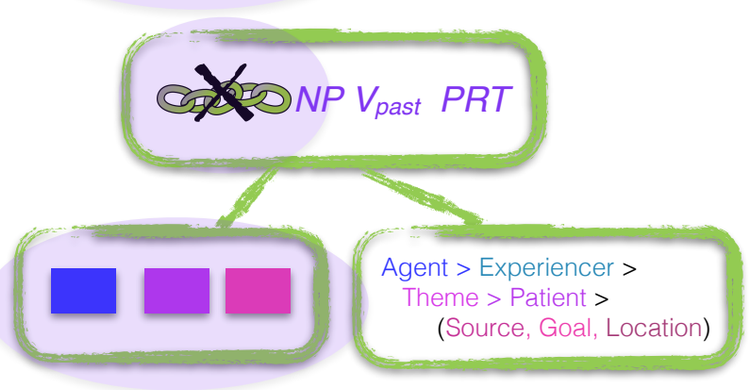
Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

NP V PRT

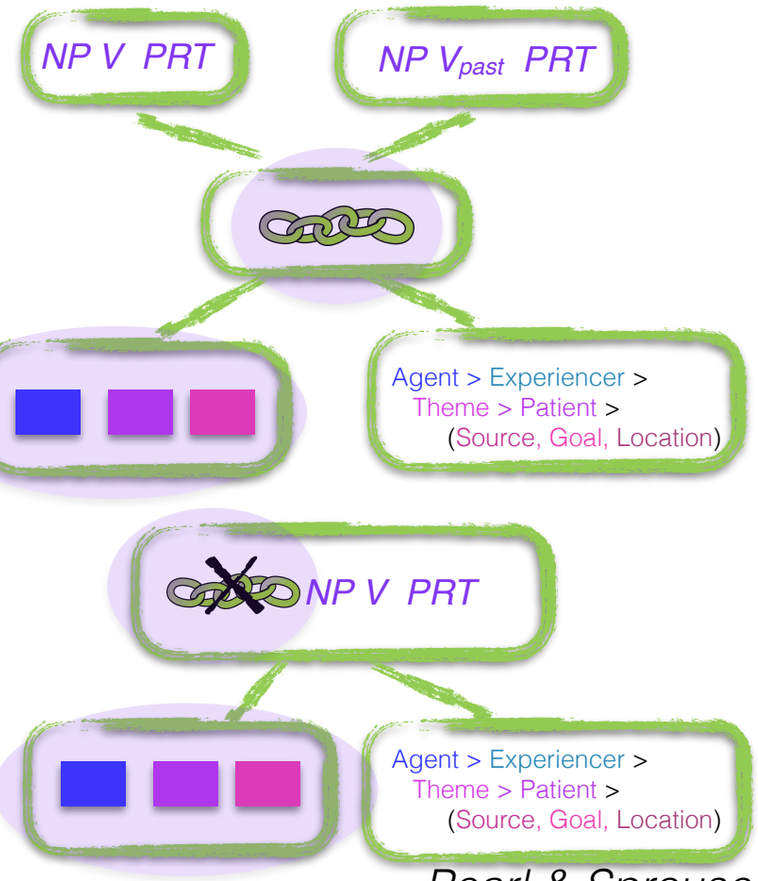


<4yrs





<5yrs



Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?

rUTAH

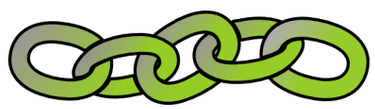
late

UTAH

+derive fixed
fixed

relative

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

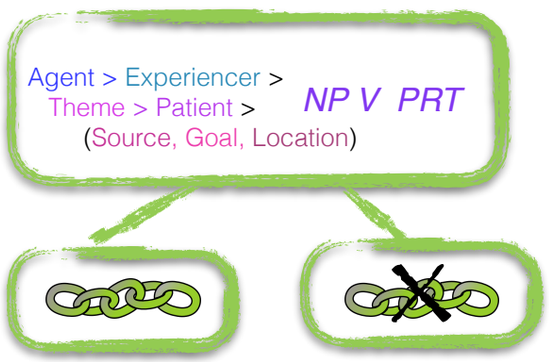


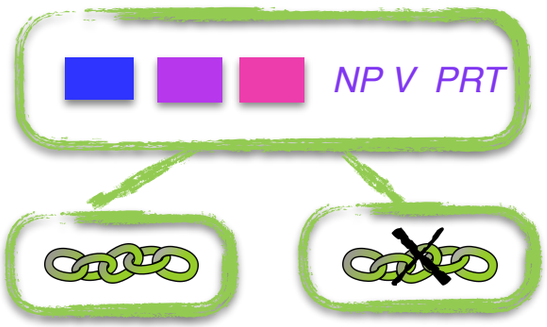
The derived-mapping variant using the relative system would look for this knowledge to be present after the child has had sufficient language experience.

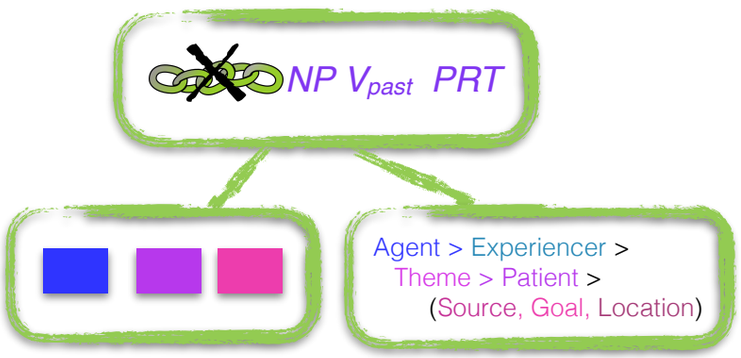
<3yrs

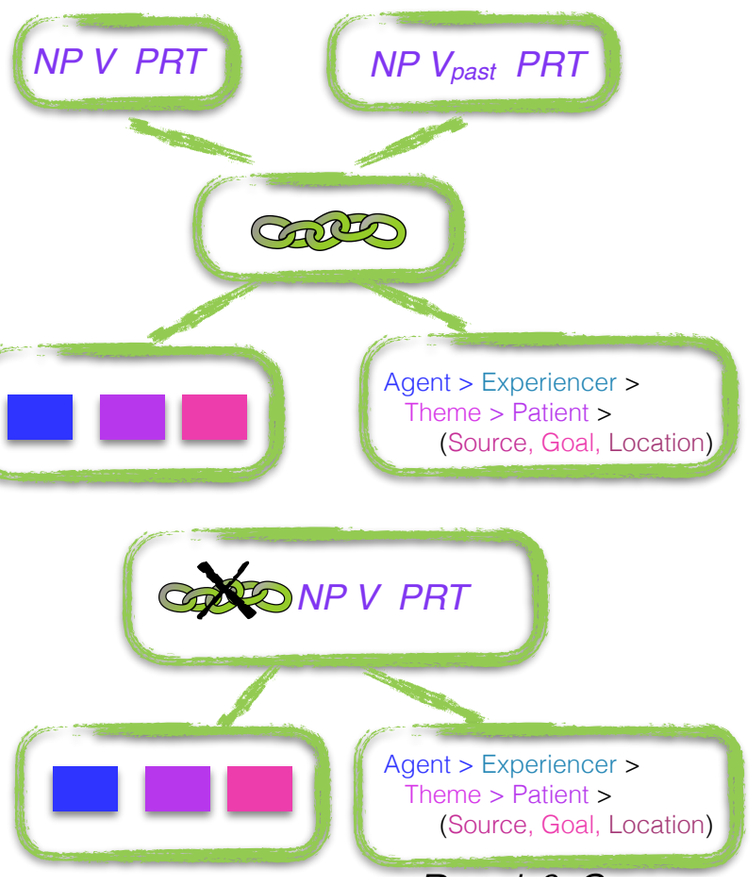
<4yrs

<5yrs



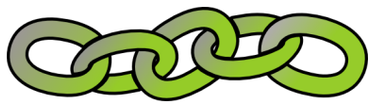






Pearl & Sprouse 2018a

How do we interpret this with respect to our linking theory proposals?



rUTAH

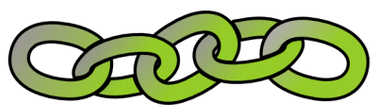
late

UTAH

+derive fixed
fixed

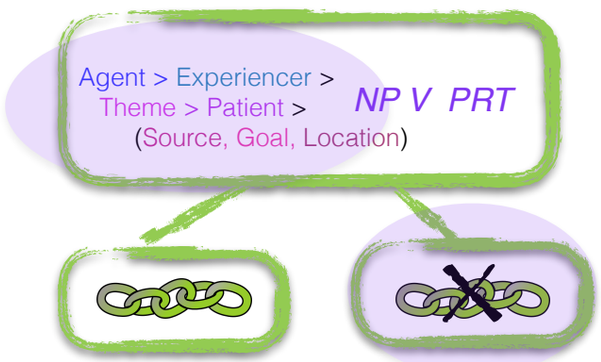
relative

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

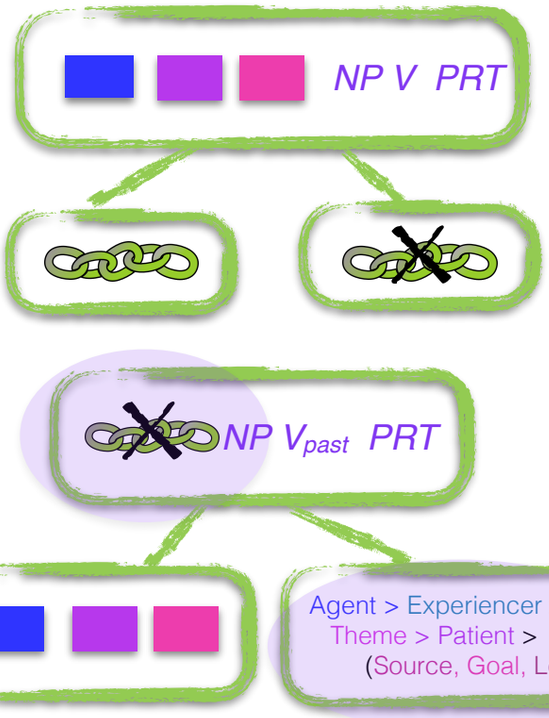


This seems compatible: for example, the linking knowledge could be absent at three and four, but derived by five.

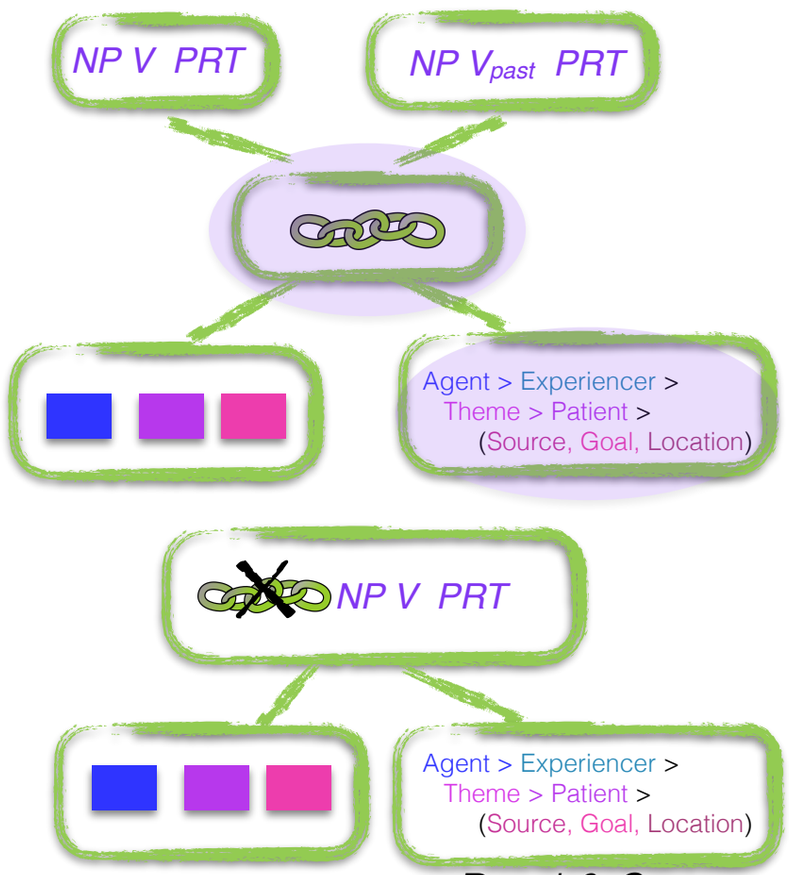
<3yrs



<4yrs



<5yrs



Pearl & Sprouse 2018a

Our linking theory proposals can now be coupled with the developmental theories that have to accompany them in order to match empirical data from children.

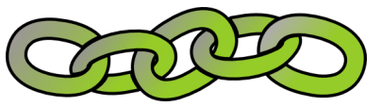
rUTAH

late maturation

UTAH

+fixed matures late

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



relative

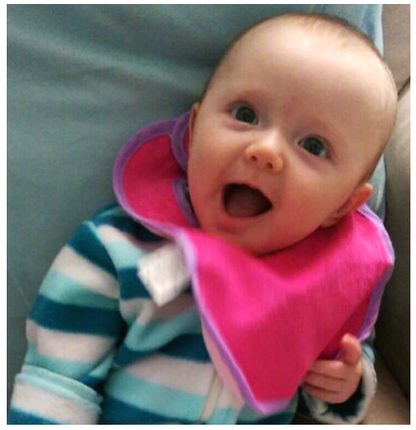
derive by five

fixed

+derive fixed

Pearl & Sprouse 2018a

Our linking theory proposals can now be coupled with the developmental theories that have to accompany them in order to match empirical data from children.



Takeaway 1: Innate-mapping approaches must involve late maturation.

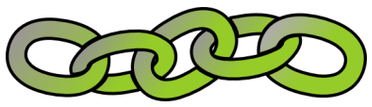
rUTAH

late maturation

UTAH

+fixed matures late

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



relative

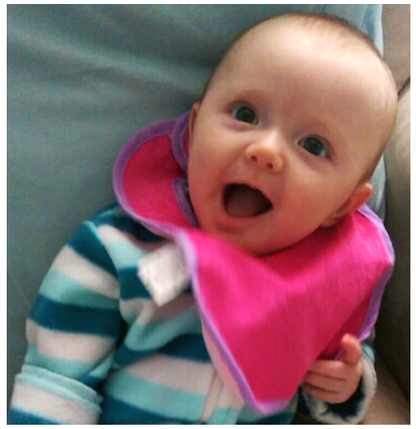
derive by five

fixed

+derive fixed

Pearl & Sprouse 2018a

Our linking theory proposals can now be coupled with the developmental theories that have to accompany them in order to match empirical data from children.



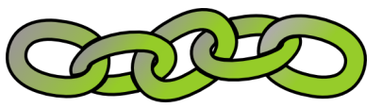
Takeaway 2: Approaches with fixed thematic systems must involve late maturation or derivation from the input.

rUTAH

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

relative

late maturation



derive by five

UTAH

+fixed matures late

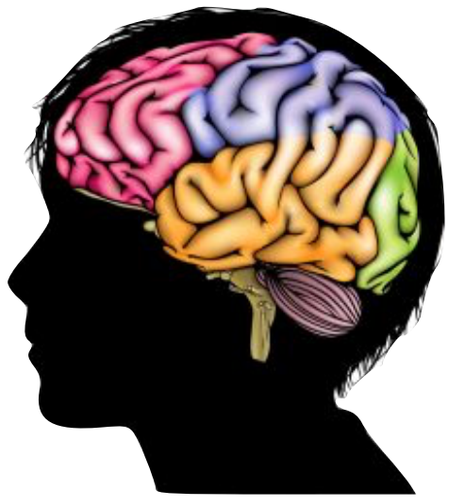
fixed

+derive fixed

Pearl & Sprouse 2018a

Our linking theory proposals can now be coupled with the developmental theories that have to accompany them in order to match empirical data from children.

Question: If knowledge matures late, how does that work?
We need evidence from developmental neurobiology.



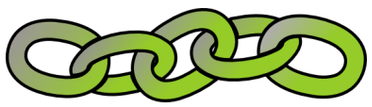
rUTAH

late maturation

UTAH

+fixed matures late

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



relative

derive by five

fixed

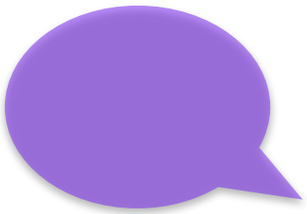
+derive fixed

Pearl & Sprouse 2018a

Our linking theory proposals can now be coupled with the developmental theories that have to accompany them in order to match empirical data from children.

relative

fixed



Question: If knowledge is derived from the input, how does that work? We need a concrete proposal for how children could do this.

rUTAH

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

late maturation

relative

derive by five

UTAH

+fixed matures late

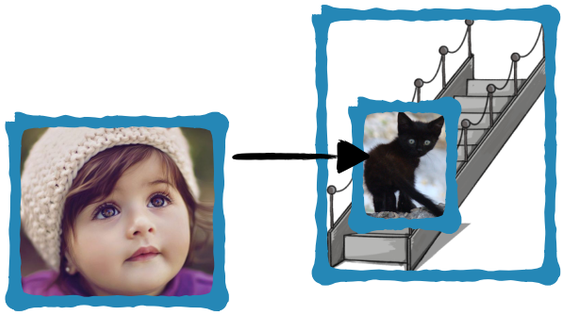
fixed

+derive fixed

Pearl & Sprouse 2018a

The Plan

The little girl *blicked* the kitten on the stairs.

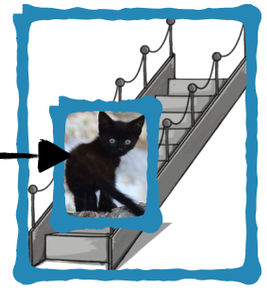


1. Evaluating different linking theory proposals using developmental modeling

2. Exploring how a linking theory could be derived from children's input

Exploring how a linking theory could be derived from children's input

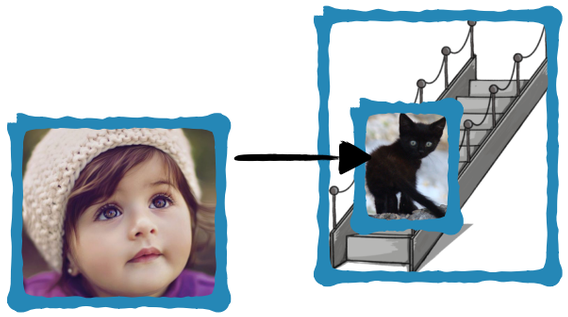
The little girl *blicked* the kitten on the stairs.



Let's remind ourselves what children are learning about links.

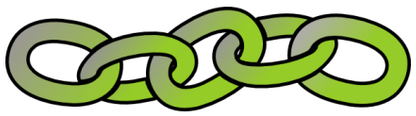
Pearl & Sprouse 2018b

Exploring how a linking theory could be derived from children's input



Subject Object Oblique Object

Syntax The little girl *blicked* the kitten on the stairs.



If children have a particular intermediate representation for thematic roles, then they need to link those representations to syntactic positions.

Intermediate representations

fixed

relative

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

Event participant roles = Thematic roles

Agent, Experiencer, Patient, Theme, Goal, Source, Location…

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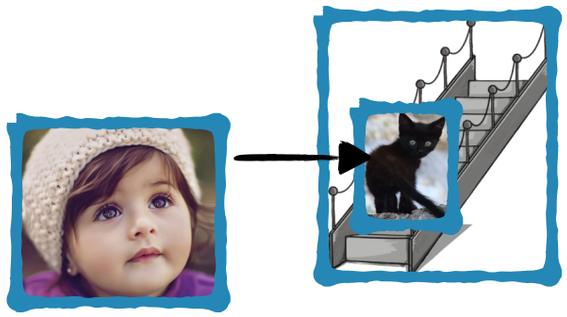
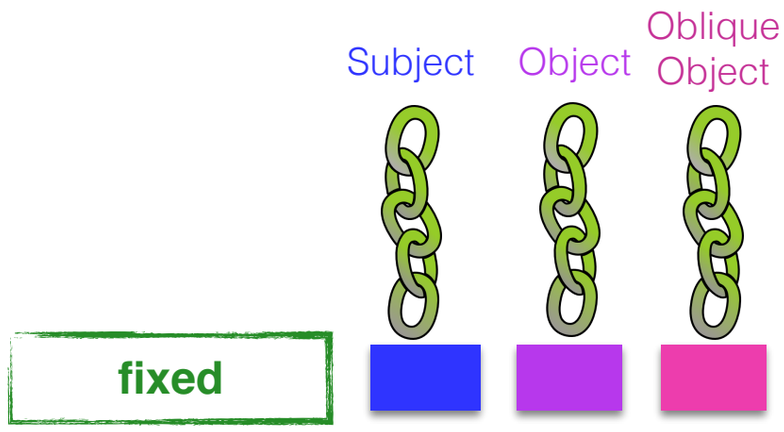
Exploring how a linking theory could be derived from children's input



The little girl *blicked* the kitten on the stairs.

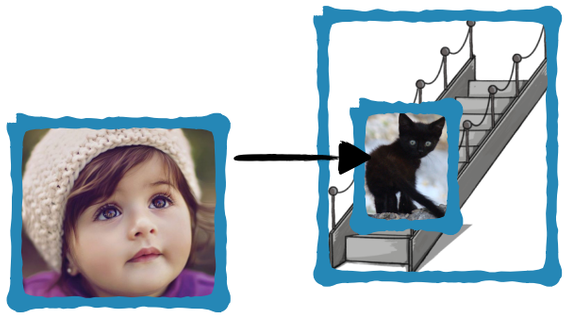


relative

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

Pearl & Sprouse 2018b

Exploring how a linking theory could be derived from children's input



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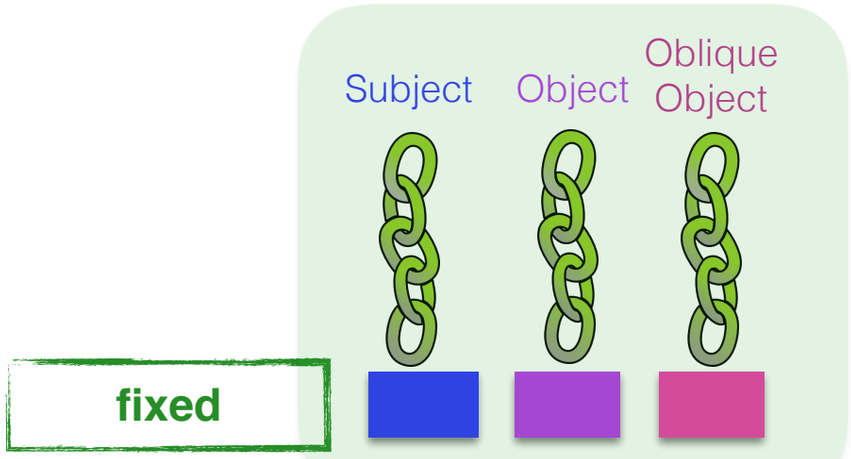
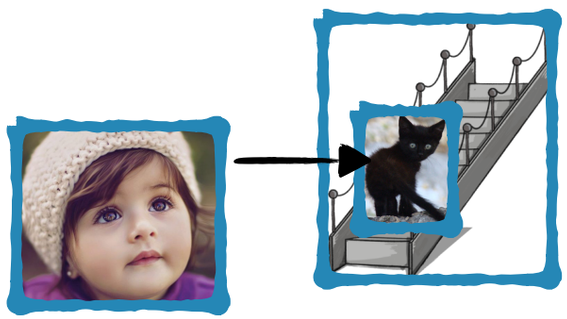


relative

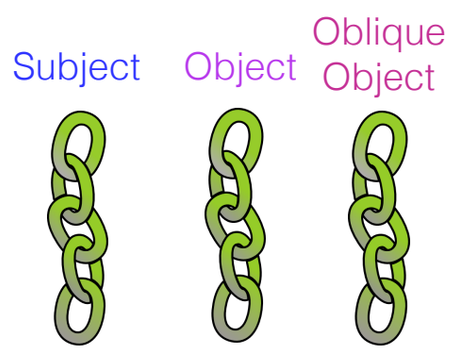
Agent > Experiencer > Theme > Patient > (Source, Goal, Location)

Pearl & Sprouse 2018b

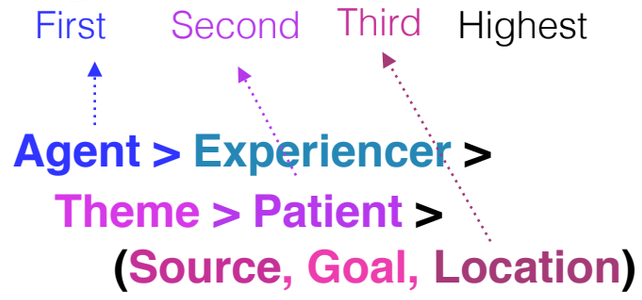
Exploring how a linking theory could be derived from children's input



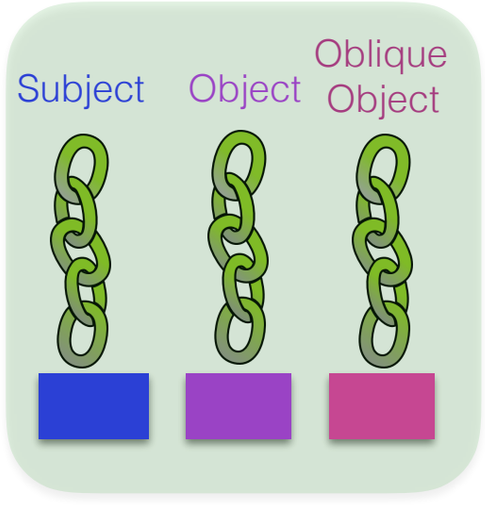
The little girl *blicked* the kitten on the stairs.



relative

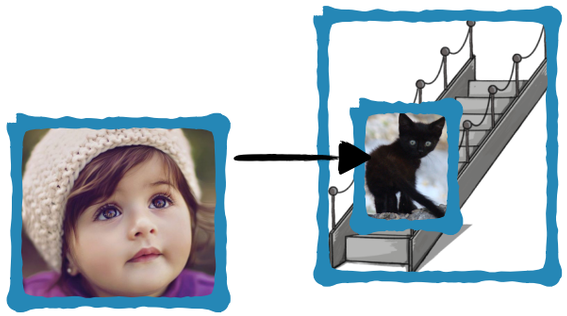


fixed



Pearl & Sprouse 2018b

Exploring how a linking theory could be derived from children's input



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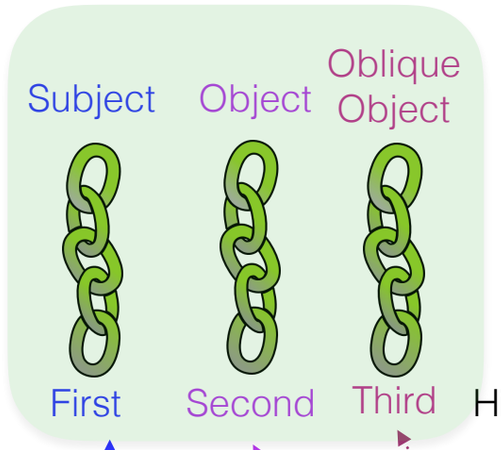
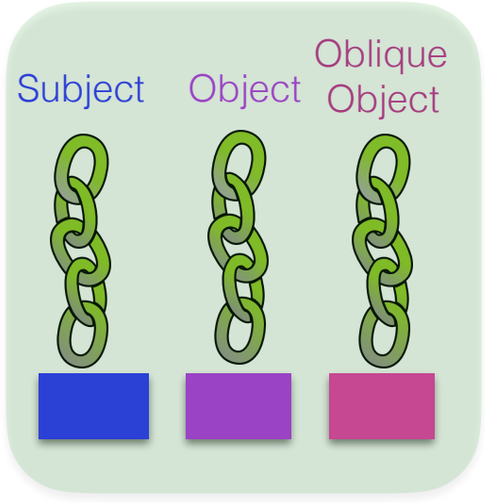


relative

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

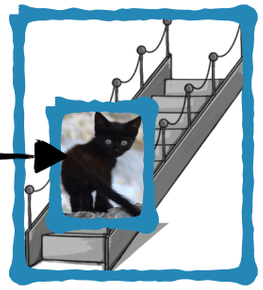
fixed



Pearl & Sprouse 2018b

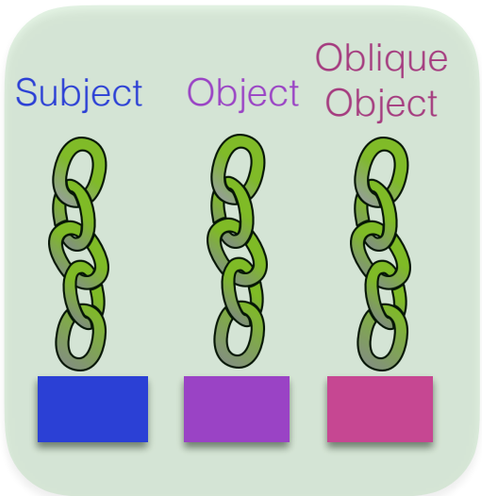
Exploring how a linking theory could be derived from children's input

The little girl *blicked* the kitten on the stairs.



The linking theories we looked at before (UTAH and rUTAH, and their derived-mapping equivalents) treat these as atomic units (3-link theories).

fixed



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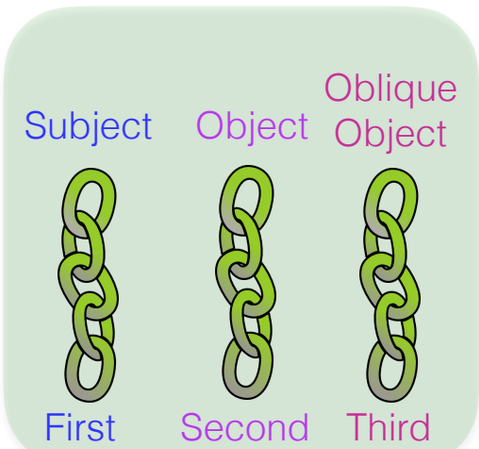
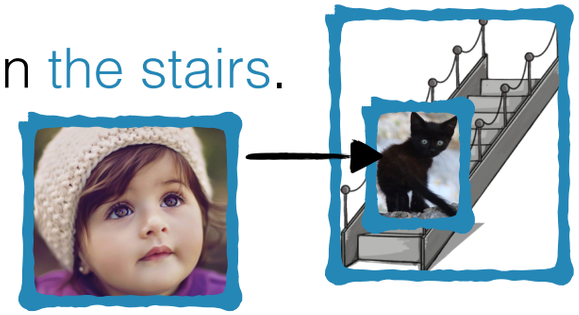


Pearl & Sprouse 2018b

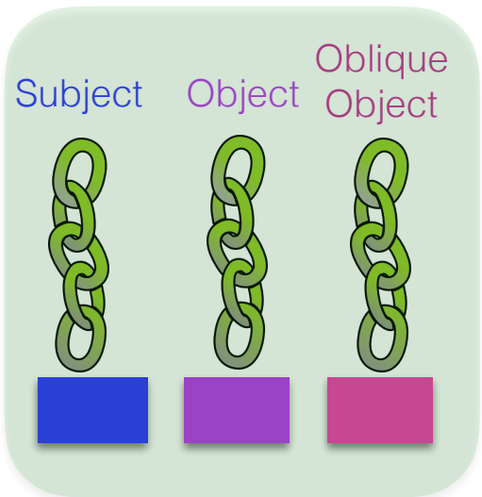
Exploring how a linking theory could be derived from children's input

The little girl *blicked* the kitten on the stairs.



Acquisition task for one 3-link theory:
(1) Derive all three links from the input.
(2) Derive the 3-link linking theory.

fixed



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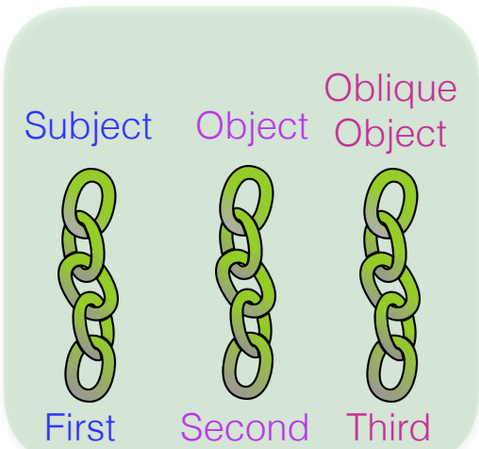
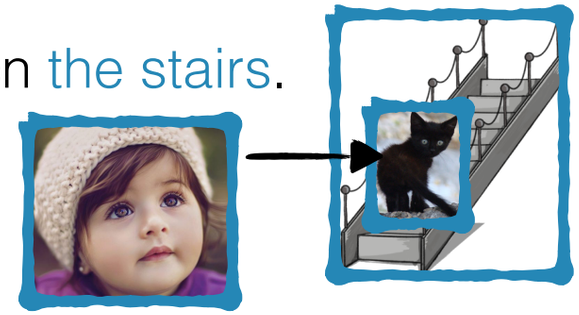


Pearl & Sprouse 2018b

Exploring how a linking theory could be derived from children's input

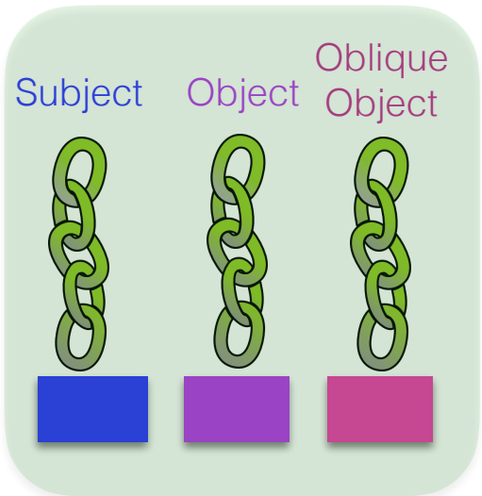
The little girl *blicked* the kitten on the stairs.



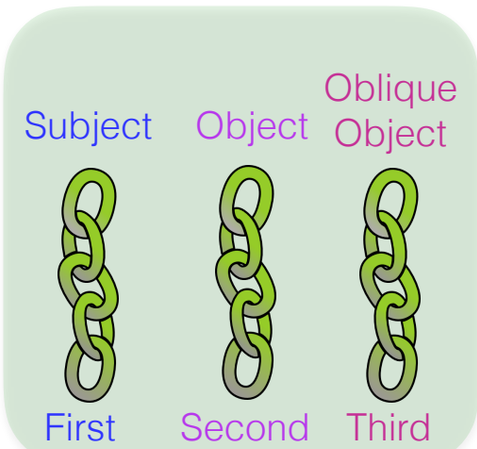
Acquisition task for one 3-link theory:
(1) Derive all three links from the input.
(2) Derive the 3-link linking theory.

How would this work?

fixed



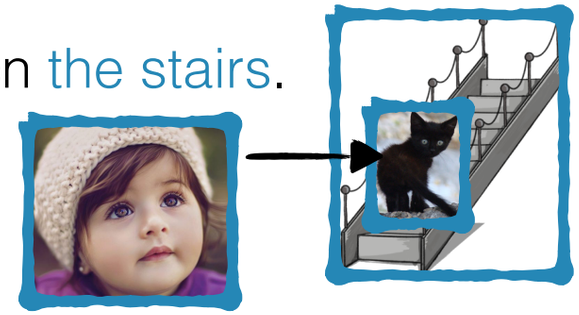
relative



Pearl & Sprouse 2018b

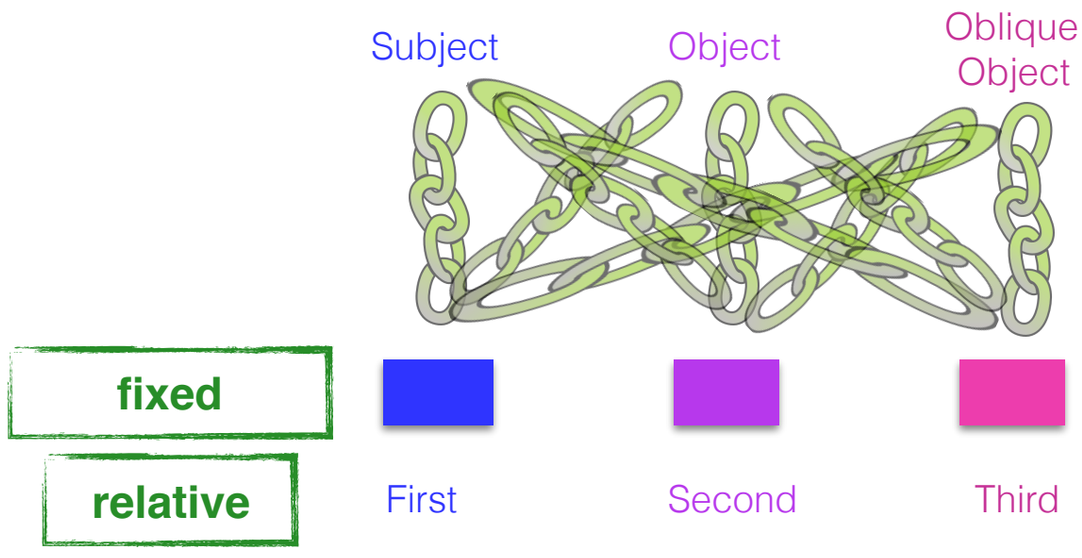
Exploring how a linking theory could be derived from children's input

The little girl *blicked* the kitten on the stairs.



Acquisition task for one 3-link theory:
(1) Derive all three links from the input.
(2) Derive the 3-link linking theory.

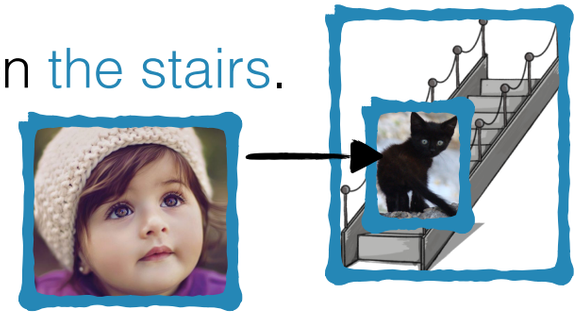
One way: Consider all possible links and see which ones are reliable enough in the input



Pearl & Sprouse 2018b

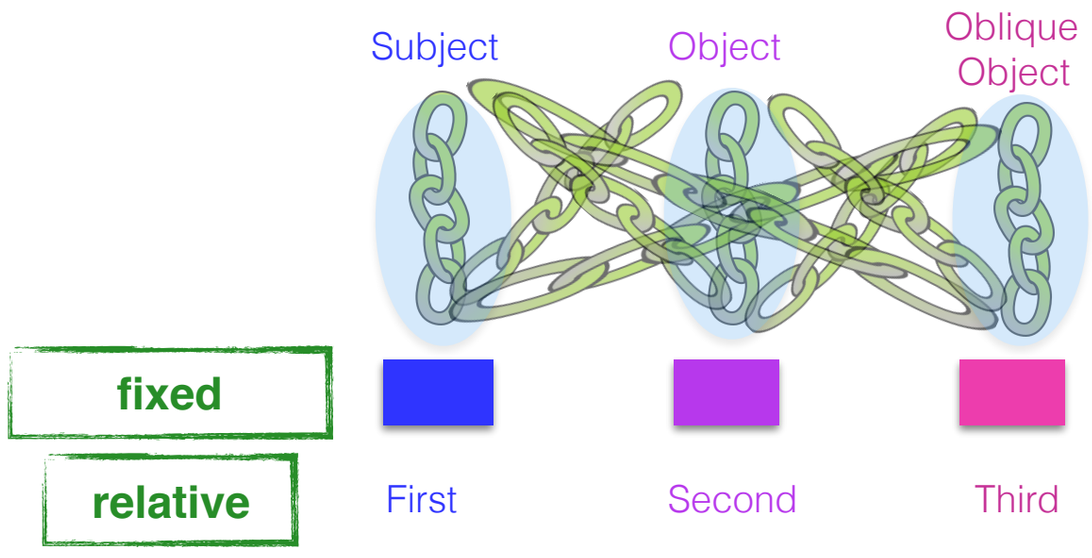
Exploring how a linking theory could be derived from children's input

The little girl *blicked* the kitten on the stairs.



Acquisition task for one 3-link theory:
(1) Derive all three links from the input.
(2) Derive the 3-link linking theory.

One way: Consider all possible links and see which ones are reliable enough in the input



Pearl & Sprouse 2018b

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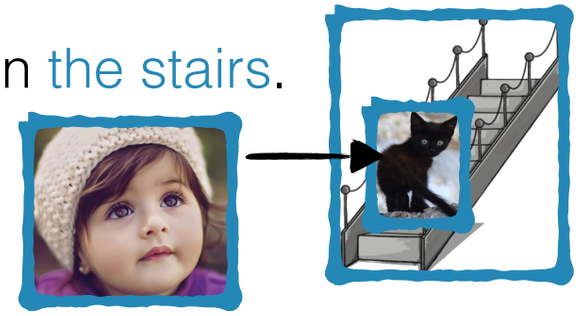
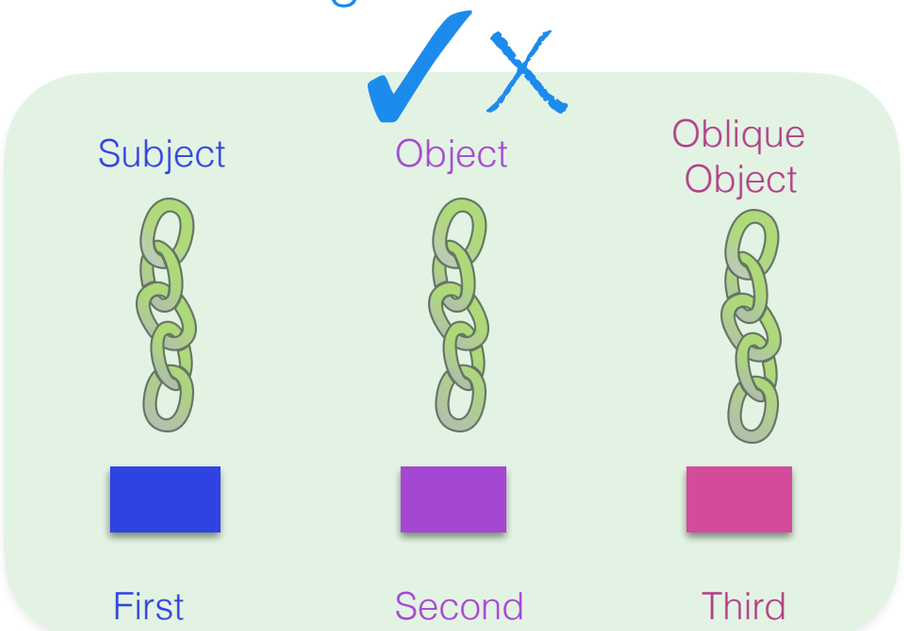


Acquisition task for one 3-link theory:
(1) Derive all three links from the input.
(2) Derive this 3-link linking theory.

One way: Then construct the multi-link linking theory from the reliable links and see if the 3-link theory is reliable enough as a unit.



Pearl & Sprouse 2018b

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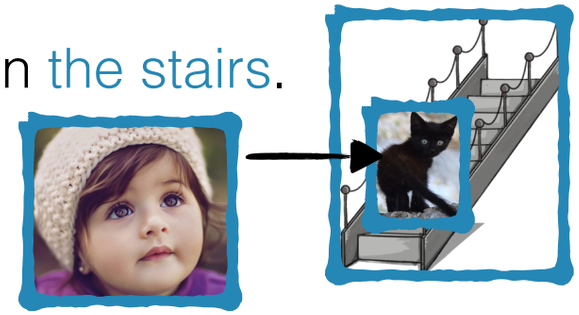
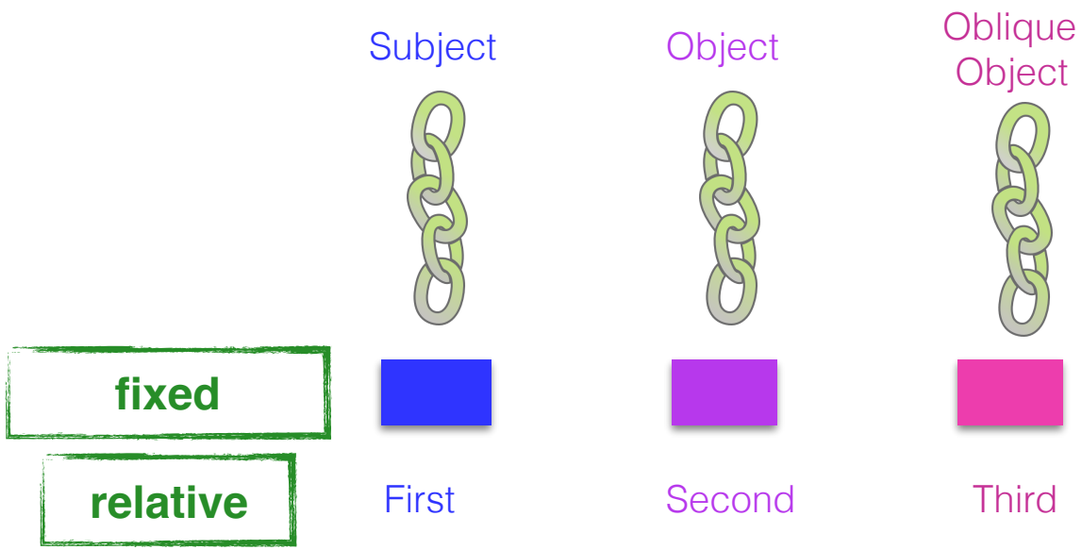


An alternative acquisition task for three 1-link theories:
Derive all three links from the input (and don't worry about binding them together — just have three 1-link theories)



Pearl & Sprouse 2018b

Exploring how a linking theory could be derived from children's input

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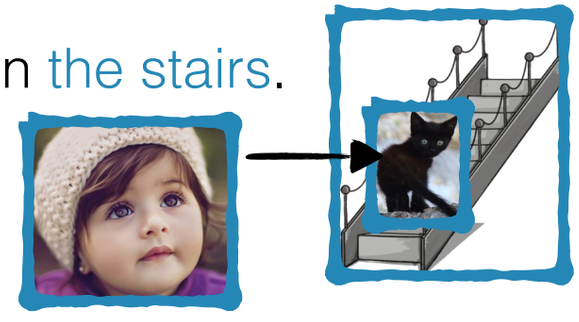
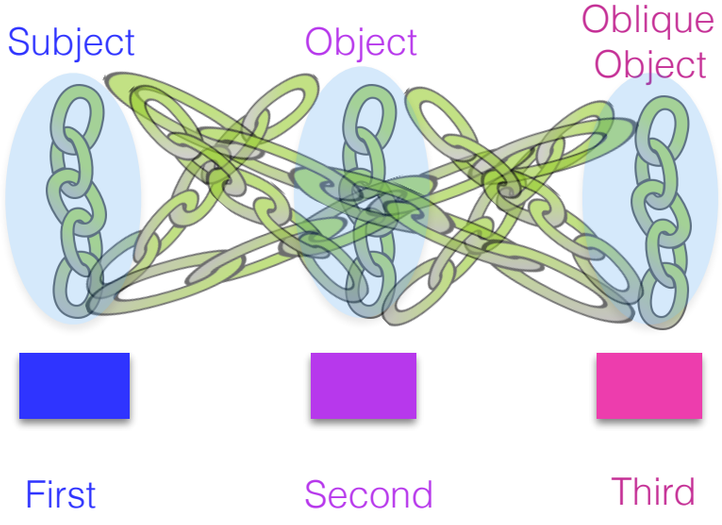


An alternative acquisition task for three 1-link theories:
Derive all three links from the input (and don't worry about binding them together — just have 3 1-link theories)

How would this work?

The same way: Consider all possible links and see which ones are reliable enough in the input



Pearl & Sprouse 2018b

Exploring how a linking theory could be derived from children's input

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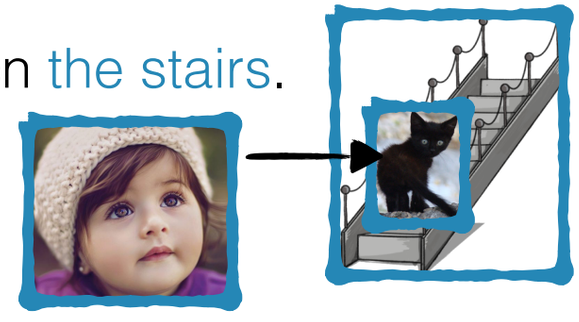
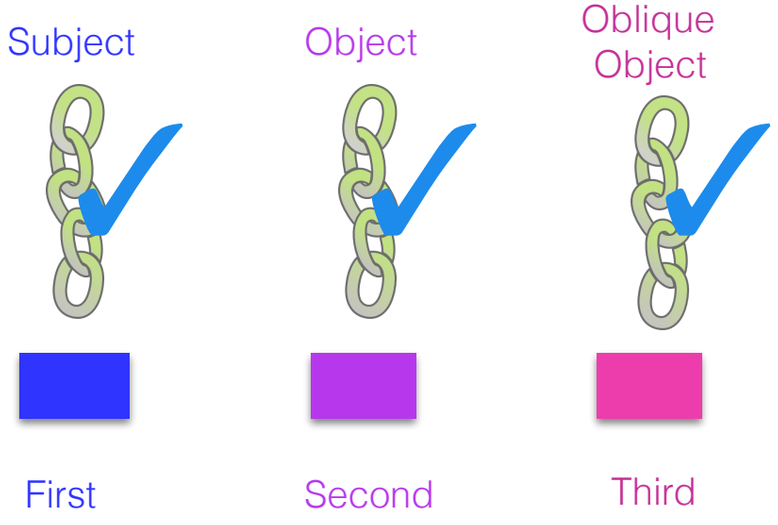


An alternative acquisition task for three 1-link theories:
Derive all three links from the input (and don't worry about binding them together — just have 3 1-link theories)

How would this work?

And then you're finished.



Pearl & Sprouse 2018b

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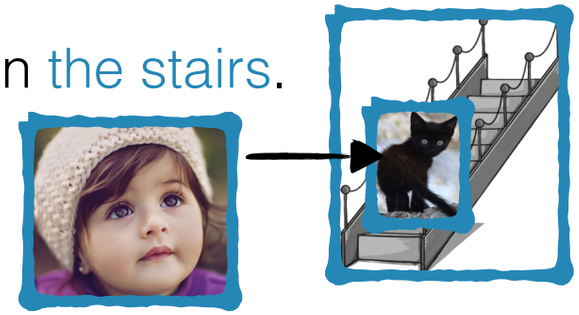
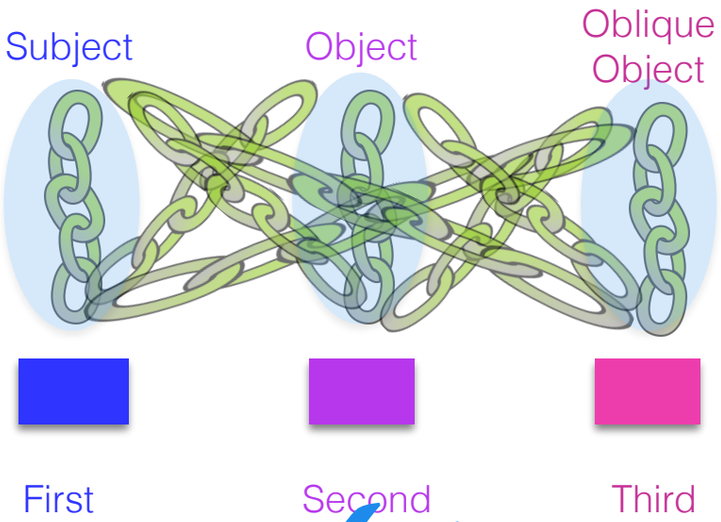
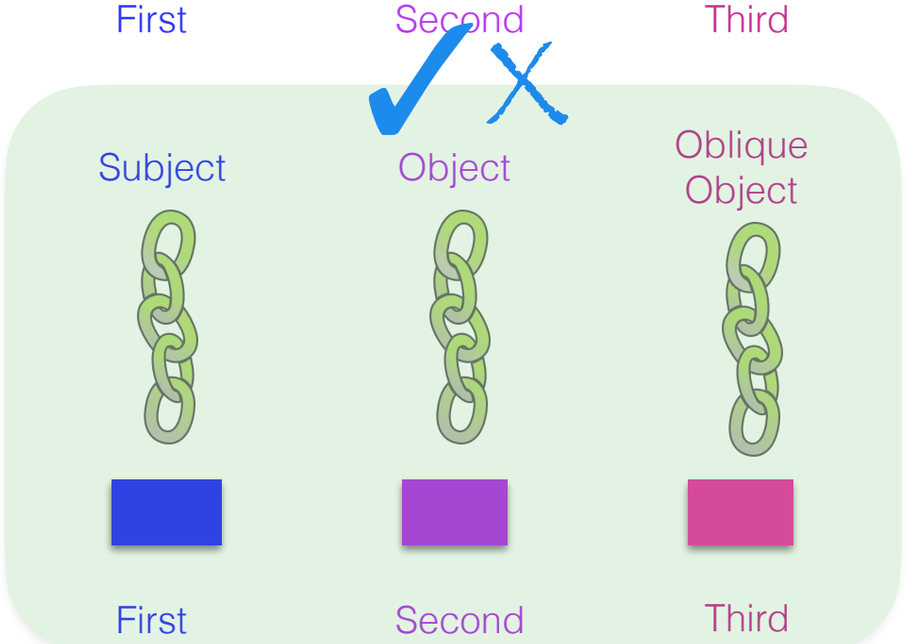
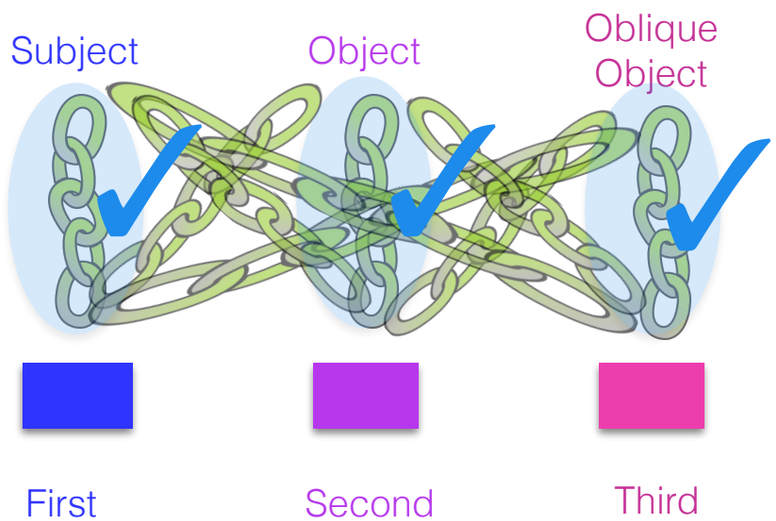


one 3-link theory





three 1-link theories



Pearl & Sprouse 2018b

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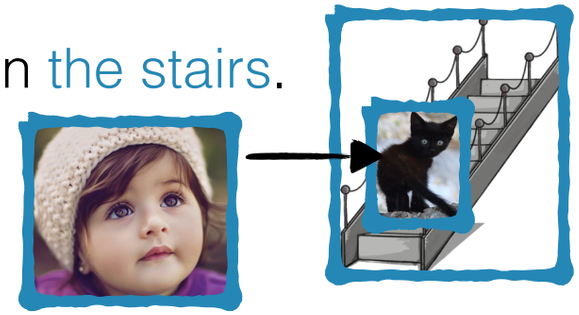
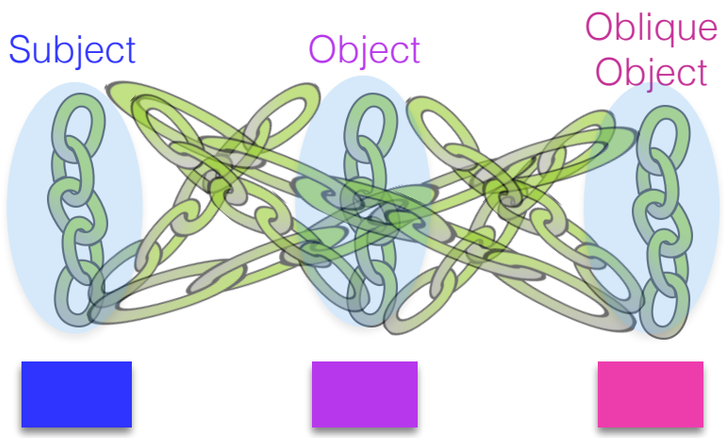
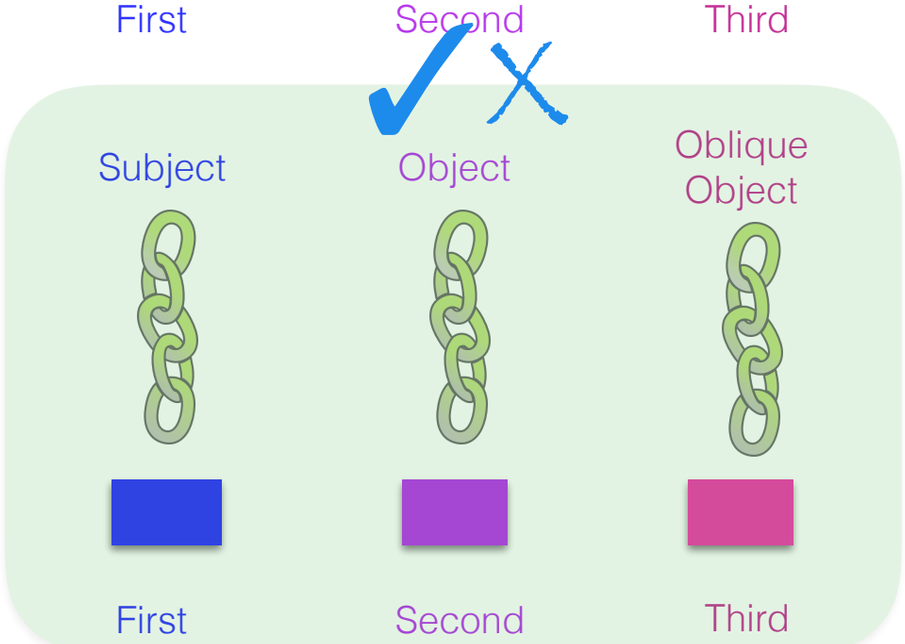


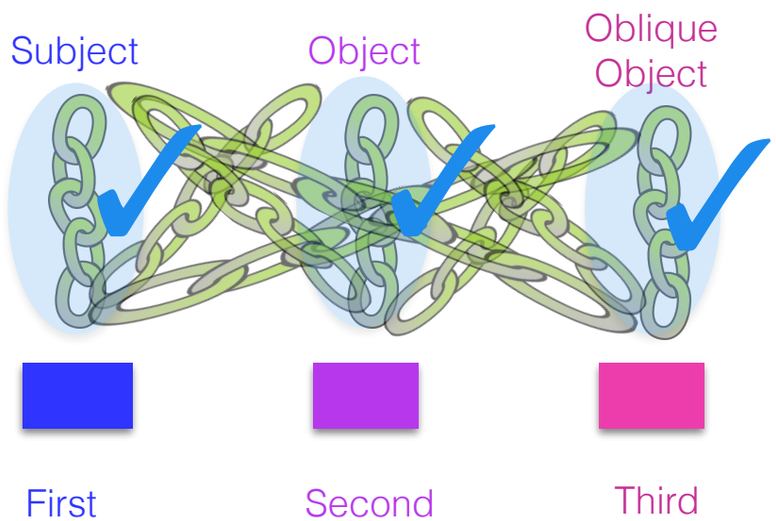
Is either of these possible, given the kind of input children get?

one 3-link theory





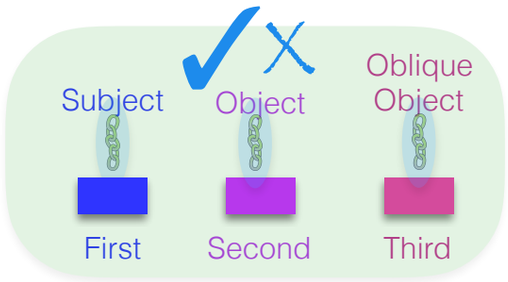
three 1-link theories



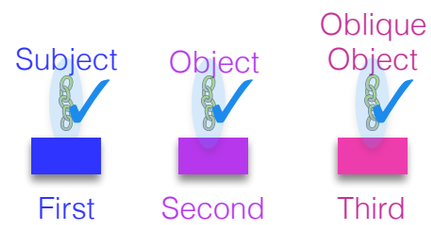
Pearl & Sprouse 2018b

Defining the acquisition task

one 3-link theory



three 1-link theories



five main parts to defining an acquisition task concretely

initial state

data intake

inference

learning period

target state

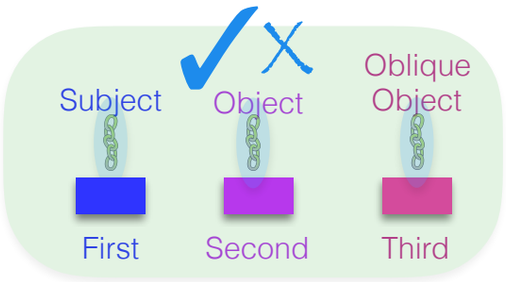
Pearl & Sprouse 2018b

Defining the acquisition task

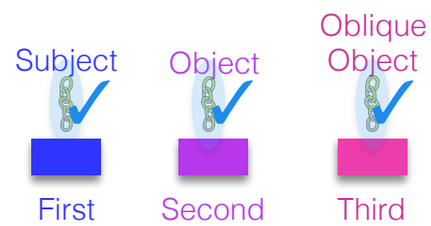
data intake inference

learning period target state

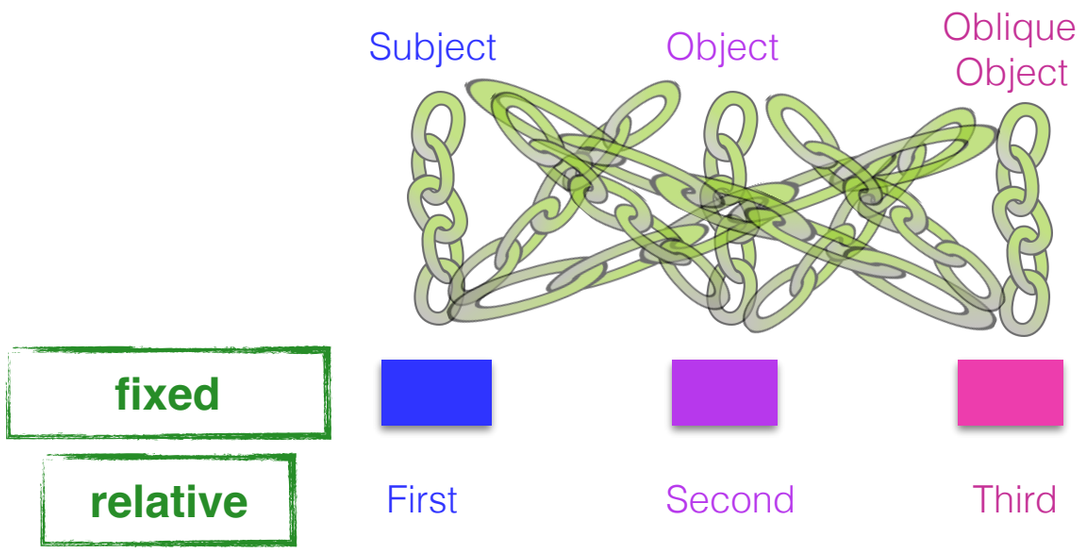
one 3-link theory



three 1-link theories



initial state



fixed

relative

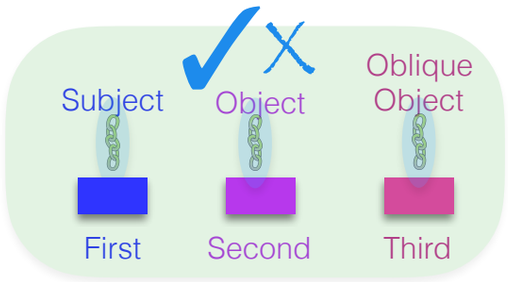
Pearl & Sprouse 2018b

Defining the acquisition task

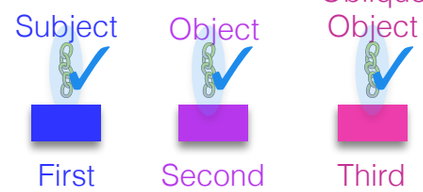
data intake inference

learning period target state

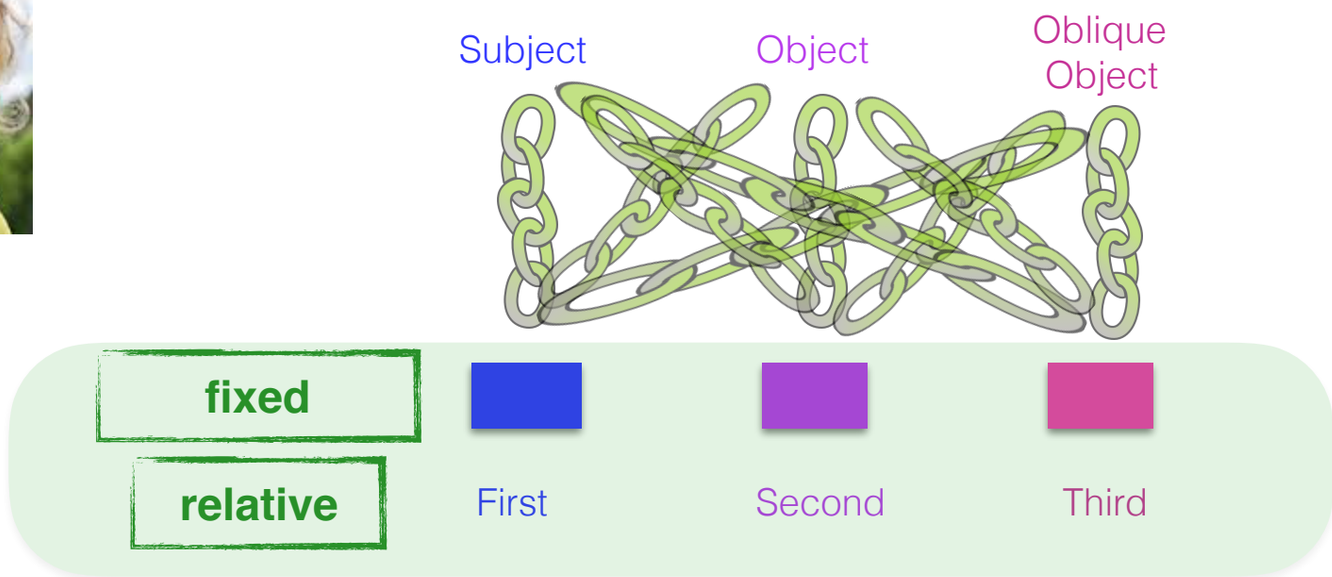
one 3-link theory



three 1-link theories



initial state



Knowledge of intermediate thematic representation

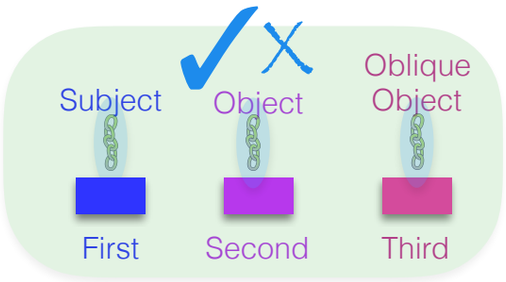
Pearl & Sprouse 2018b

Defining the acquisition task

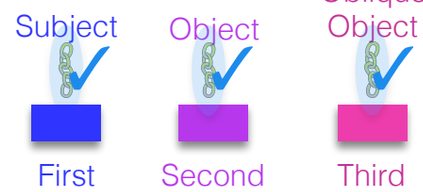
data intake inference

learning period target state

one 3-link theory



three 1-link theories



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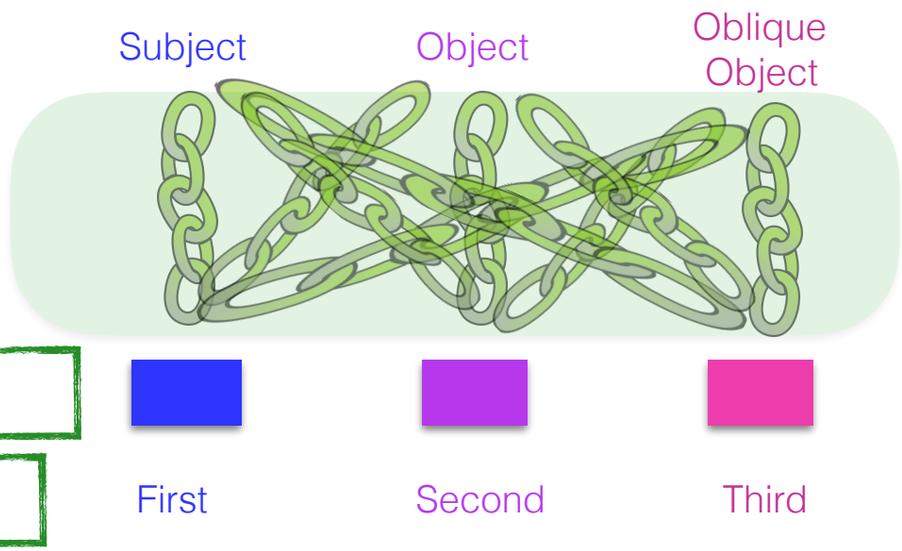


fixed

relative

Constraints on possible links

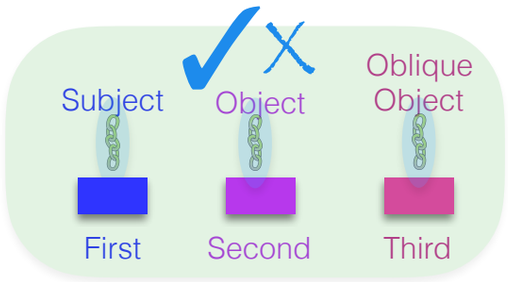
Pearl & Sprouse 2018b

Defining the acquisition task

data intake inference

learning period target state

one 3-link theory



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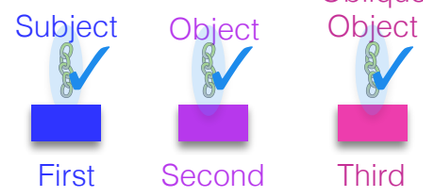

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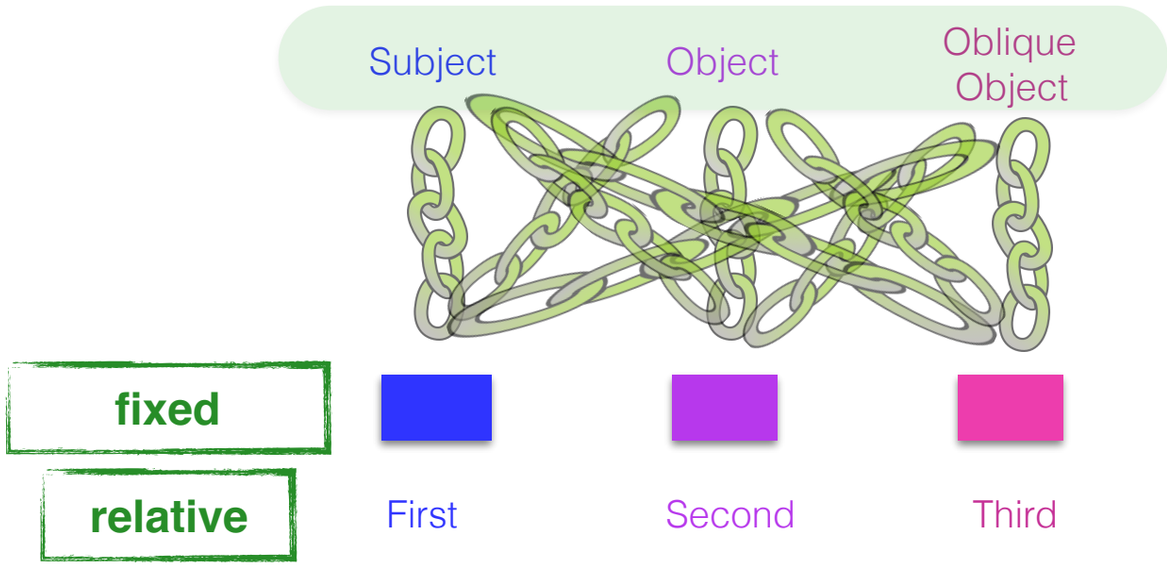


fixed

relative

Constraints on possible links:

- Knowing which syntactic positions are relevant

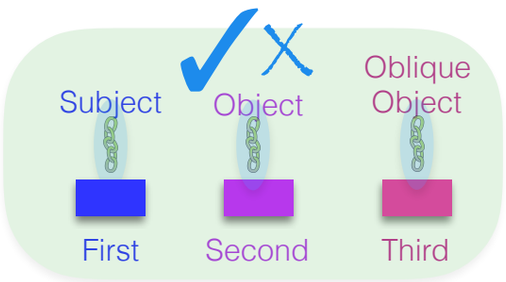
Pearl & Sprouse 2018b

Defining the acquisition task

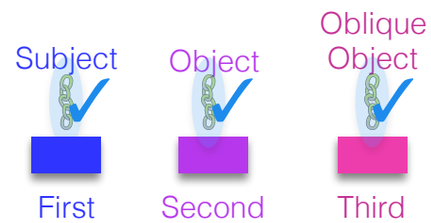
data intake inference

learning period target state

one 3-link theory



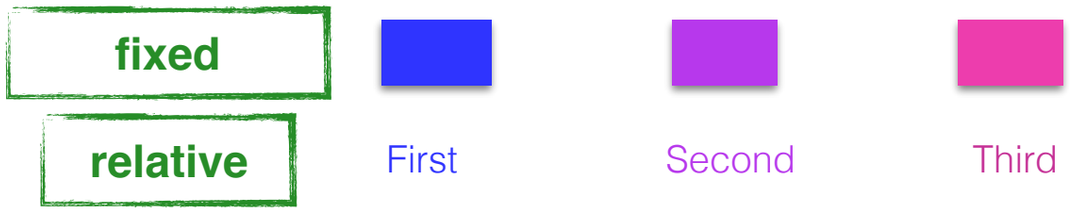
three 1-link theories



initial state

Constraints on possible links:

- Knowing which syntactic positions are relevant
- A link can go from role to position…



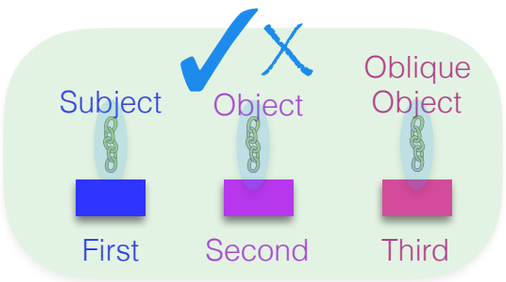
Pearl & Sprouse 2018b

Defining the acquisition task

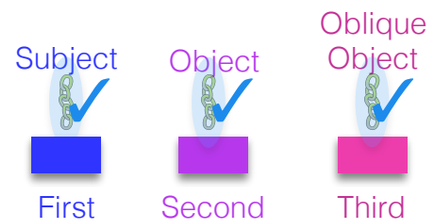
data intake inference

learning period target state

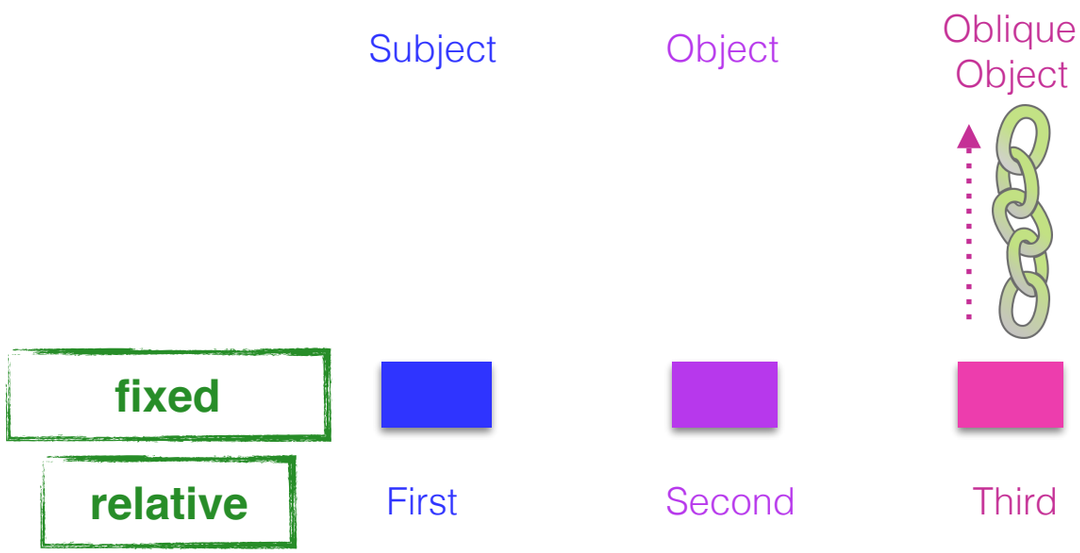
one 3-link theory



three 1-link theories



initial state



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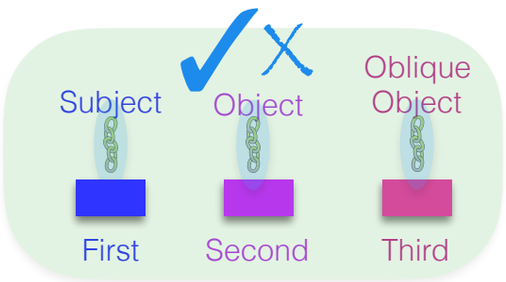
Pearl & Sprouse 2018b

Defining the acquisition task

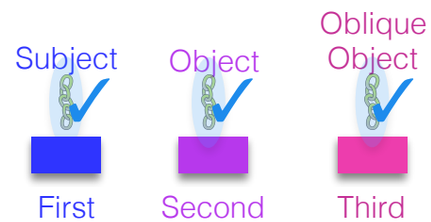
data intake inference

learning period target state

one 3-link theory



three 1-link theories



initial state

fixed

relative

Constraints on possible links:

- Knowing which syntactic positions are relevant
- A link can go from role to position or from position to role

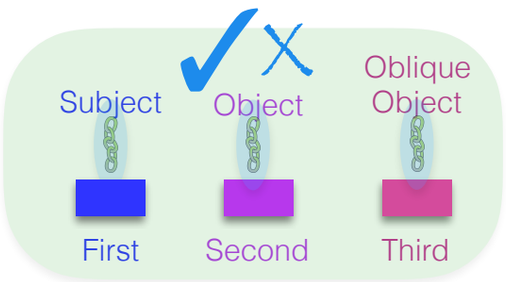
Pearl & Sprouse 2018b

Defining the acquisition task

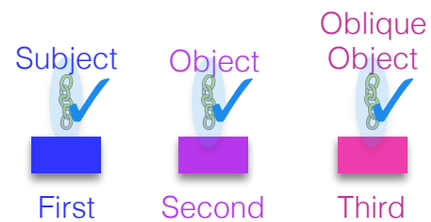
data intake inference

learning period target state

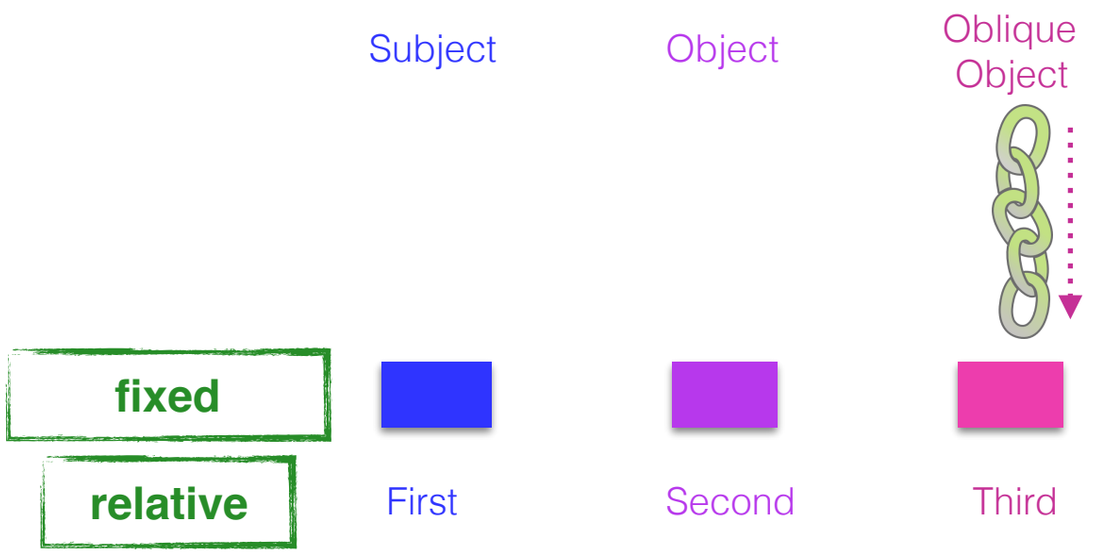
one 3-link theory



three 1-link theories



initial state



Constraints on possible links:

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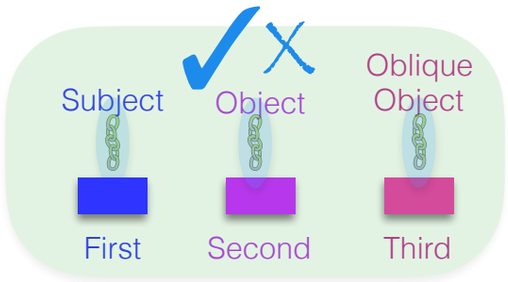
Pearl & Sprouse 2018b

Defining the acquisition task

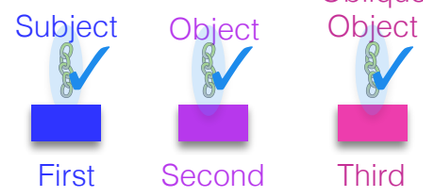
data intake inference

learning period target state

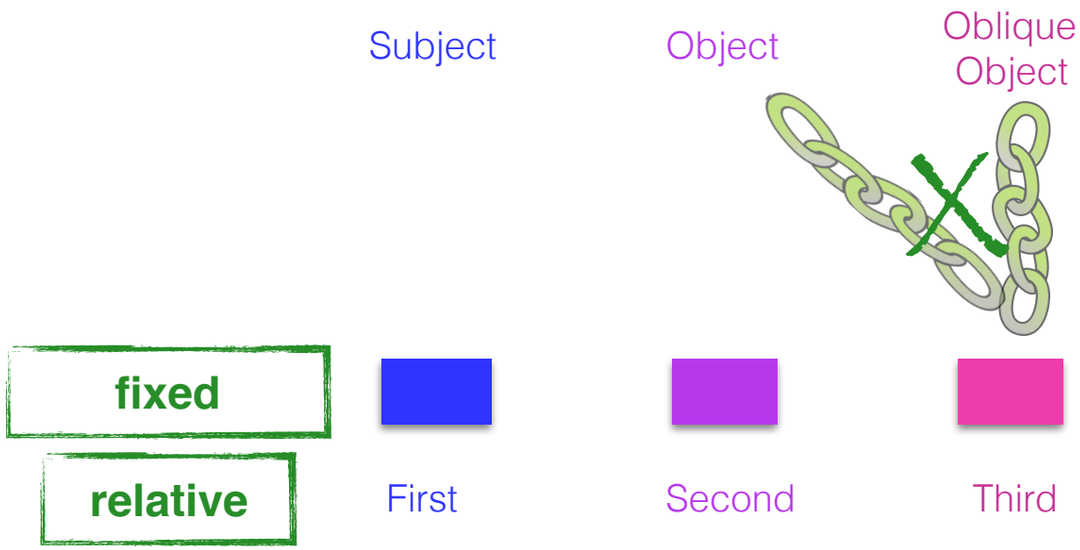
one 3-link theory



three 1-link theories



initial state



Constraints on possible links:

- Knowing which syntactic positions are relevant
- A link can go from role to position or from position to role
- A thematic role can only participate in one link at a time

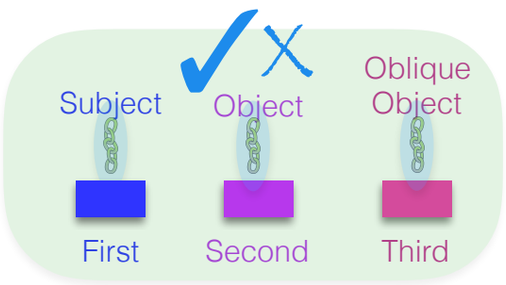
Pearl & Sprouse 2018b

Defining the acquisition task

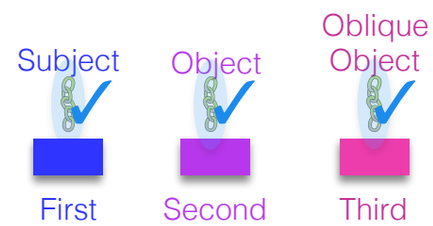
data intake inference

learning period target state

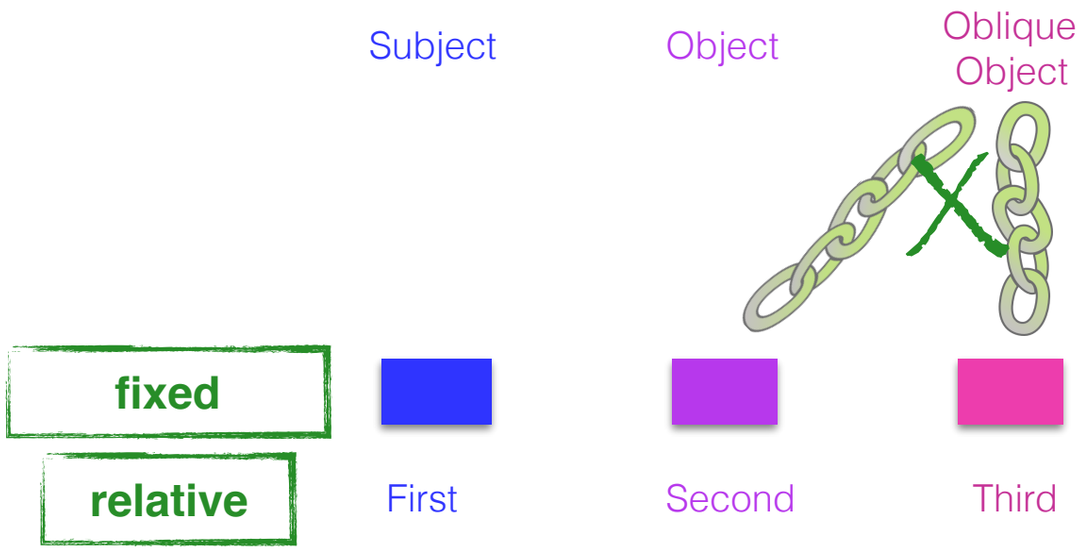
one 3-link theory



three 1-link theories



initial state



Constraints on possible links:

- Knowing which syntactic positions are relevant
- A link can go from role to position or from position to role
- A thematic role can only participate in one link at a time
- A syntactic position can only participate in one link at a time

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Defining the acquisition task

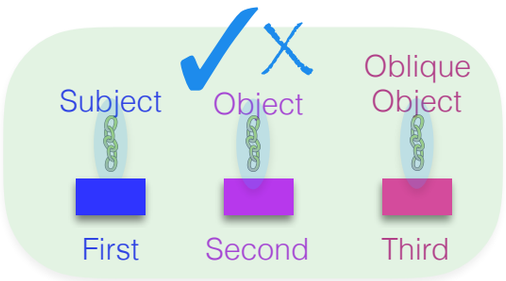
data intake

inference

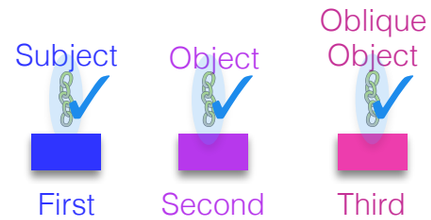
learning period

target state

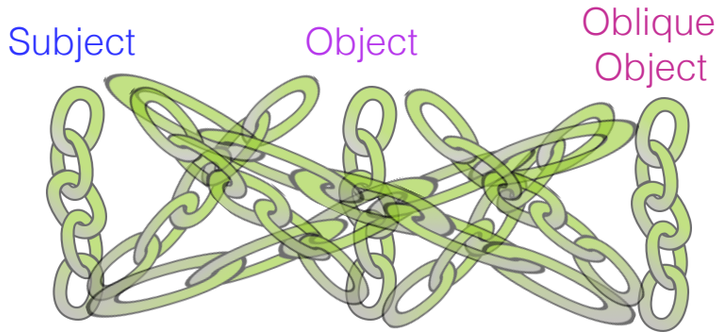
one 3-link theory



three 1-link theories



initial state



fixed

relative

First

Second

Third

+ whatever abilities are required to do inference

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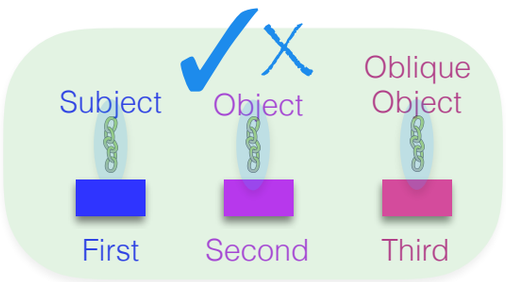
Defining the acquisition task

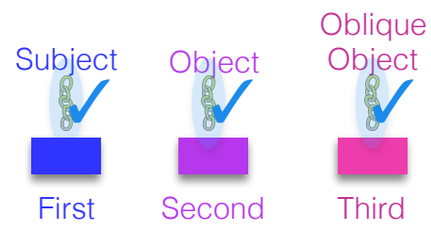
initial state inference

learning period target state

one 3-link theory



three 1-link theories



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

input that yields data intake

The little girl *blicked* the kitten on the stairs.

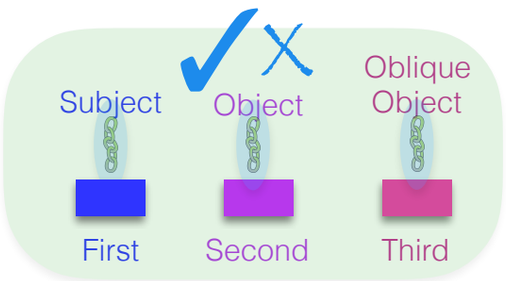
Pearl & Sprouse 2018b

Defining the acquisition task

initial state inference

learning period target state

one 3-link theory



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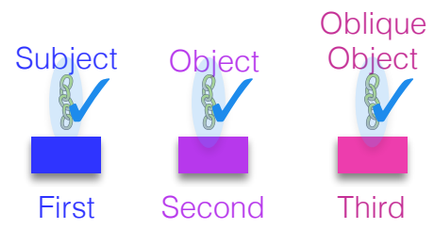

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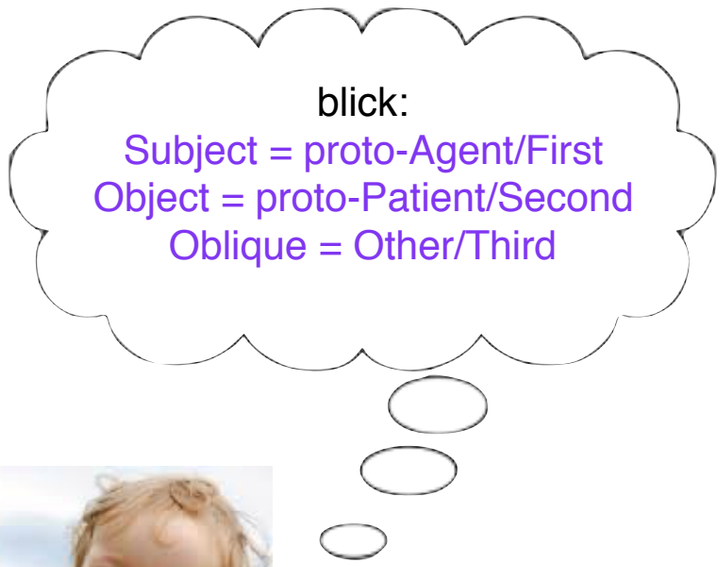

Pearl & Sprouse 2018b

Defining the acquisition task

initial state

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learning period

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inference

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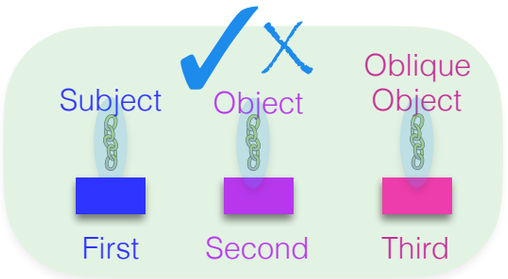
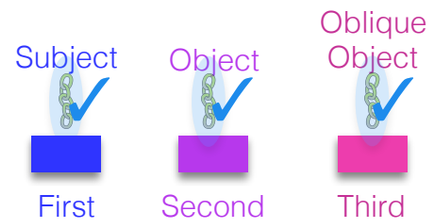


three 1-link theories



Remember that the acquisition process we imagined hinges on a child perceiving individual links and multi-link theories as "**reliable enough**", given the input.

Pearl & Sprouse 2018b

Defining the acquisition task

initial state

data intake

learning period

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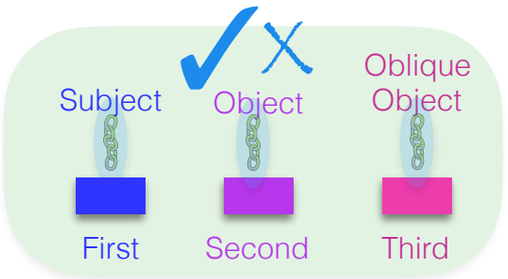
inference

one 3-link theory



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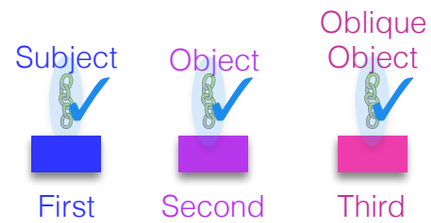

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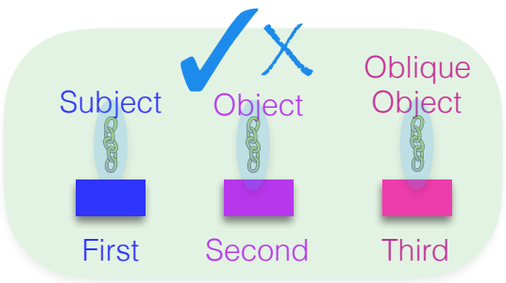

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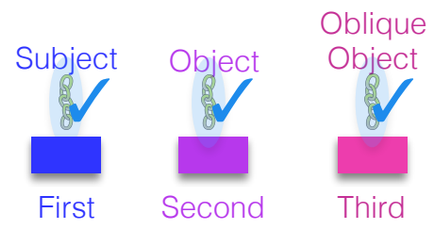

How can "**reliable enough**" be implemented?

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Defining the acquisition task

initial state

data intake

learning period

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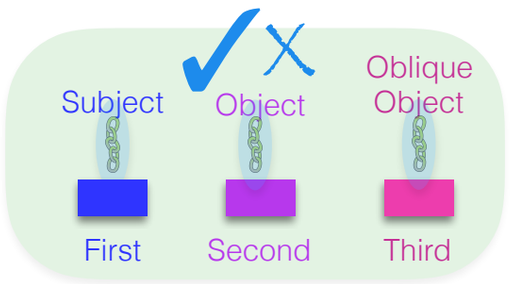
one 3-link theory



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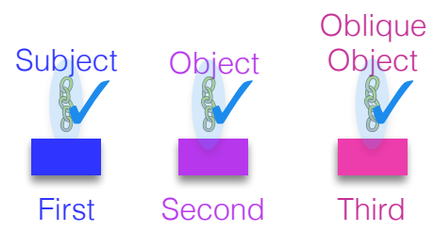

One answer: **The Tolerance Principle** (Yang 2005, 2016)

This principle is derived from considerations of knowledge storage and retrieval in real time, incorporating how frequently individual items occur, the absolute ranking of items by frequency, and serial memory access.

Pearl & Sprouse 2018b

Defining the acquisition task

initial state

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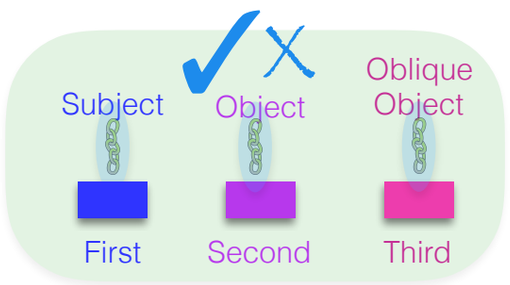
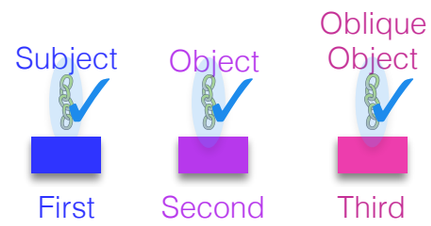
inference

one 3-link theory

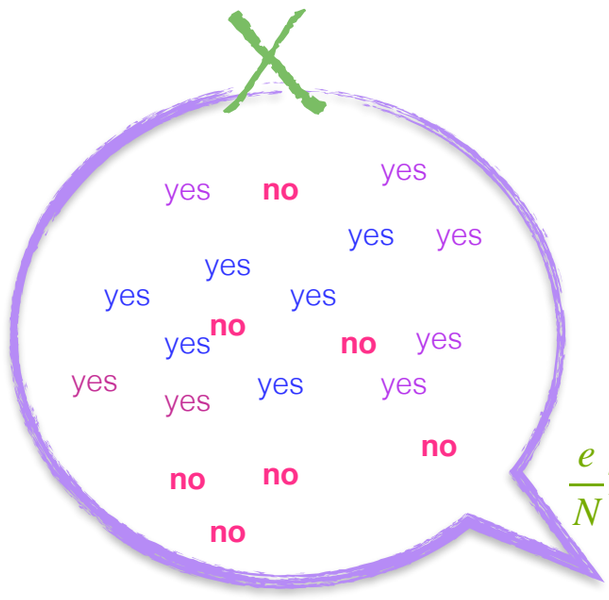


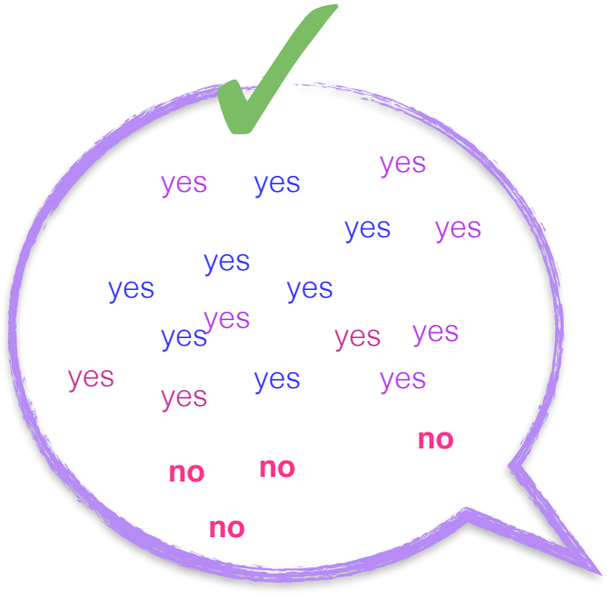
three 1-link theories



The Tolerance Principle (Yang 2005, 2016)

Designed for situations where there are exceptions to a potential rule — provides a **precise threshold** for how many exceptions a potential rule can tolerate before it's no longer worthwhile to have the rule.





$$Time(N, e) < Time(N, N)$$

$$\frac{e}{N}Time(e, e) + (1 - \frac{e}{N})e < \sum_{r=1}^{N} r\frac{1}{rH_n}$$

$$\frac{e}{N}\frac{e}{\sum_{k=1}^{e}\frac{1}{k}} + (1 - \frac{e}{N})e < \sum_{r=1}^{N}\frac{1}{\sum_{k=1}^{N}\frac{1}{k}}$$

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Defining the acquisition task

initial state

data intake

learning period

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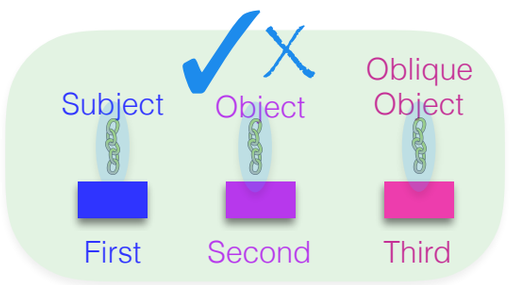
inference

one 3-link theory



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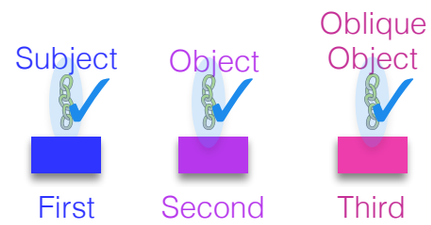

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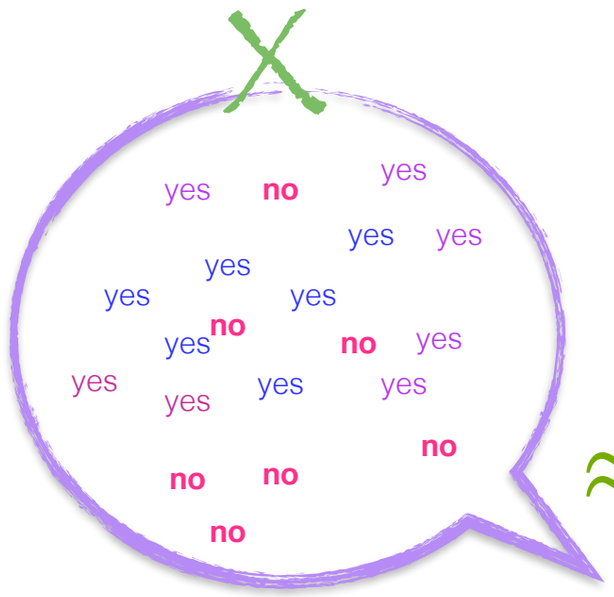
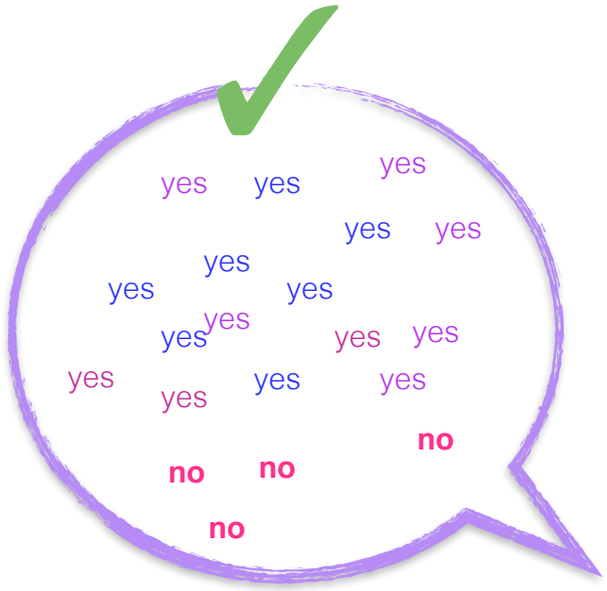


$$\approx \frac{N}{ln(N)}$$

N = # of items that the rule could apply to



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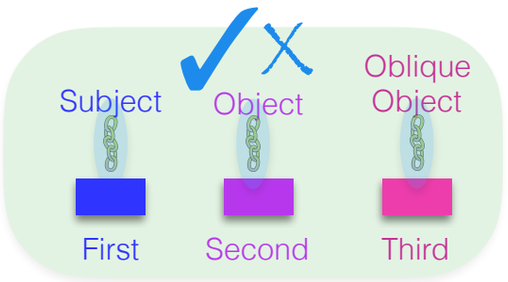
Defining the acquisition task

initial state data intake

learning period target state

one 3-link theory



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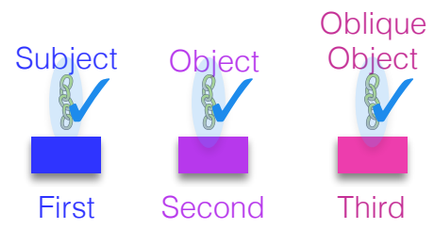

inference

$$\frac{N}{ln(N)}$$

The Tolerance Principle (Yang 2005, 2016)

Here we can use it to evaluate both individual links and multi-link theories.

Pearl & Sprouse 2018b

Defining the acquisition task

initial state

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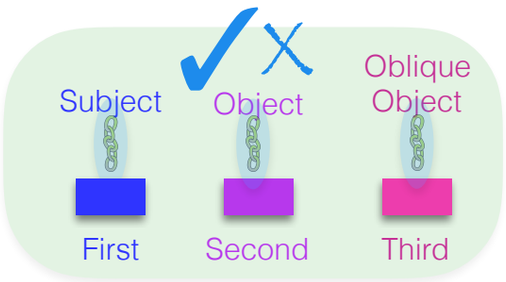

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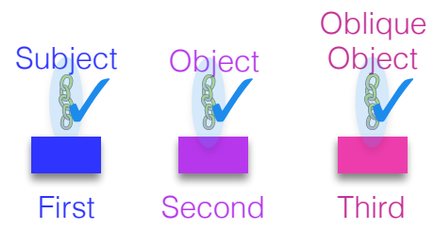

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learning period

As before, we'll be using an ideal learner model, where the learner applies the Tolerance Principle to all the data available, rather than deploying it with the cognitive limitations and incremental learning restrictions real children have.

Goal: Is it possible to derive the linking theories from realistic child input?

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Defining the acquisition task

initial state

data intake

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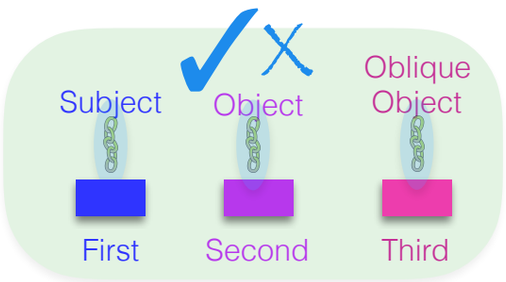
inference

one 3-link theory



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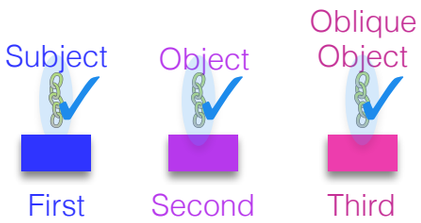

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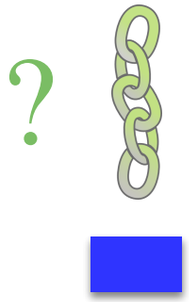
How do we evaluate an individual link?



Pearl & Sprouse 2018b

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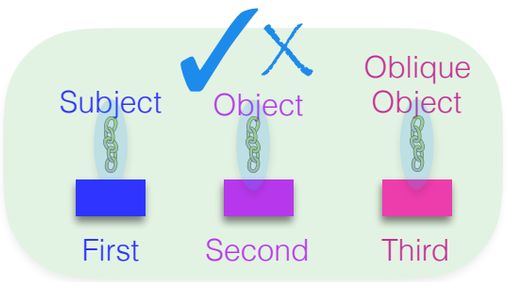

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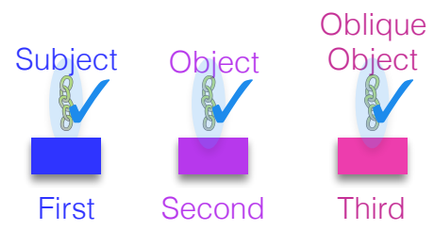

$$\frac{N}{ln(N)}$$

How do we evaluate an individual link?

If it goes from role to position, we compare this link to the others that link from this role.

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Defining the acquisition task

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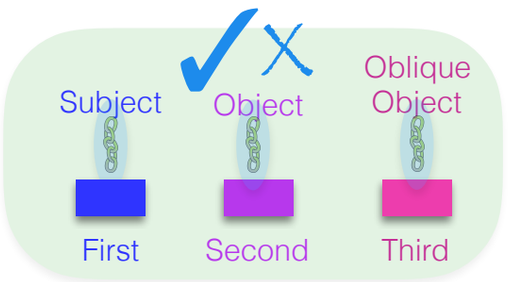

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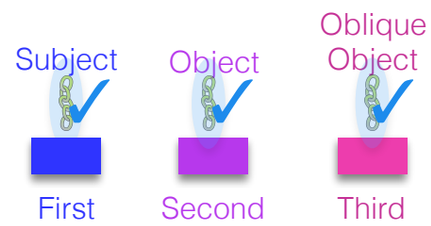

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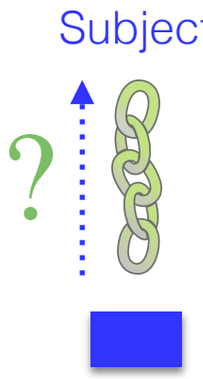

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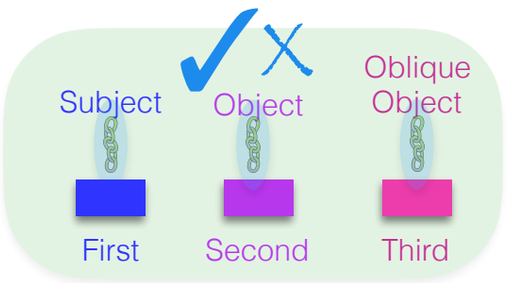

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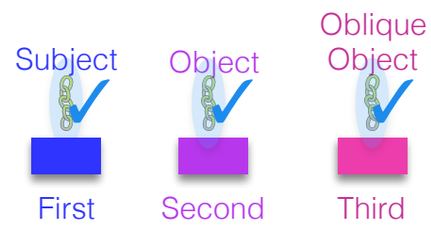

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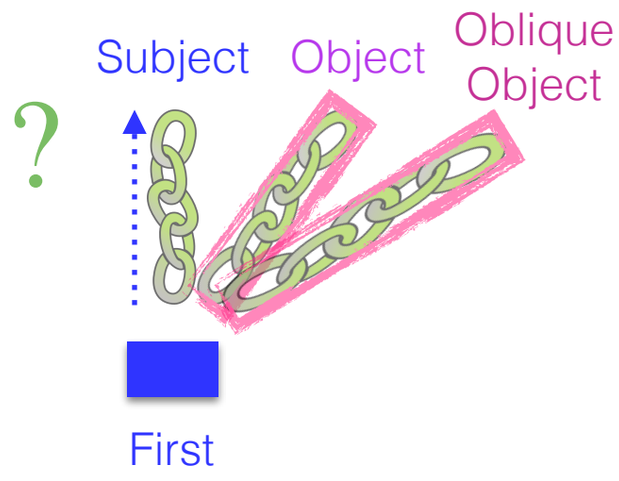

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$$< \frac{N}{ln(N)}$$

Which has few enough exceptions (if any) according to the child's intake?

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Defining the acquisition task

initial state

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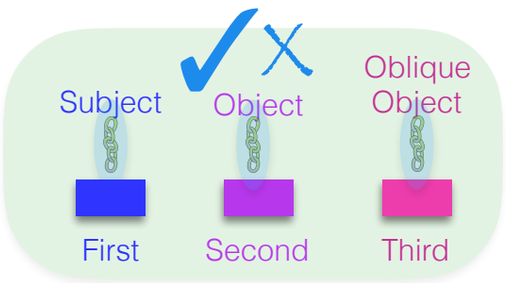

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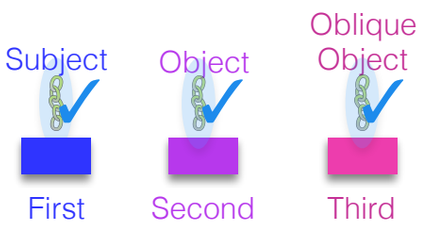

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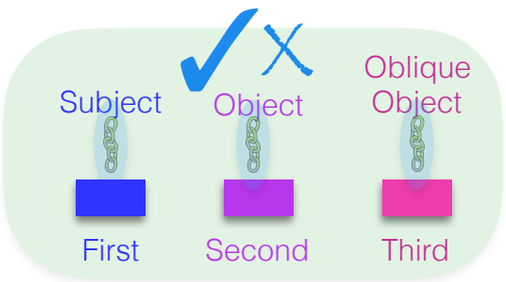

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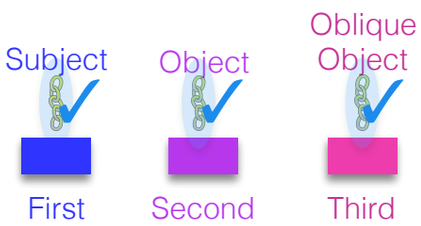

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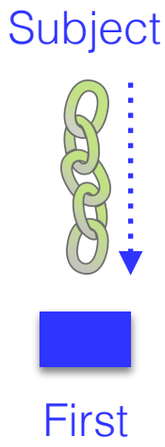

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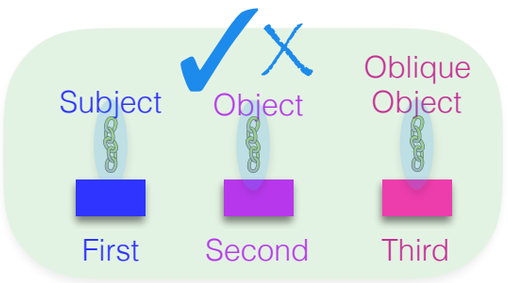

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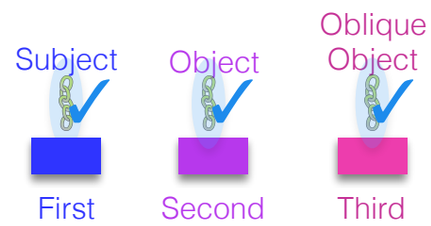

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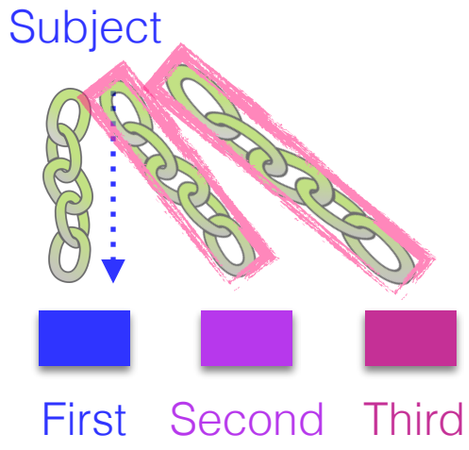

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$$< \frac{N}{ln(N)}$$

Which has few enough exceptions (if any) according to the child's intake?

Pearl & Sprouse 2018b

Defining the acquisition task

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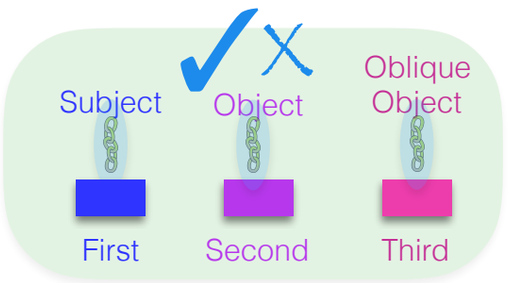

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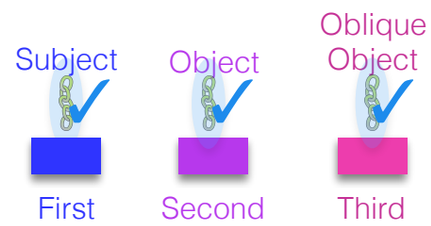
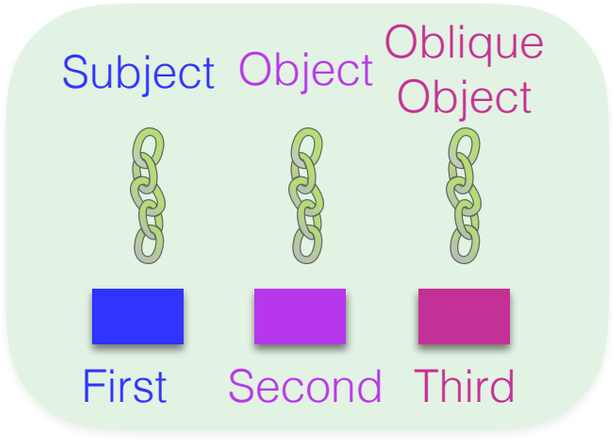


How do we evaluate multi-link theories?



Pearl & Sprouse 2018b

Defining the acquisition task

initial state

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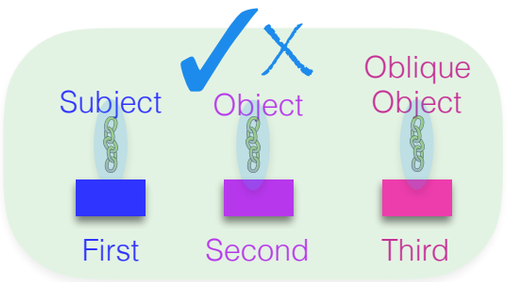
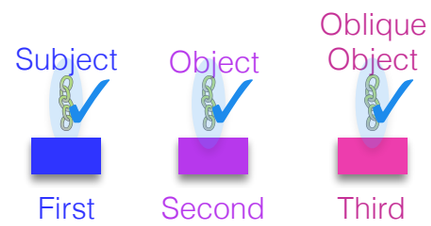


three 1-link theories



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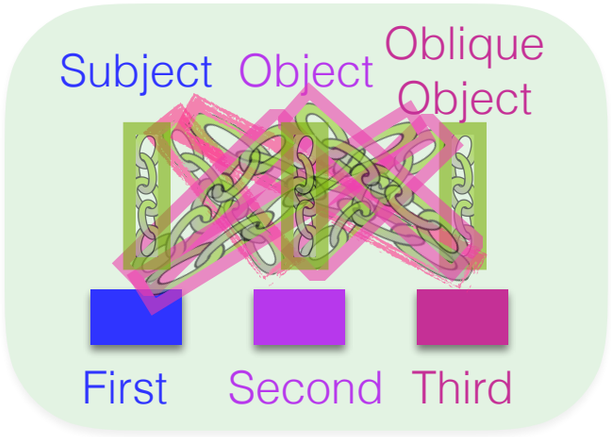

We compare the link instances that follow the multi-link theory against the link instances that don't (the exceptions to this multi-link theory).

$$< \frac{N}{ln(N)}$$

Note: This is a simple binary distinction between links that follow the multi-link theory and links that don't.

Does the 3-link theory have few enough exceptions according to the child's intake?

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Defining the acquisition task

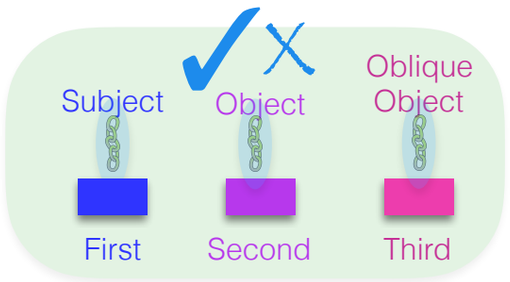
initial state

data intake

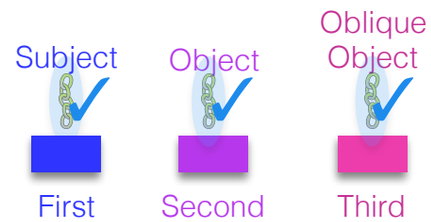
inference

target state

one 3-link theory



three 1-link theories



<3yrs

<4yrs

<5yrs

The rest of the inference process depends on the target knowledge for the modeled learner.

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Defining the acquisition task

initial state

data intake

inference

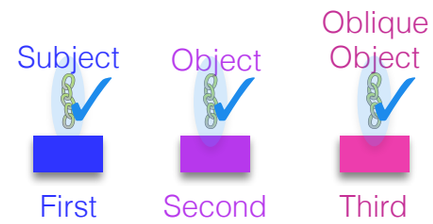
target state

<3yrs

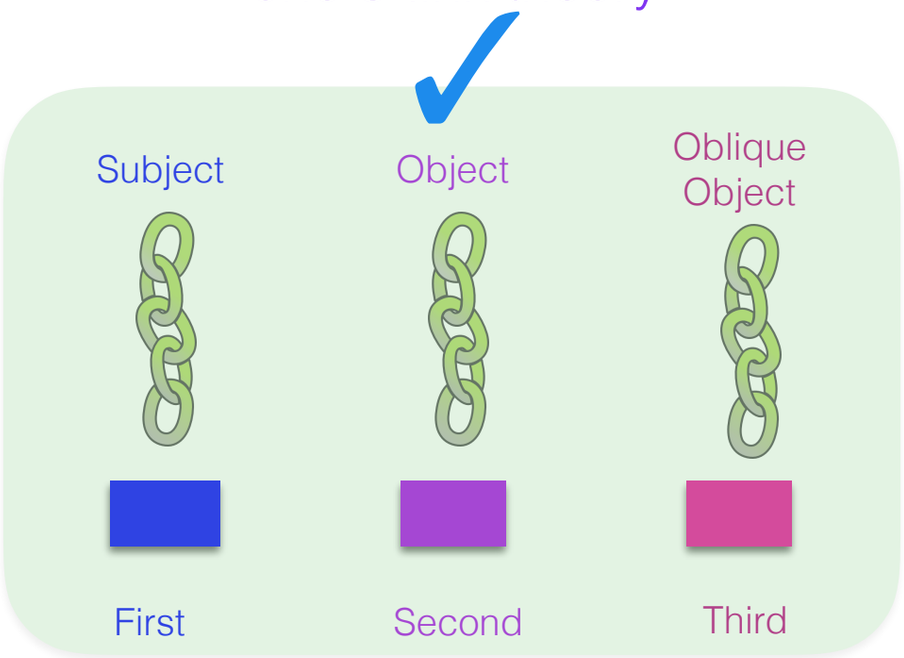
<4yrs

<5yrs

three 1-link theories



one 3-link theory



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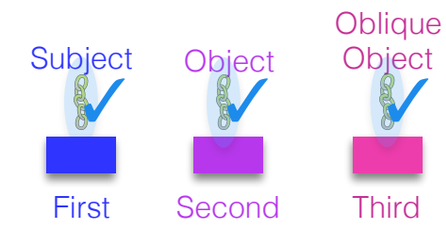
Defining the acquisition task

initial state data intake

target state

inference

three 1-link theories



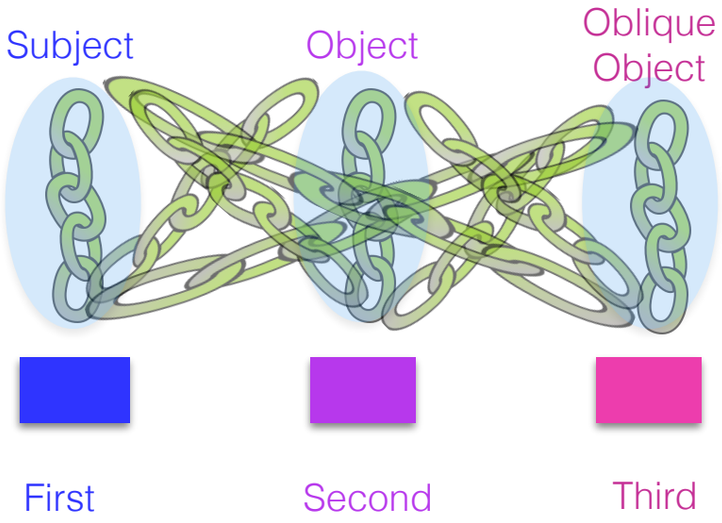
<3yrs

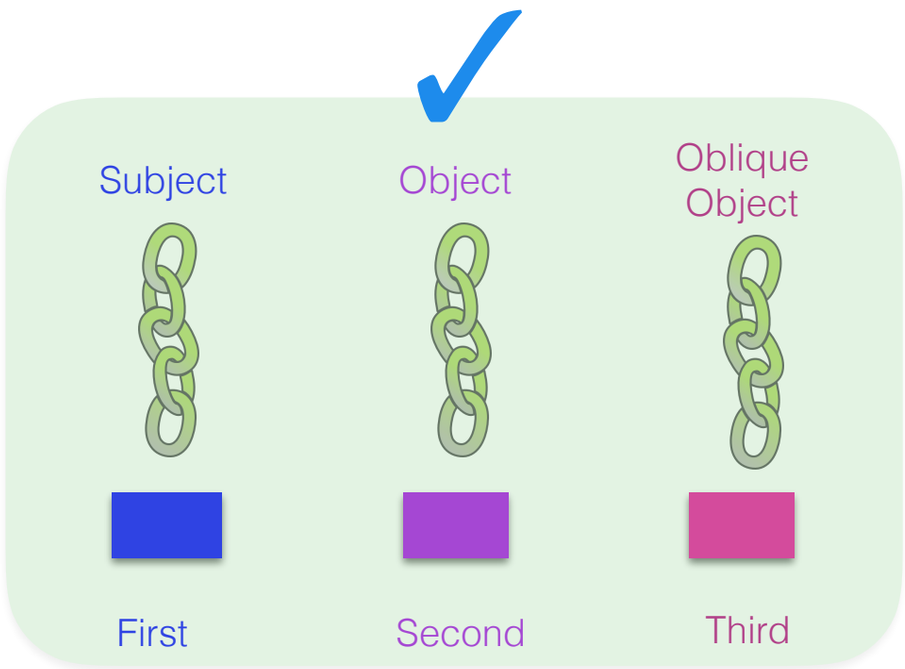
<4yrs

<5yrs

one 3-link theory

…requires a few steps





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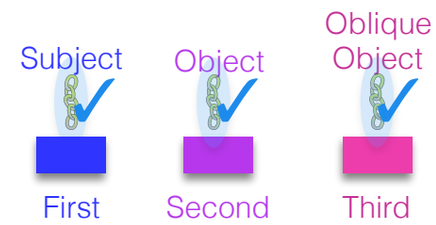
inference

three 1-link theories



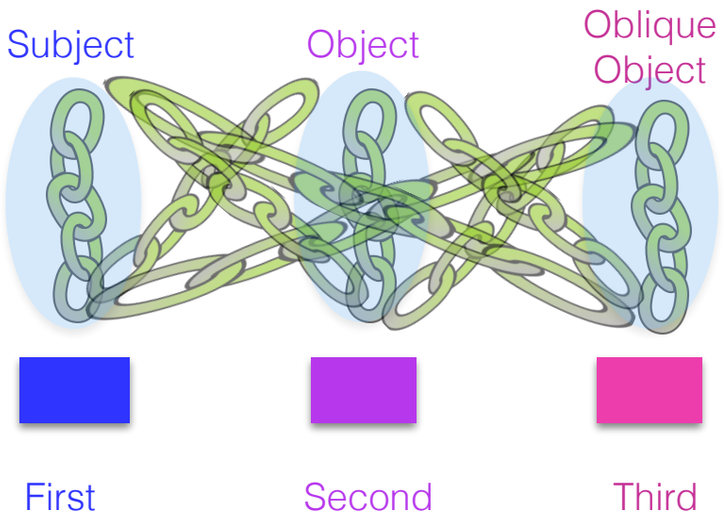
<3yrs

<4yrs

<5yrs

one 3-link theory

Step 1: Are the individual links reliable enough?



Look at all the instances from all the verbs collectively — which links surface as reliable?

He kicked the ball to his friend.
She fell on the ice. I like penguins.
I love kittens. I think so.
She's hugging the kitten.
I hear you talking.
This belongs to me.

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Defining the acquisition task

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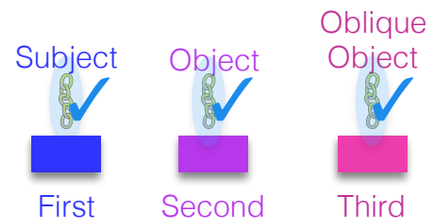
target state

inference

three 1-link theories



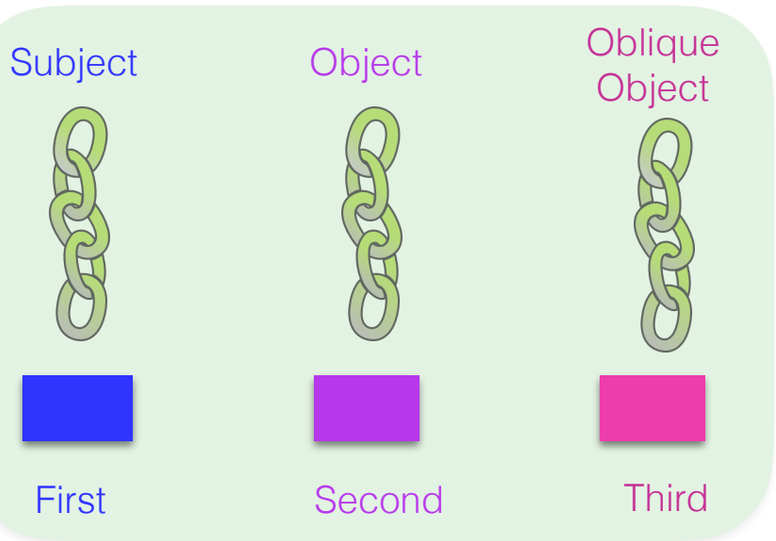
<3yrs

<4yrs

<5yrs

one 3-link theory

Step 2: If the right links are reliable, the child posits this as one 3-link theory.



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Defining the acquisition task

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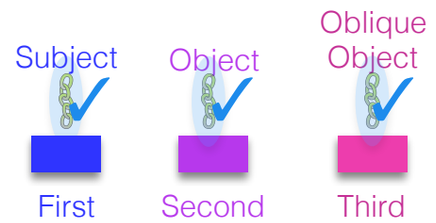
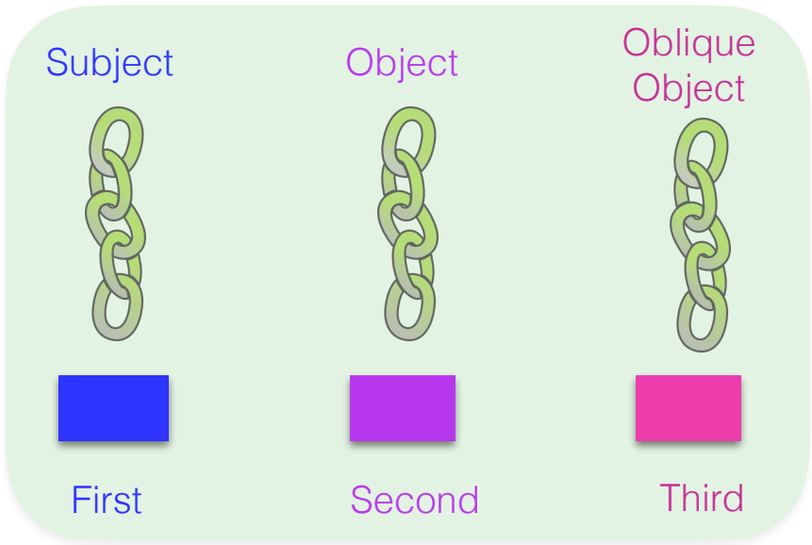
inference

three 1-link theories



one 3-link theory

Step 3: …and evaluates it against the verbs of the language.



fall kick like

hug love think

belong hear

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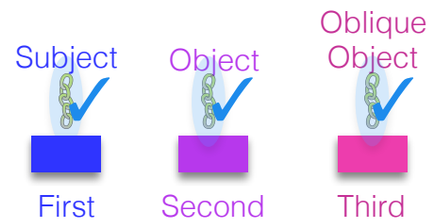
Defining the acquisition task

initial state data intake

target state

inference

three 1-link theories

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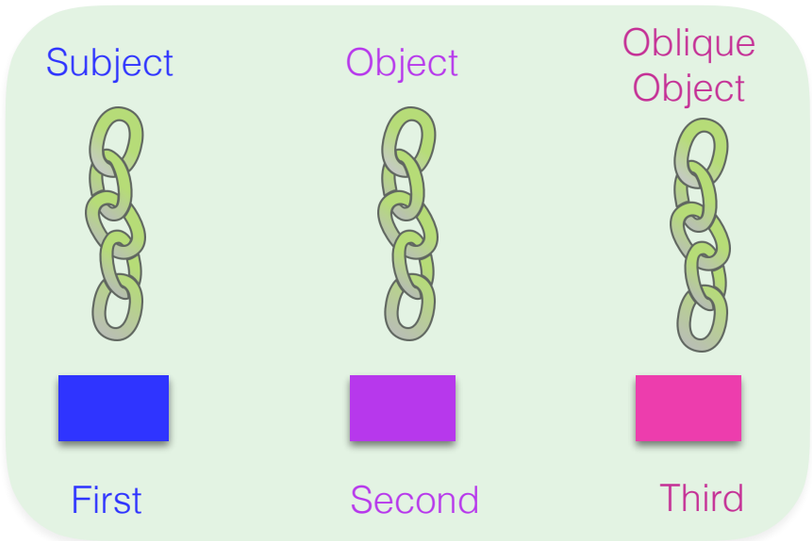

fall kick like

hug love think

belong hear

This means this linking theory should hold for the verb *lexical items* (types).

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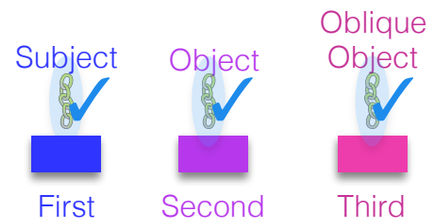
Defining the acquisition task

initial state data intake

target state

inference

three 1-link theories

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<4yrs


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one 3-link theory

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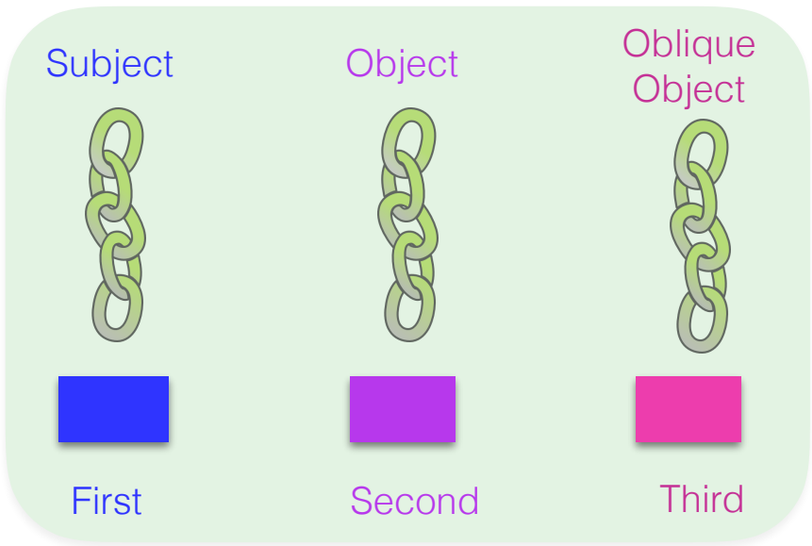

fall kick like

hug love think

belong hear

So we want the number of verb types that disobey this 3-link theory to be less than the Tolerance Principle threshold.

$$< \frac{N}{ln(N)}$$

N = verb types this theory could apply to

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Defining the acquisition task

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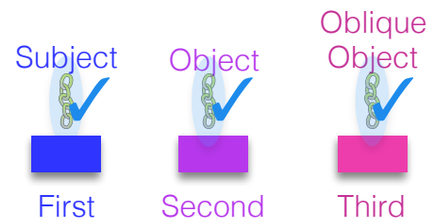
inference

three 1-link theories




<3yrs


<4yrs


<5yrs

one 3-link theory

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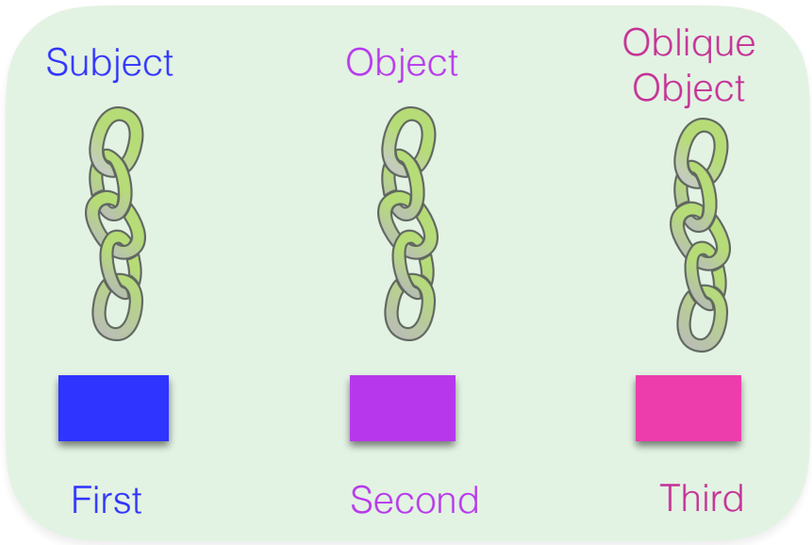

$$\frac{N}{ln(N)}$$ = **verb types** this theory could apply to

fall kick like hug love think belong hear

How do we tell if a verb type obeys the 3-link theory?

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Defining the acquisition task

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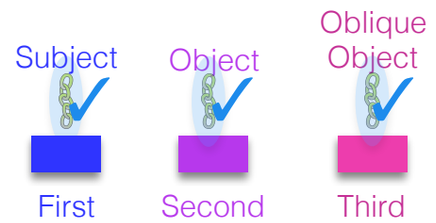
target state

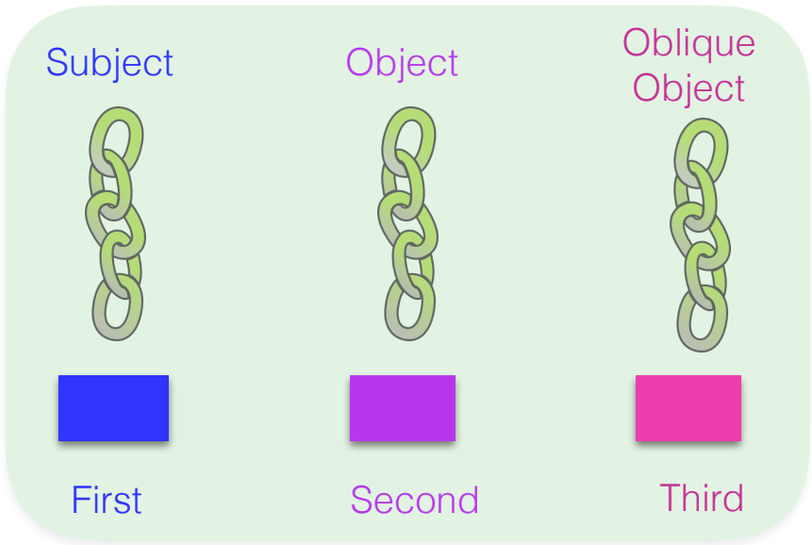
inference

three 1-link theories



one 3-link theory

Step 3: …and evaluates it against the verbs of the language.



$$\frac{N}{ln(N)}$$ = **verb types** this theory could apply to

She's hugging the kitten on the stairs.
I hugged him.
Penguins should be hugged.
Please hug me.
hug
She'll hug the penguin.
She was hugged.
Hug the kitten.

We evaluate that verb type's instances according to whether they follow the linking theory or not.

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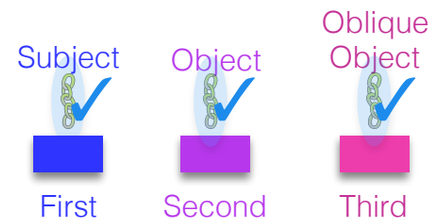
Defining the acquisition task

initial state data intake

target state

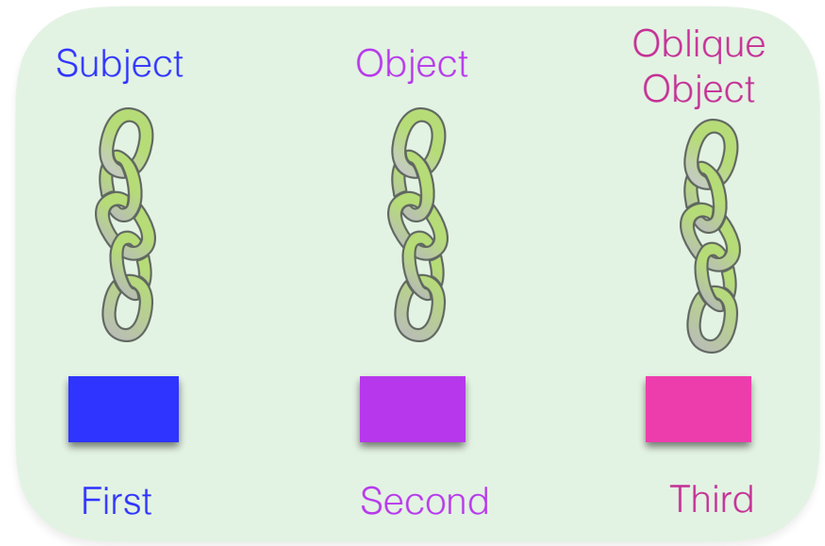
inference

three 1-link theories



one 3-link theory

Step 3: …and evaluates it against the verbs of the language.



She's hugging the kitten on the stairs.
I hugged him.
Penguins should be hugged.
Please hug me.
hug
She'll hug the penguin.
She was hugged.
Hug the kitten.

We want the number of verb instances that disobey this 3-link theory to be less than the Tolerance Principle threshold.

$\frac{N}{ln(N)}$ = **verb types** this theory could apply to

$<$

$\frac{N}{ln(N)}$ = verb instances this theory could apply to

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Defining the acquisition task

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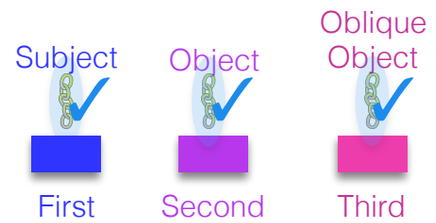
three 1-link theories



one 3-link theory

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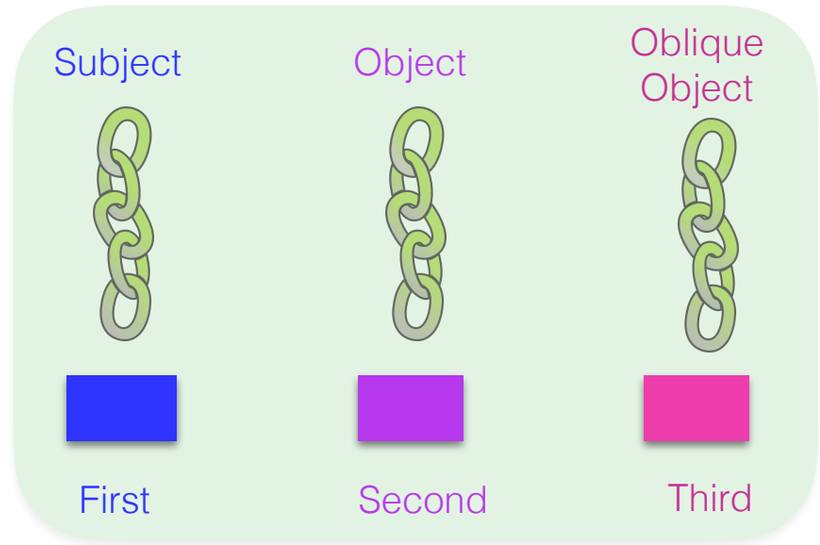

If it is, then this linking theory is reliable enough for this verb type.

$$\frac{N}{ln(N)}$$ = **verb types** this theory could apply to

$<$

$$\frac{N}{ln(N)}$$ = verb instances this theory could apply to

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Defining the acquisition task

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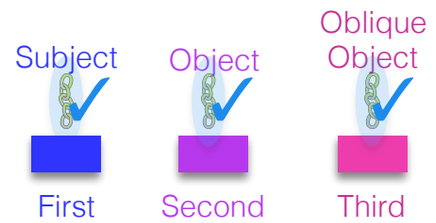

one 3-link theory

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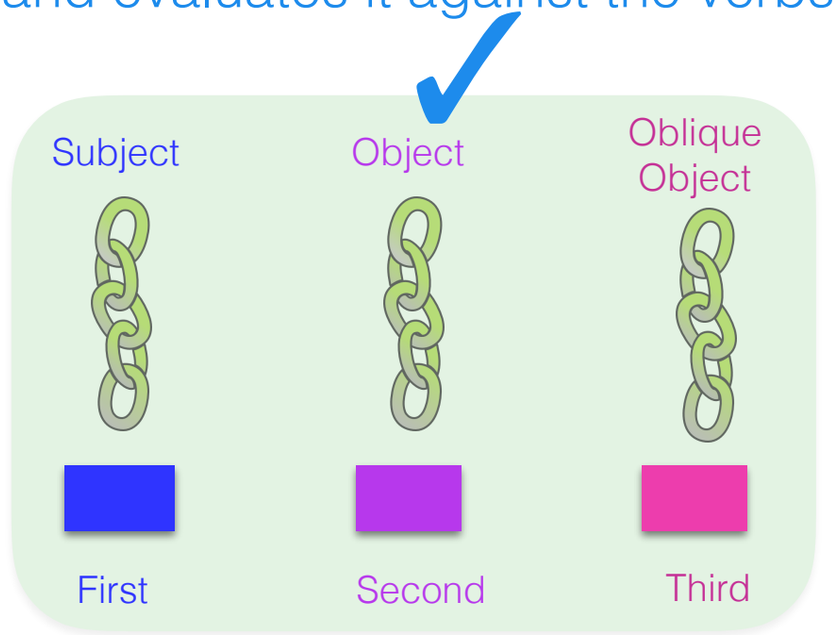

fall kick like

hug love think

belong hear

If enough verb types are reliable enough, then this linking theory is reliable enough for the verbs of the language.

$$< \frac{N}{ln(N)}$$ = **verb types** this theory could apply to

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Defining the acquisition task

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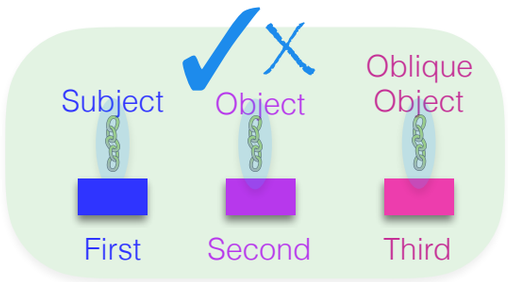
target state

one 3-link theory

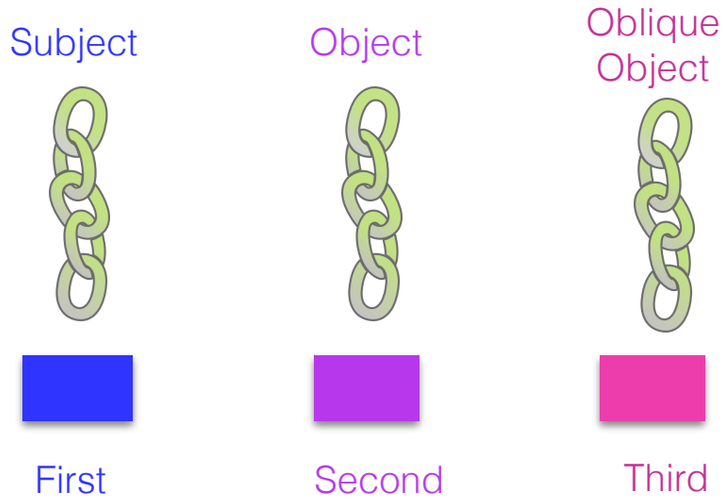


<3yrs

<4yrs

<5yrs

But what if the target state is three 1-link theories?



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Defining the acquisition task

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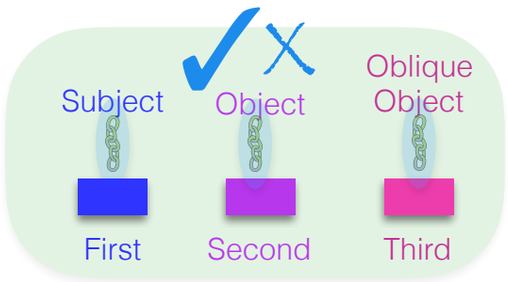
target state

inference

one 3-link theory



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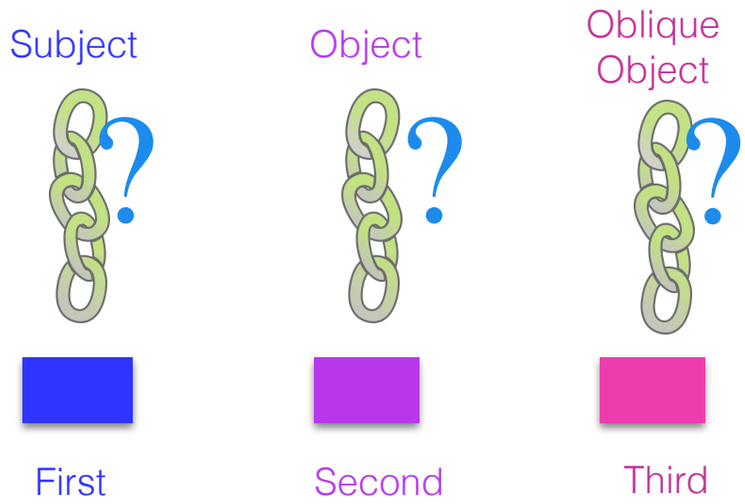
<4yrs

<5yrs

three 1-link theories

Step 1: Are the 1-link theories reliable enough?



fall kick like

hug love think

belong hear

This means each link should individually hold for the verb *lexical items* (types).

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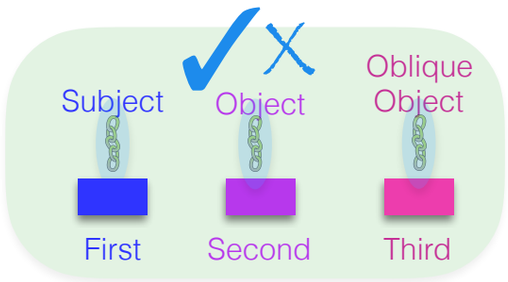
Defining the acquisition task

initial state data intake

target state

inference

one 3-link theory



<3yrs

<4yrs

<5yrs

three 1-link theories

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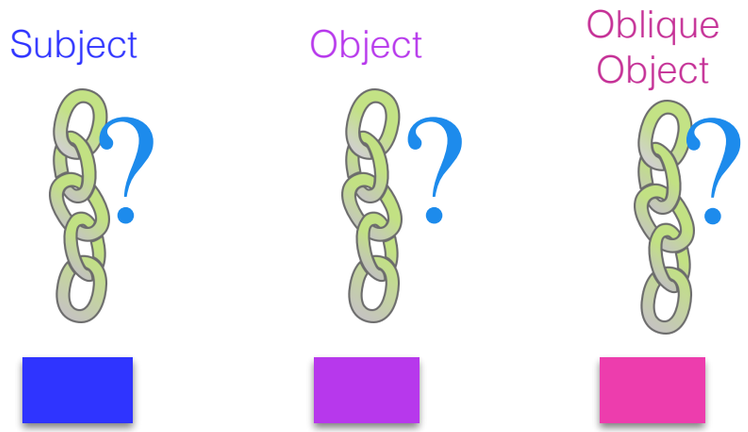

fall kick like

hug love think

belong hear

So we want the number of verb types that disobey each 1-link theory to be less than the Tolerance Principle threshold.

$$< \frac{N}{ln(N)}$$

N = verb types this theory could apply to

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Defining the acquisition task

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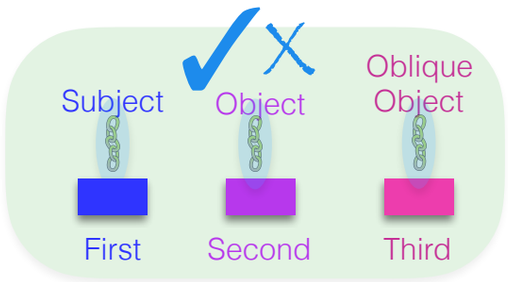
inference

one 3-link theory



<3yrs

<4yrs

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three 1-link theories

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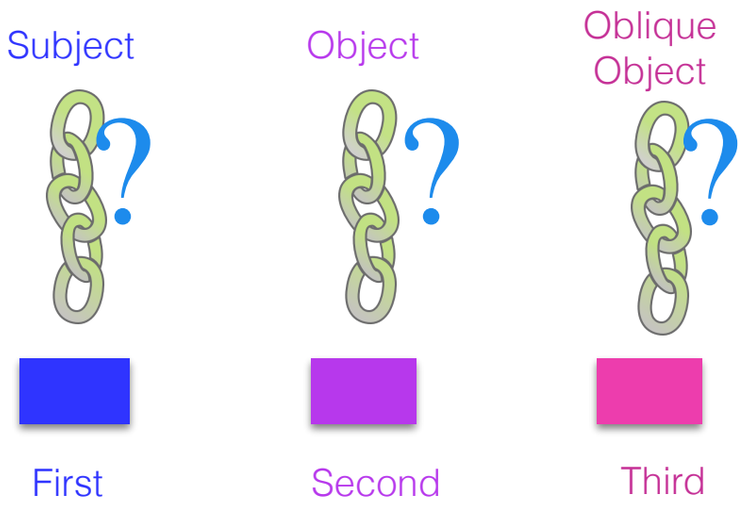

$$\frac{N}{ln(N)}$$

= **verb types** this theory could apply to

fall kick like

hug love think

belong hear

How do we tell if a verb type obeys a 1-link theory?

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Defining the acquisition task

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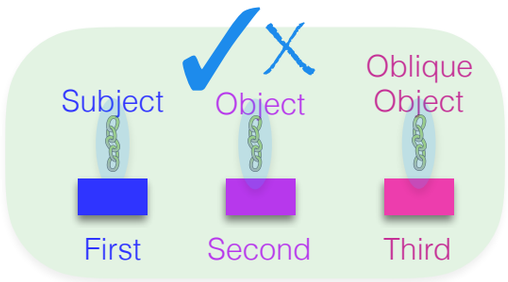
one 3-link theory



<3yrs

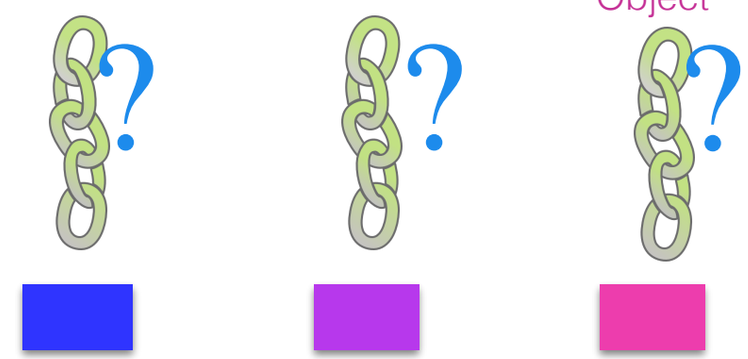
<4yrs

<5yrs

three 1-link theories

Step 1: Are the 1-link theories reliable enough?

Subject Object Oblique Object



First Second Third

$$\frac{N}{ln(N)}$$

= **verb types** this theory could apply to

She's hugging the kitten on the stairs.

I hugged him. Penguins should be hugged.

hug

Please hug me. She'll hug the penguin.

She was hugged.

Hug the kitten.

We evaluate that verb type's instances according to whether they follow the 1-link theory or not.

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Defining the acquisition task

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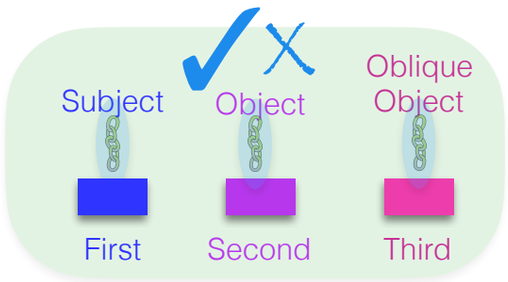
one 3-link theory



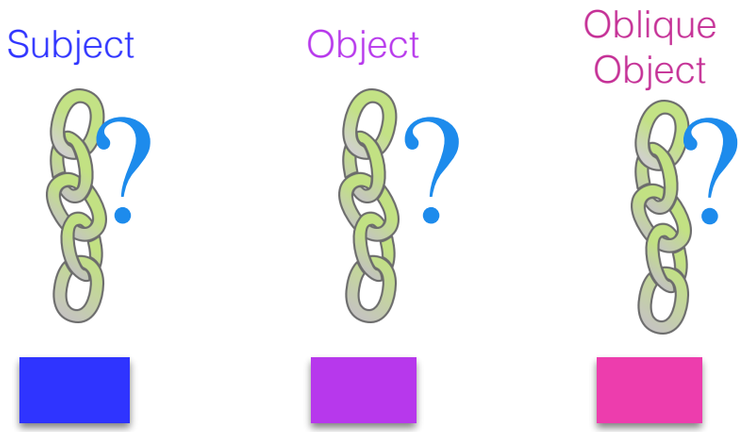
<3yrs

<4yrs

<5yrs

three 1-link theories

Step 1: Are the 1-link theories reliable enough?



She's hugging the kitten on the stairs.
I hugged him.
Penguins should be hugged.
Please hug me.
hug
She'll hug the penguin.
She was hugged.
Hug the kitten.

We want the number of verb instances that disobey the 1-link theory to be less than the Tolerance Principle threshold.

$$\frac{N}{ln(N)}$$ = **verb types** this theory could apply to

$<$

$$\frac{N}{ln(N)}$$ = verb instances this theory could apply to

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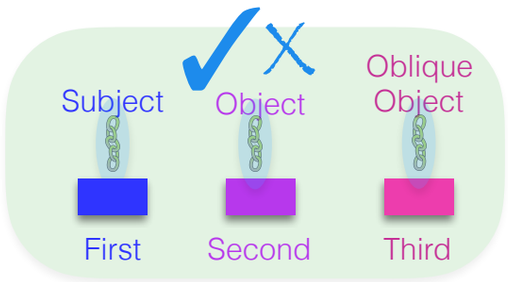
inference

one 3-link theory



<3yrs

<4yrs

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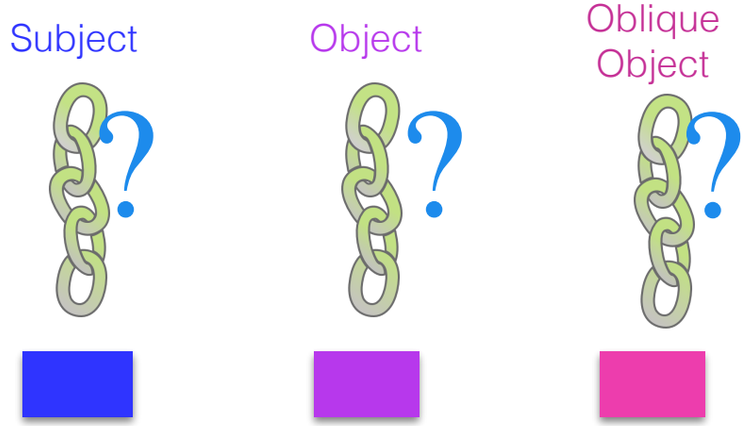
three 1-link theories

Step 1: Are the 1-link theories reliable enough?



She's hugging the kitten on the stairs.
I hugged him.
Penguins should be hugged.
hug
Please hug me.
She'll hug the penguin.
She was hugged.
Hug the kitten.

If it is, then this 1-link linking theory is reliable enough for this verb type.

$\frac{N}{ln(N)}$ = **verb types** this theory could apply to

$<$

$\frac{N}{ln(N)}$ = verb instances this theory could apply to

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Defining the acquisition task

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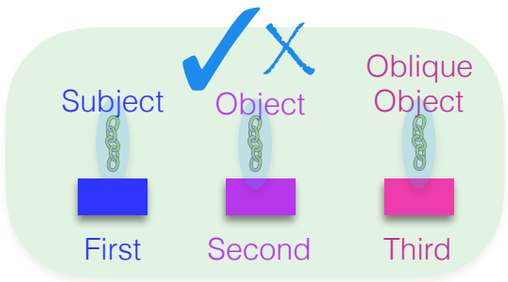
inference

one 3-link theory



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three 1-link theories

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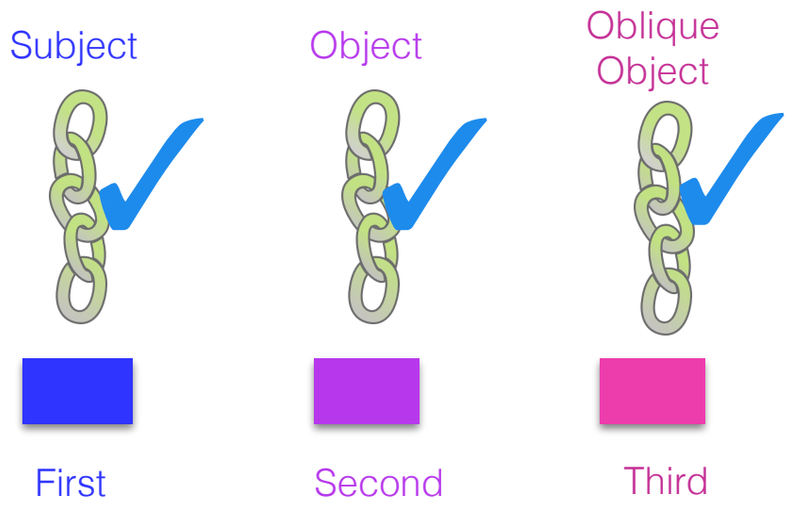

fall kick like

hug love think

belong hear

If enough verb types are reliable enough, then this linking theory is reliable enough for the verbs of the language.

$$< \frac{N}{ln(N)}$$ = **verb types** this theory could apply to

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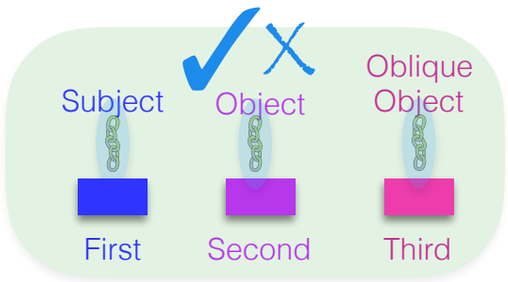
inference

one 3-link theory



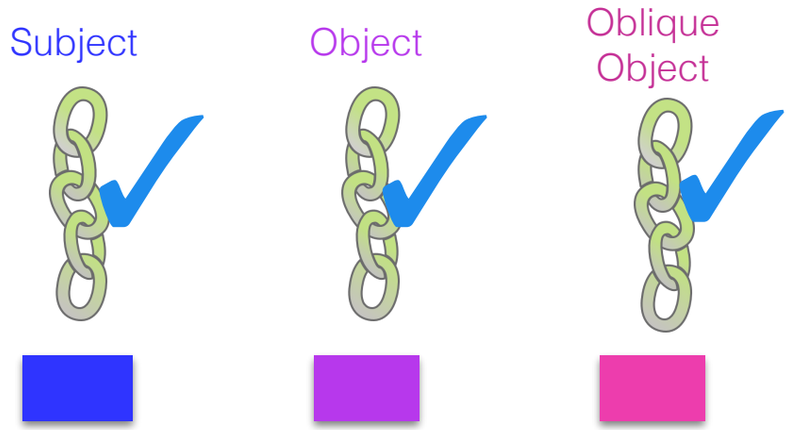
<3yrs

<4yrs

<5yrs

three 1-link theories

…and that's it.



fall kick like

hug love think

belong hear

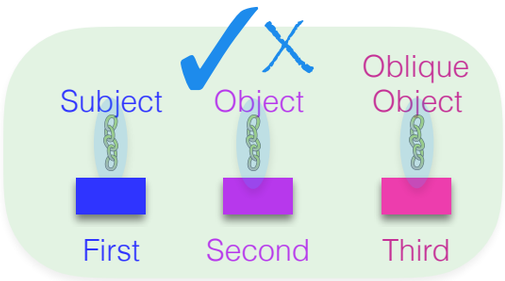
If enough verb types are reliable enough, then this linking theory is reliable enough for the verbs of the language.

$$< \frac{N}{ln(N)}$$ = **verb types** this theory could apply to

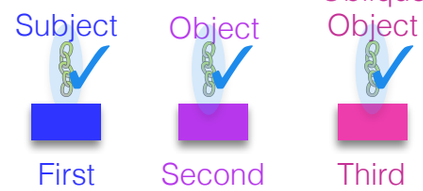
Pearl & Sprouse 2018b

Which linking theories are derivable from children's input?

one 3-link theory



three 1-link theories



<3yrs

<4yrs

<5yrs

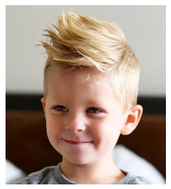
Same results for all three ages.

Pearl & Sprouse 2018b

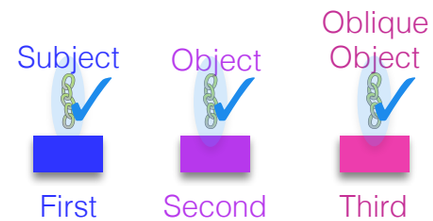
Which linking theories are derivable from children's input?


<3yrs


<4yrs

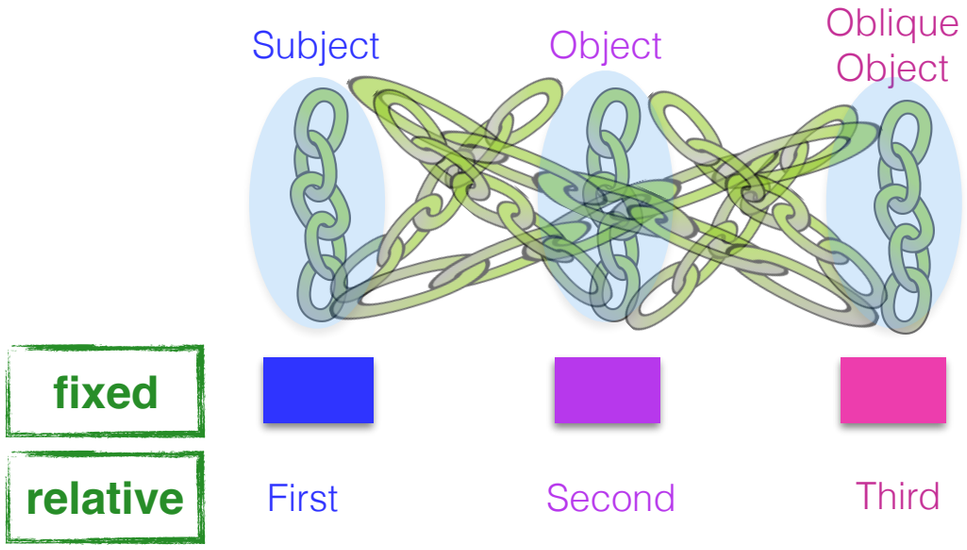

<5yrs

three 1-link theories



one 3-link theory

Step 1: Are the individual links reliable enough?

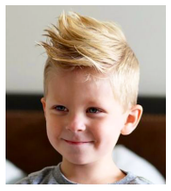


Pearl & Sprouse 2018b

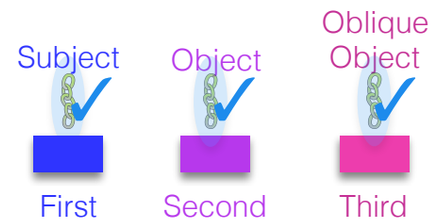
Which linking theories are derivable from children's input?


<3yrs


<4yrs

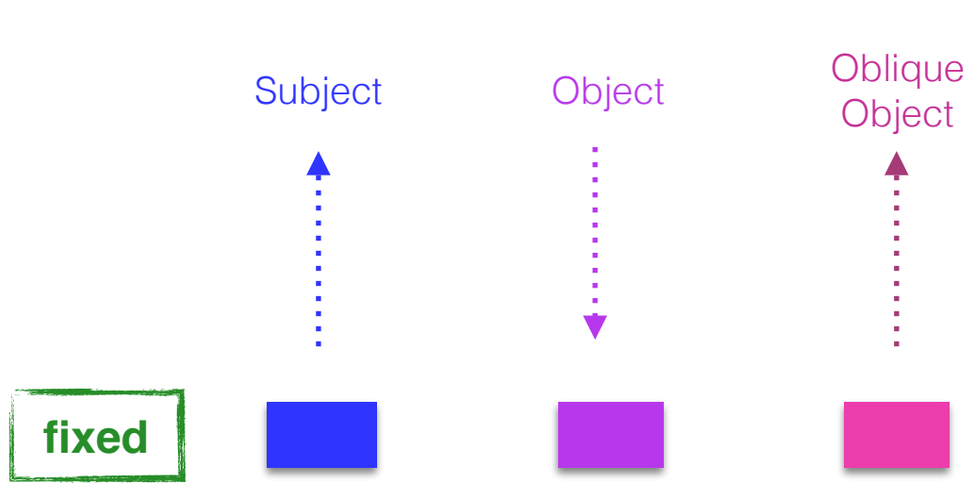

<5yrs

three 1-link theories



one 3-link theory

Step 1: Here are the ones that are.



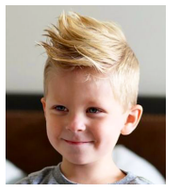
Good: At least one in one direction (role to position or position to role) for each of the three posited links.

Pearl & Sprouse 2018b

Which linking theories are derivable from children's input?


<3yrs


<4yrs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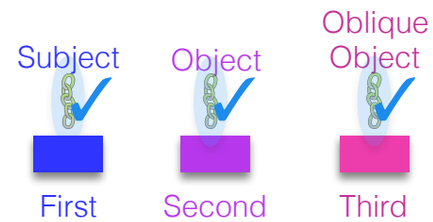
three 1-link theories



one 3-link theory

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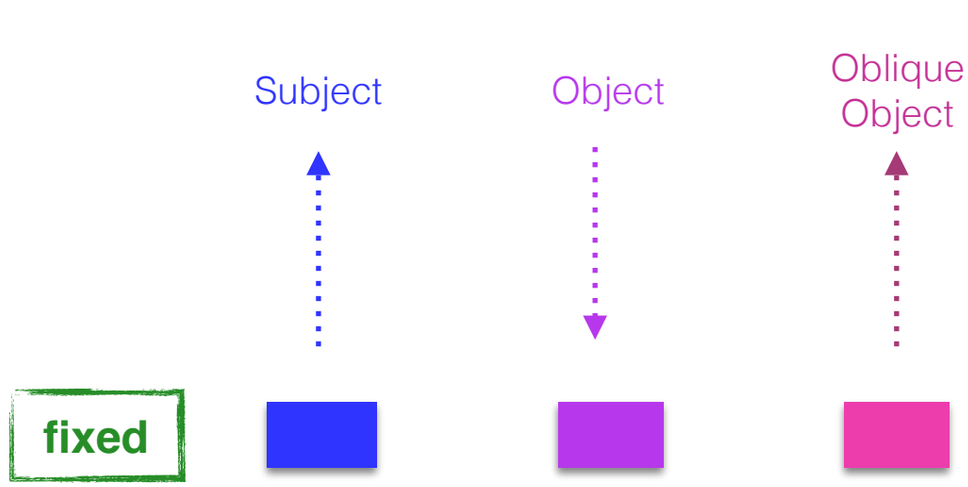


Good: At least one in one direction (role to position or position to role) for each of the three posited links.

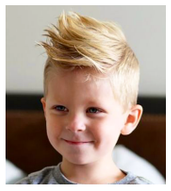
Good: No extraneous links are reliable enough.

Pearl & Sprouse 2018b

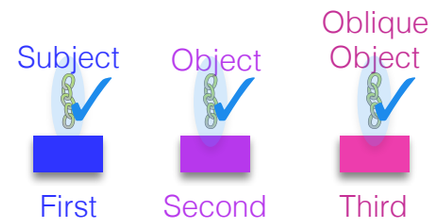
Which linking theories are derivable from children's input?


<3yrs


<4yrs


<5yrs

three 1-link theories



one 3-link theory

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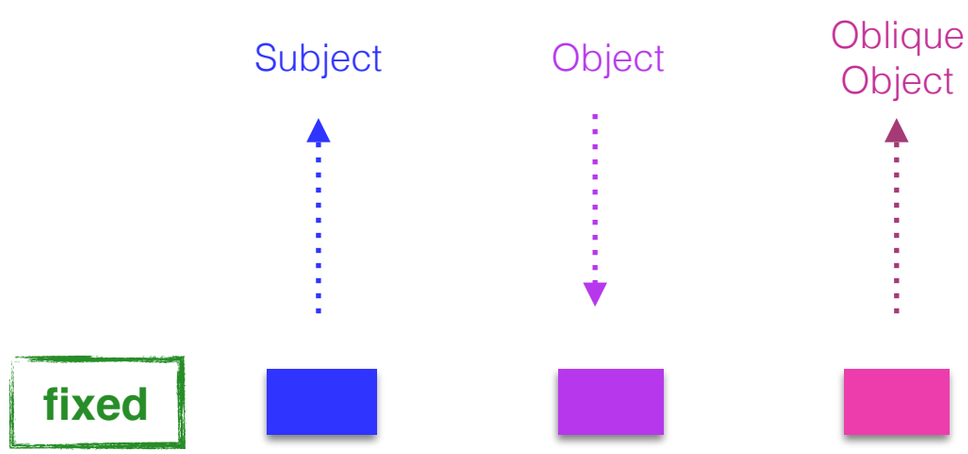


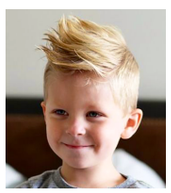
relative
First
Second
Third

…but none have a reliable link in both directions, and it's not clear if both directions are needed to posit a link for the linking theory.

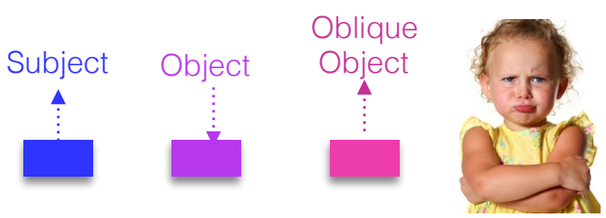
Pearl & Sprouse 2018b

Which linking theories are derivable from children's input?

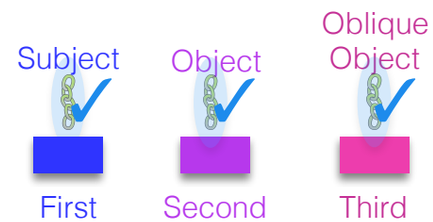




<3yrs <4yrs <5yrs



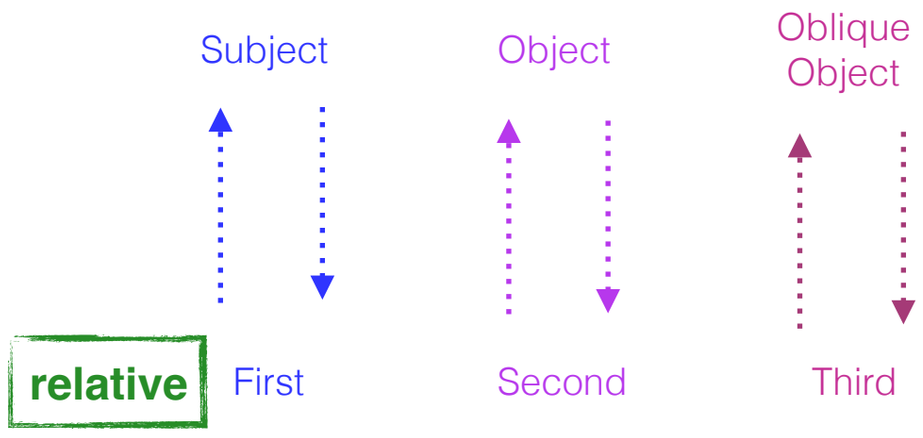
three 1-link theories

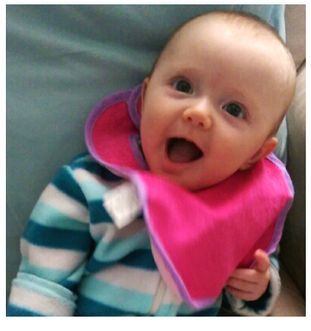


one 3-link theory

Step 1: Here are the ones that are.

fixed



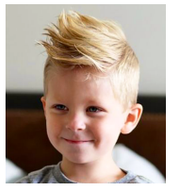


This contrasts with the relative thematic system, where links in both directions are reliable enough (and there are also no extraneous links).

Pearl & Sprouse 2018b

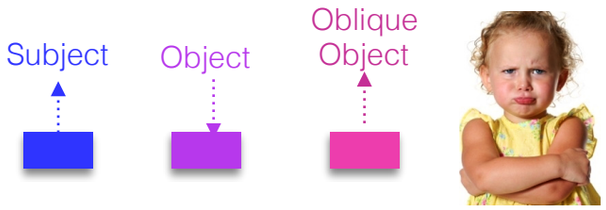
Which linking theories are derivable from children's input?





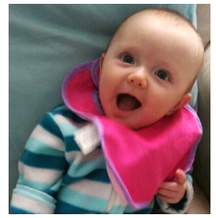
<3yrs <4yrs <5yrs

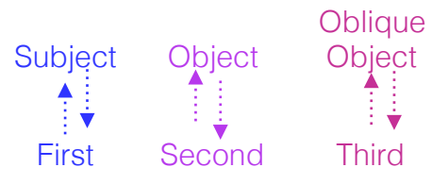
three 1-link theories



one 3-link theory

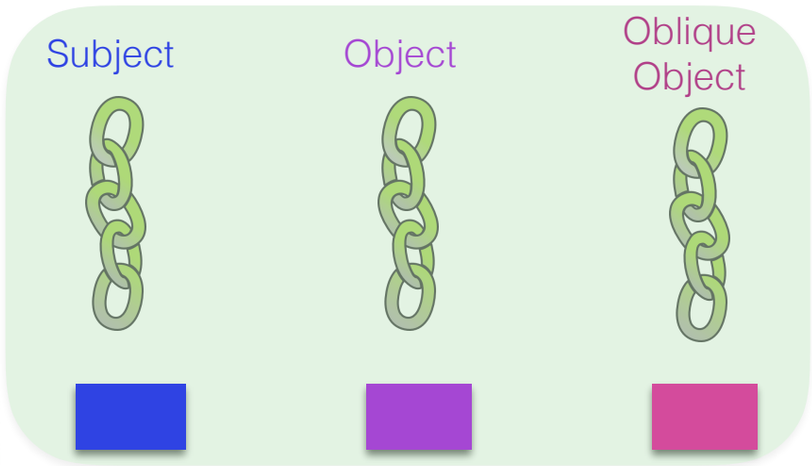
Step 2 & 3: Compose the links into a 3-link theory & evaluate it.





fixed

relative



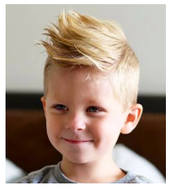
fixed

But let's suppose that one unidirectional link is enough to form a link between thematic representation and syntactic position.

Pearl & Sprouse 2018b

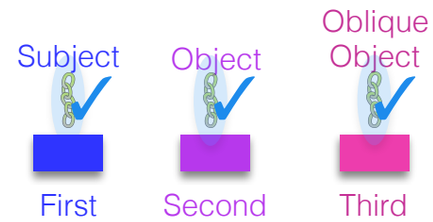
Which linking theories are derivable from children's input?

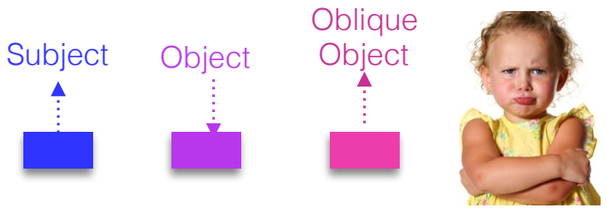




<3yrs <4yrs <5yrs

three 1-link theories





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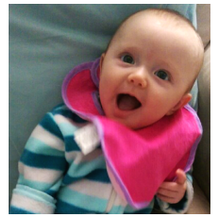
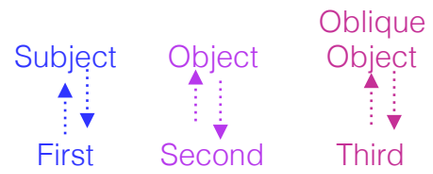
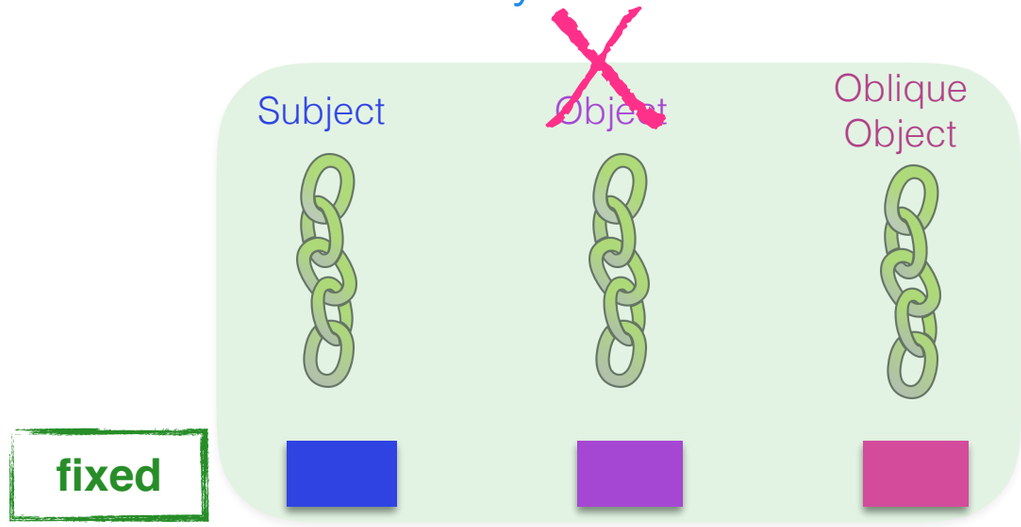




fixed

relative



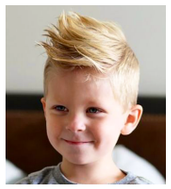
fixed

It turns out that this 3-link theory isn't reliable enough — not enough verb types obey it.

Pearl & Sprouse 2018b

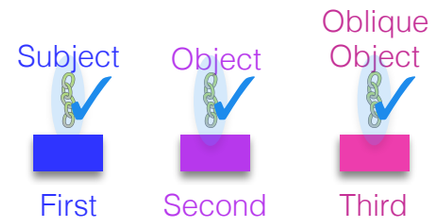
Which linking theories are derivable from children's input?

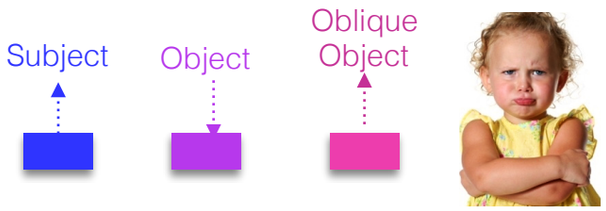




<3yrs <4yrs <5yrs

three 1-link theories





one 3-link theory

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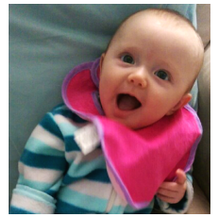

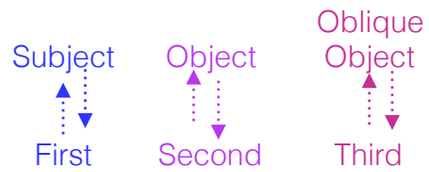

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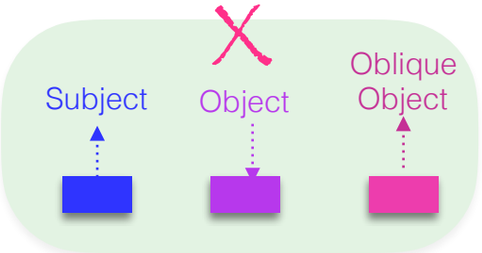
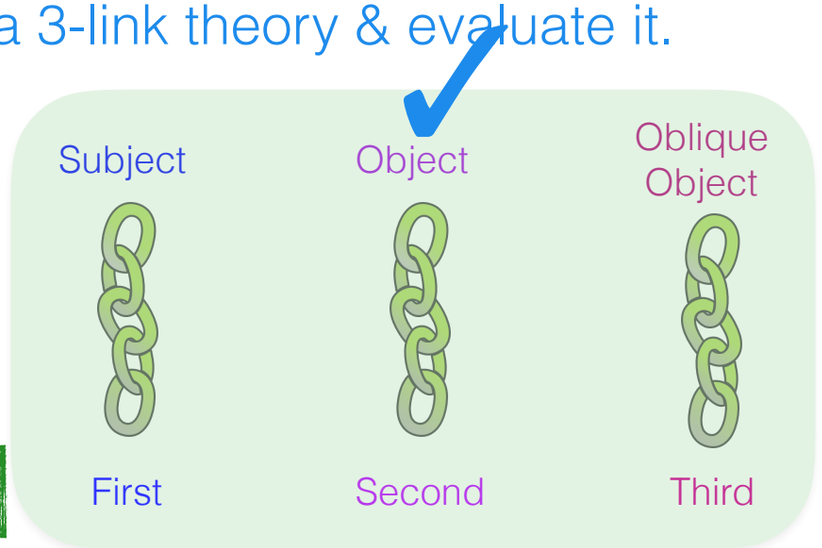
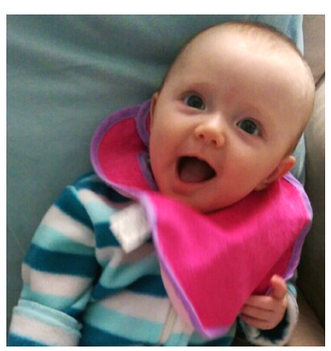


relative



relative

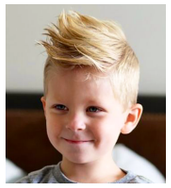


Meanwhile, the 3-link theory using the relative thematic representation is easy to form from reliable links and is reliable enough as a unit.

Pearl & Sprouse 2018b

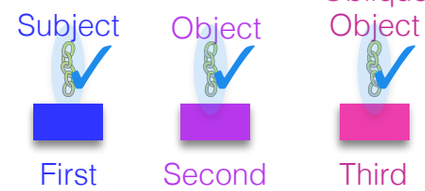
Which linking theories are derivable from children's input?

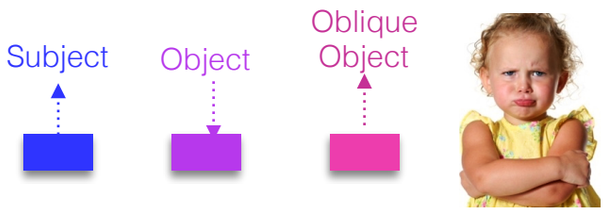




<3yrs <4yrs <5yrs

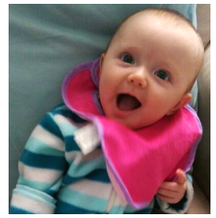
three 1-link theories

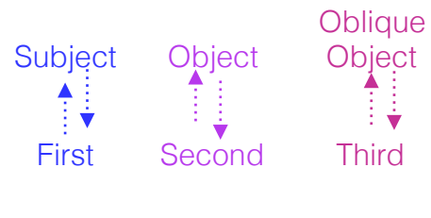


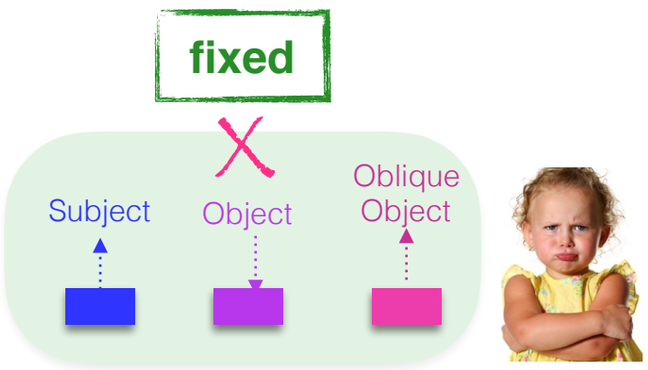


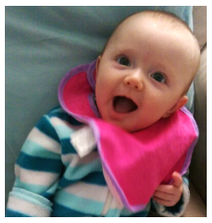
one 3-link theory

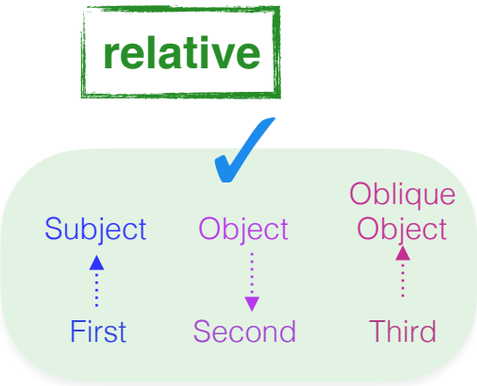
Takeaway: Relying on a relative thematic representation is the only way to derive a 3-link theory of the kind linguists have theorized (UTAH, rUTAH).







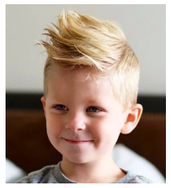




Pearl & Sprouse 2018b

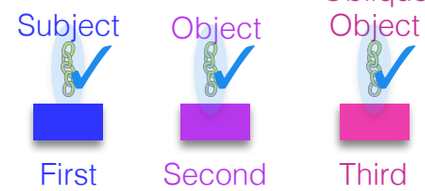
Which linking theories are derivable from children's input?

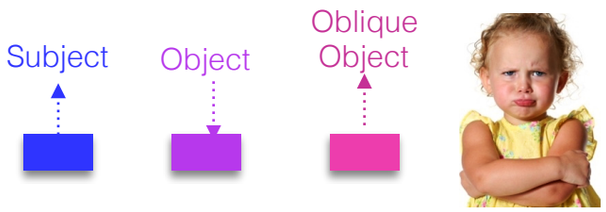




<3yrs <4yrs <5yrs

three 1-link theories





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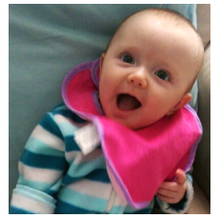
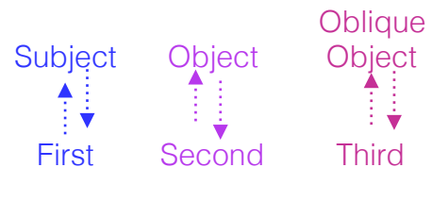
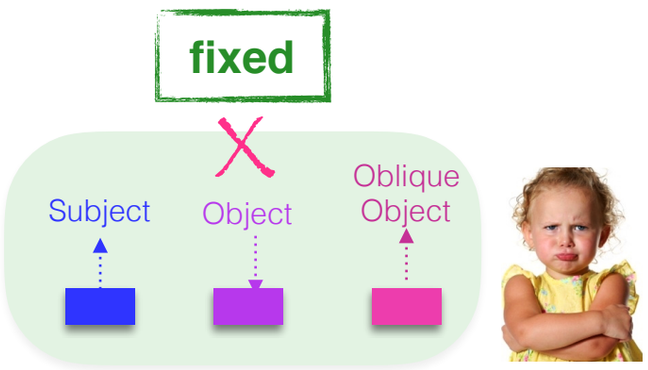
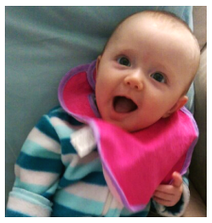
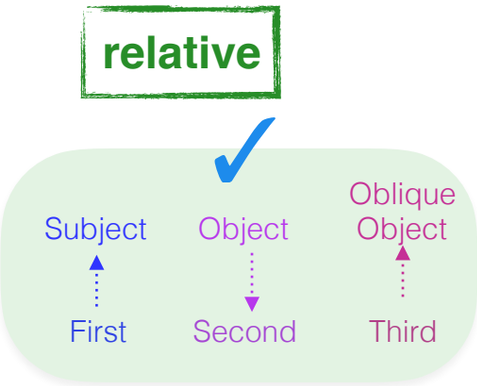








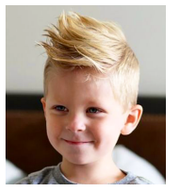


Pearl & Sprouse 2018b

Which linking theories are derivable from children's input?

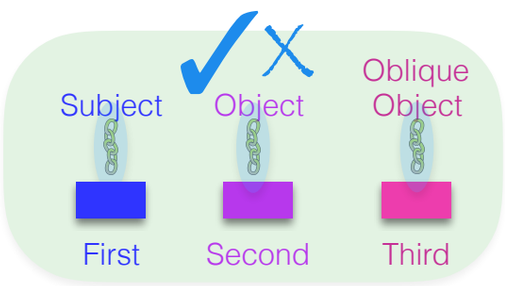
<3yrs

<4yrs



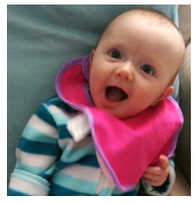
<5yrs

one 3-link theory

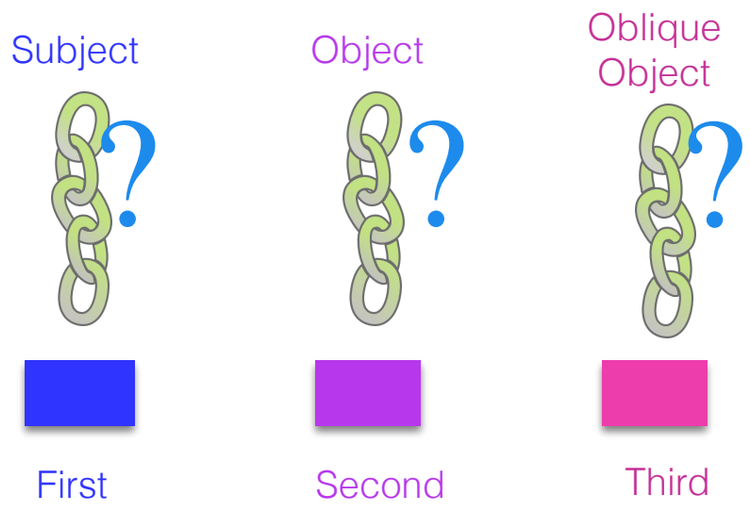


fixed

relative



What about if children only have to derive three 1-link theories?

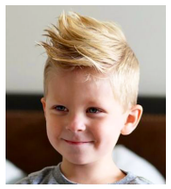


Pearl & Sprouse 2018b

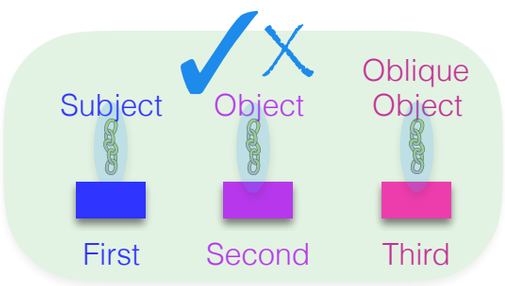
Which linking theories are derivable from children's input?


<3yrs


<4yrs

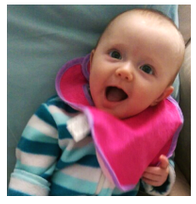

<5yrs

one 3-link theory



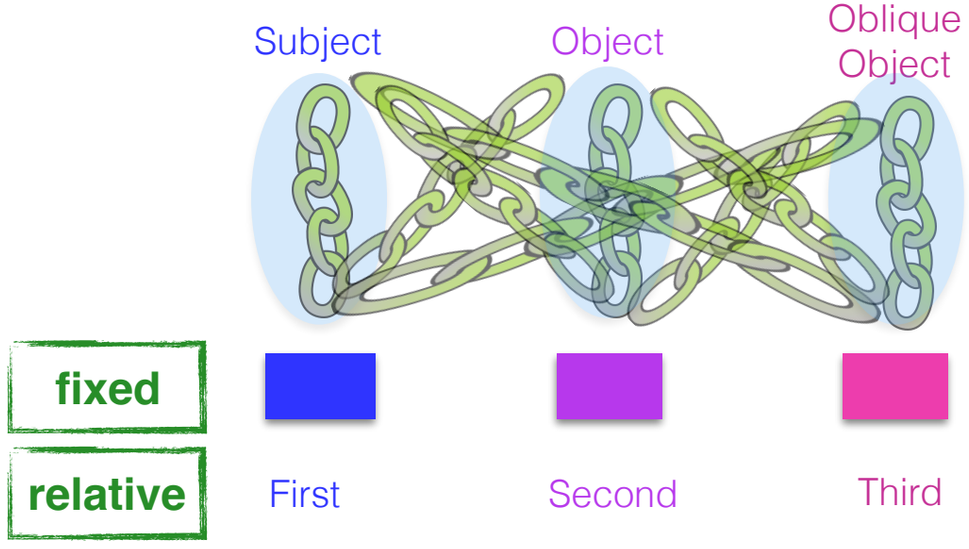
fixed

relative



three 1-link theories

Step 1: Are the individual links reliable enough?

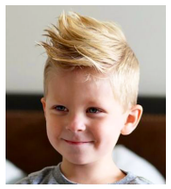


Pearl & Sprouse 2018b

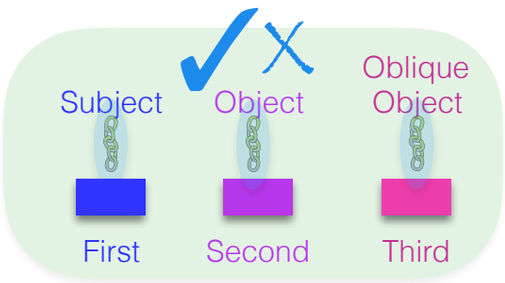
Which linking theories are derivable from children's input?


<3yrs


<4yrs

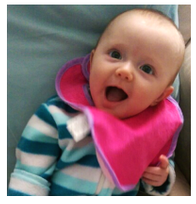

<5yrs

one 3-link theory



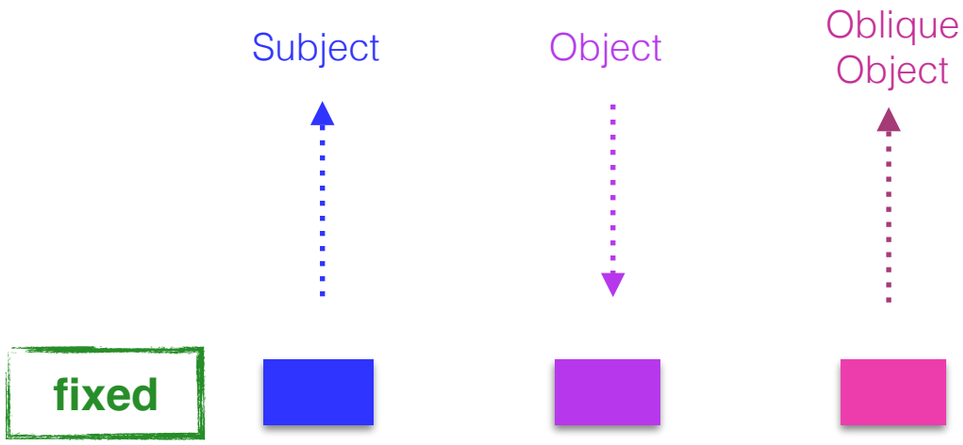
fixed

relative



three 1-link theories

Step 1: Here are the ones that are.

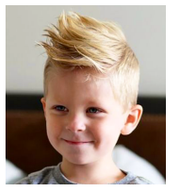


The same 3 unidirectional links as before are reliable enough when the learner relies on a fixed thematic representation.

Pearl & Sprouse 2018b

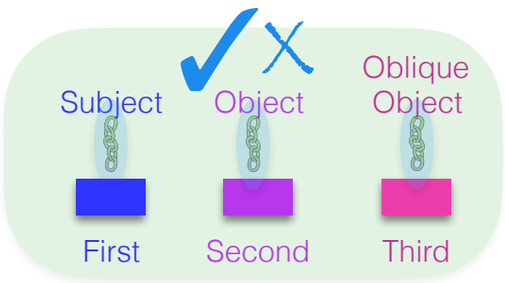
Which linking theories are derivable from children's input?





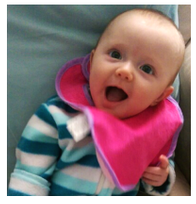
<3yrs <4yrs <5yrs

one 3-link theory



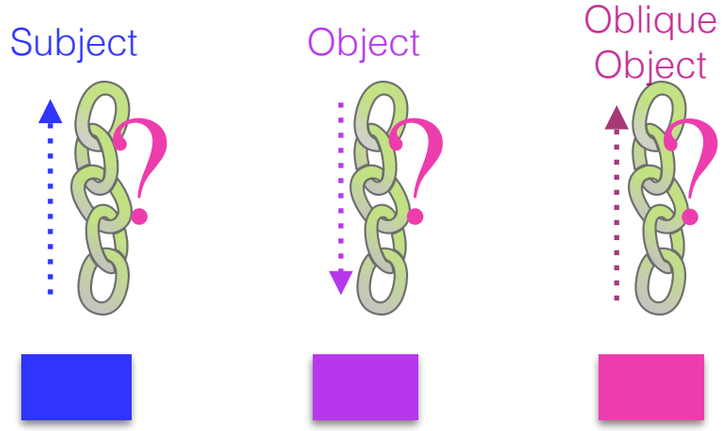
fixed

relative



three 1-link theories

Step 1: Here are the ones that are.



relative

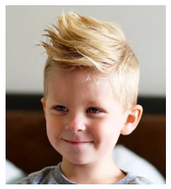
First
Second
Third

This means it may be harder to form 1-link theories.

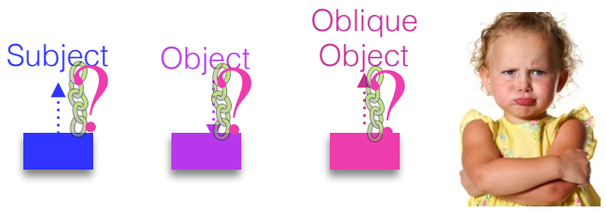
Pearl & Sprouse 2018b

Which linking theories are derivable from children's input?

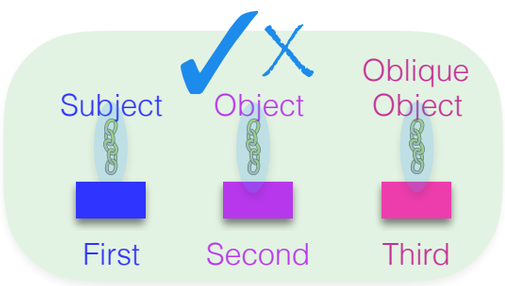




<3yrs <4yrs <5yrs

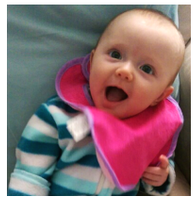


one 3-link theory



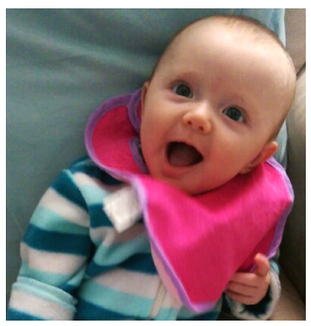
fixed

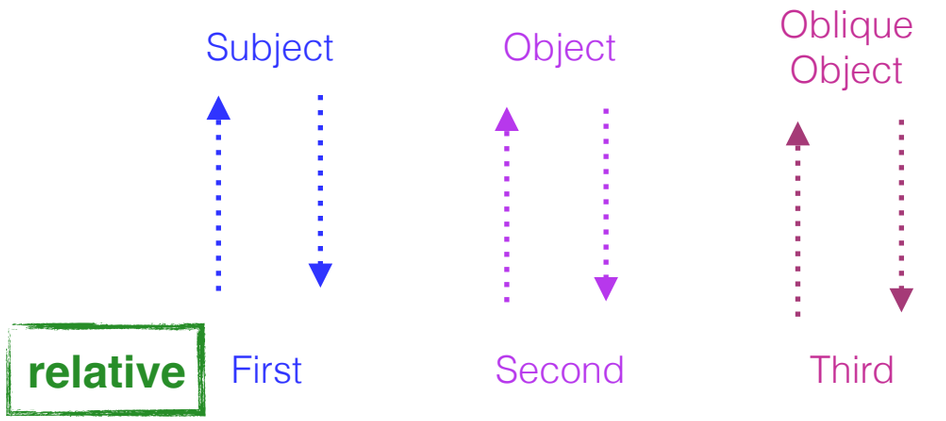
relative



three 1-link theories

Step 1: Here are the ones that are.



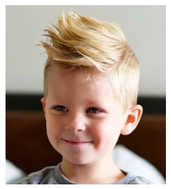


This again contrasts with the relative thematic system, where links in both directions are reliable enough (and there are also no extraneous links).

Pearl & Sprouse 2018b

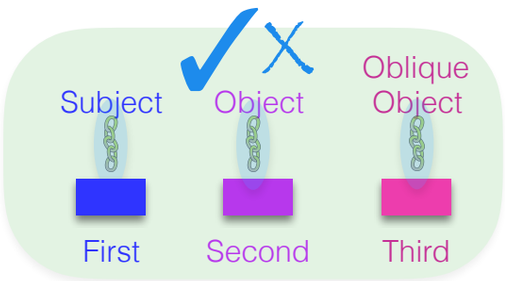
Which linking theories are derivable from children's input?





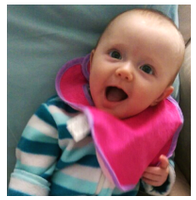
<3yrs <4yrs <5yrs

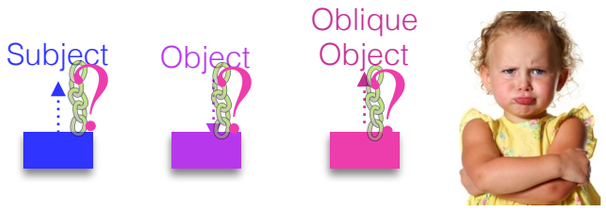
one 3-link theory



fixed

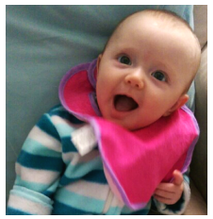
relative

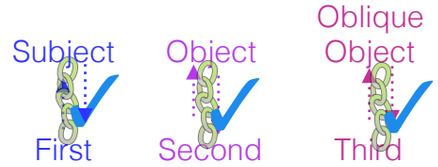




fixed

three 1-link theories





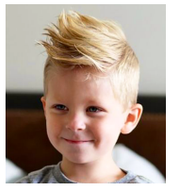
relative

Takeaway: Relying on a relative thematic representation is the only way to easily derive three 1-link theories of the kind compatible with those that linguists have theorized (UTAH, rUTAH).

Pearl & Sprouse 2018b

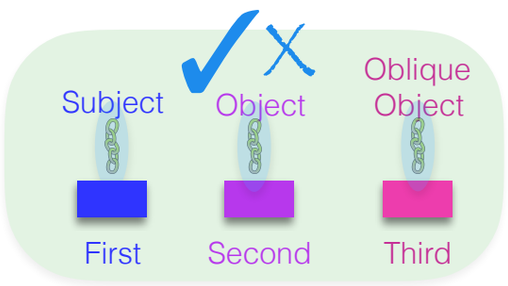
Which linking theories are derivable from children's input?



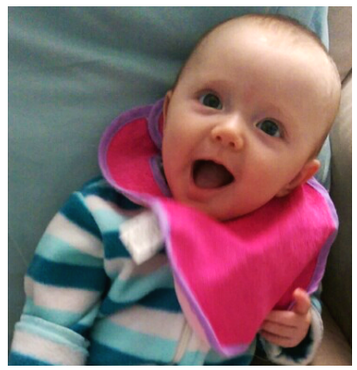


<3yrs <4yrs <5yrs

one 3-link theory

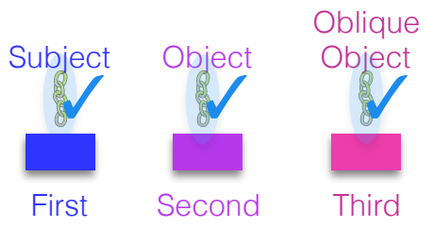


relative



fixed

three 1-link theories



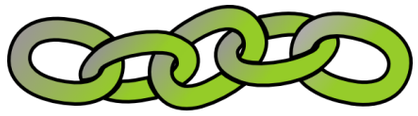
Bigger takeaway:
Developmental support for rUTAH over UTAH.

Whether we think the linking theories that humans use are multi-link theories or multiple 1-link theories, it seems that English children would need to rely on a relative thematic representation if they're going to derive these linking theories from their input.

Pearl & Sprouse 2018b

What we learned about linking theories using quantitative approaches

The little girl *blicked* the kitten on the stairs.



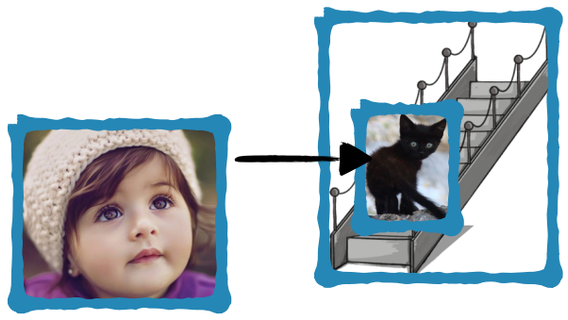
rUTAH

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

relative

UTAH

fixed



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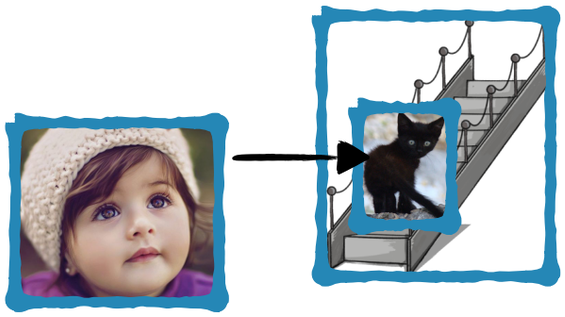
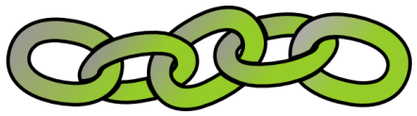




Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

rUTAH

UTAH

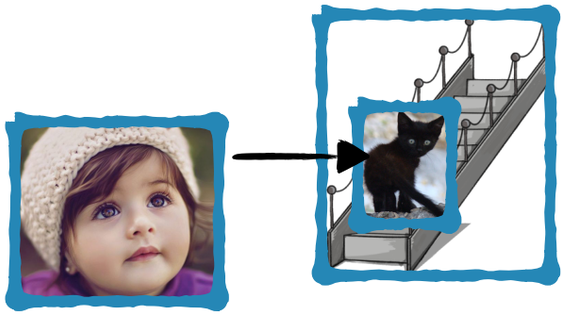
relative

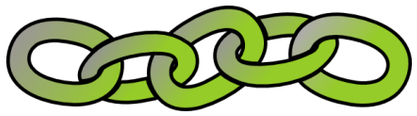
fixed

Linking theory proposals relying on innate knowledge require late maturation if they're going to be compatible with what we know about English children's developing verb knowledge.

What we learned about linking theories using quantitative approaches

The little girl *blicked* the kitten on the stairs.





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

rUTAH

relative

UTAH

fixed

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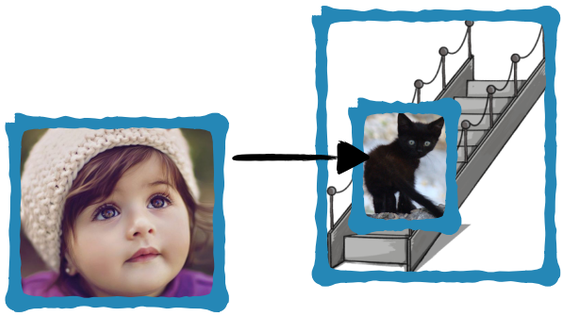
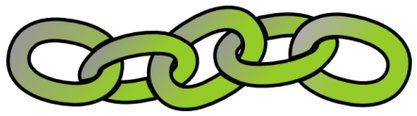




Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

rUTAH

UTAH

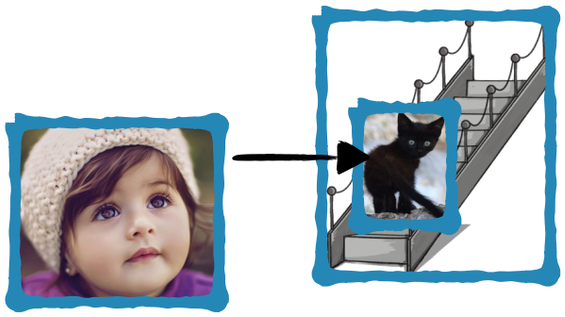
relative

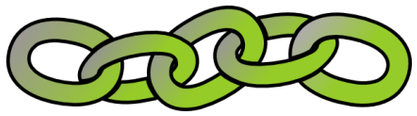
fixed

Linking theory proposals relying on derived knowledge are also compatible with what we know about English children's developing verb knowledge.

What we learned about linking theories using quantitative approaches

The little girl *blicked* the kitten on the stairs.





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

rUTAH

UTAH

relative

fixed

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What we learned about linking theories using quantitative approaches

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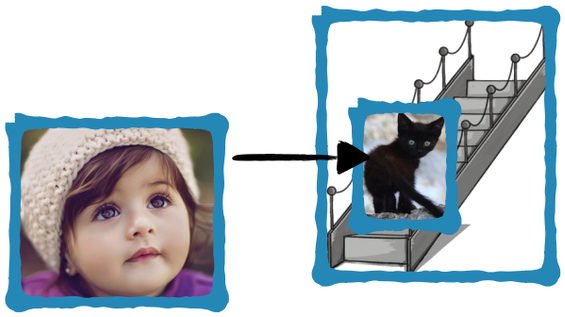
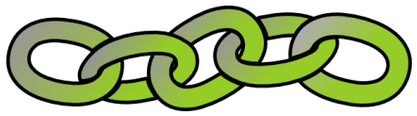




Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

rUTAH

relative

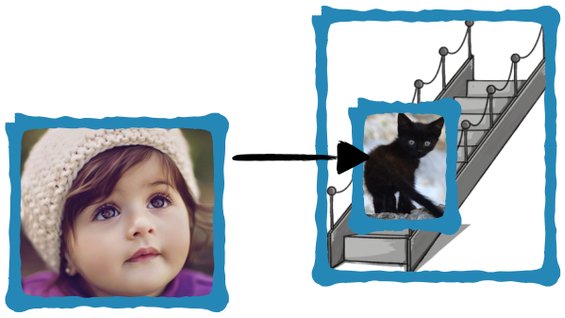
UTAH

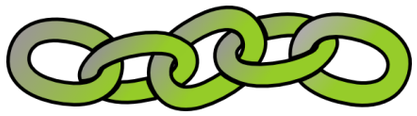
fixed

We provided an existence proof for how linking knowledge could be derived from realistic English child input. It only works for learners relying on relative thematic representations.

What we learned about linking theories using quantitative approaches

The little girl *blicked* the kitten on the stairs.





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

rUTAH

relative

UTAH

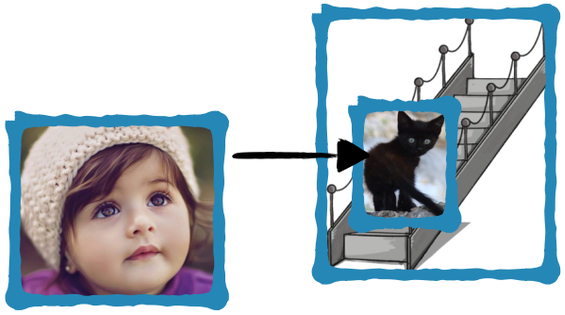
fixed

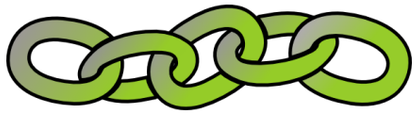
We provided an existence proof for how linking knowledge could be derived from realistic English child input. It only works for learners relying on relative thematic representations.

This can be interpreted as developmental support for theories of relative thematic representations over theories of fixed thematic representations.

Open questions

The little girl *blicked* the kitten on the stairs.





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

rUTAH

relative

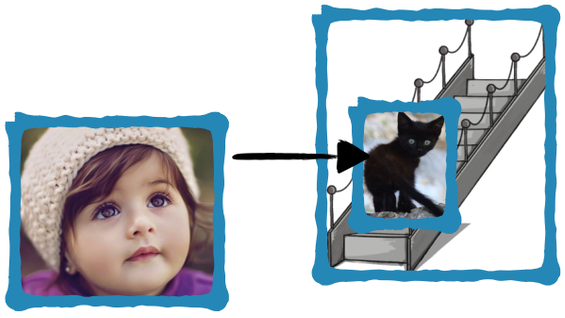
UTAH

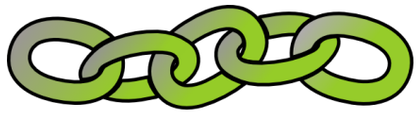
fixed

So now what?

Open questions

The little girl *blicked* the kitten on the stairs.





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

rUTAH

UTAH

relative

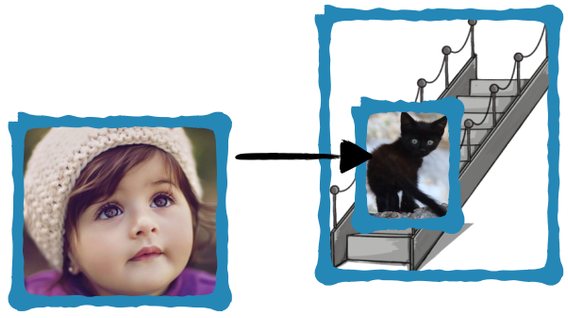
fixed

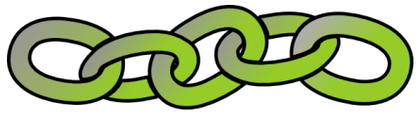
(1) A broader assessment of children's verb class knowledge

This will allow us to further validate our developmental modeling results for these theoretical proposals.

Open questions

The little girl *blicked* the kitten on the stairs.





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

rUTAH

UTAH

relative

fixed

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

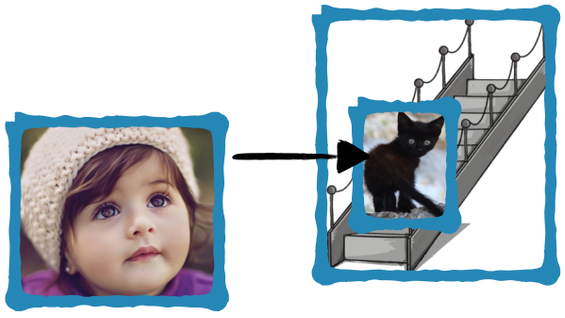
	<3yrs	<4yrs	<5yrs
			
Children's input	239 verbs	267 verbs	284 verbs
Children's known behavior	15 classes of 60 verbs	23 classes of 76 verbs	24 classes of 82 verbs

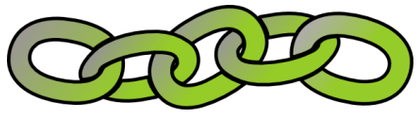
There are nearly 200 verbs in each age that we have developmental model predictions for based on children's input but no behavioral data for.

This will allow us to further validate our developmental modeling results for these theoretical proposals.

Open questions

The little girl *blicked* the kitten on the stairs.





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

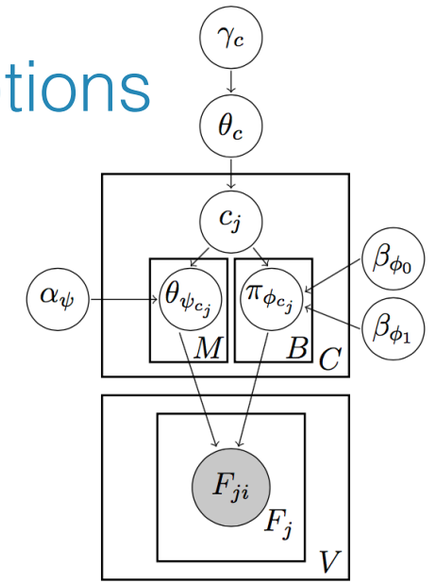
rUTAH

UTAH

relative

fixed

(2) Models incorporating more cognitively plausible assumptions



This will allow us to further validate our developmental modeling results for these theoretical proposals.

Open questions

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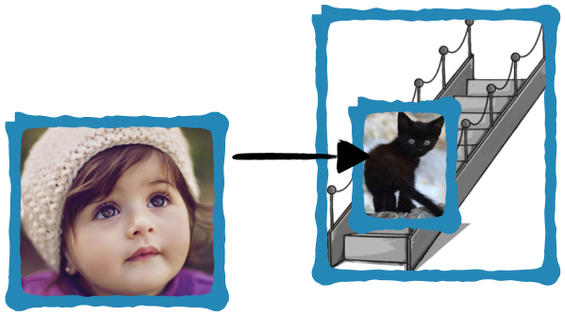

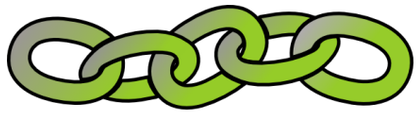

Agent > Experiencer >
Theme > Patient >
(Source, Goal, Location)

rUTAH

UTAH

relative

fixed

(2) Models incorporating more cognitively plausible assumptions

about intake & inference:
+memory & processing limitations

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Open questions

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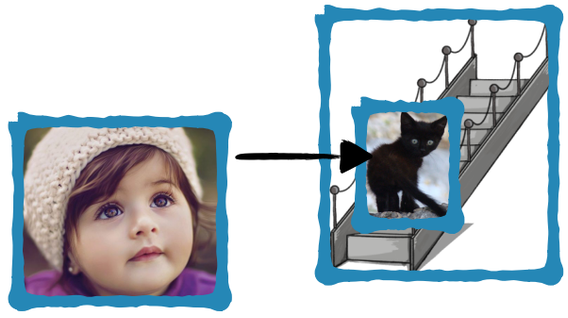
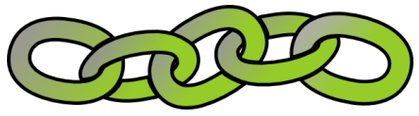




rUTAH

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

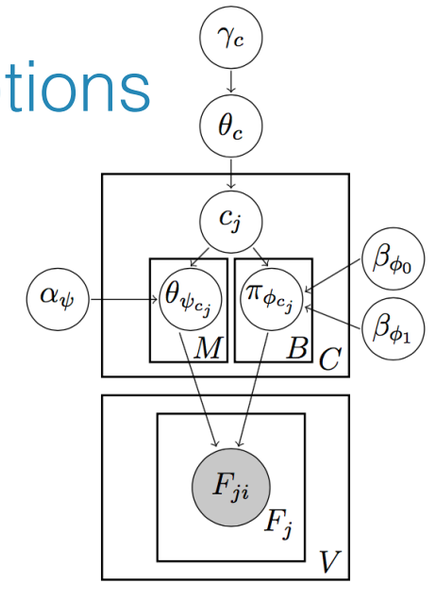
relative

UTAH

fixed

(2) Models incorporating more cognitively plausible assumptions

about developing grammar:
+incorporating additional
age-appropriate information



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Open questions

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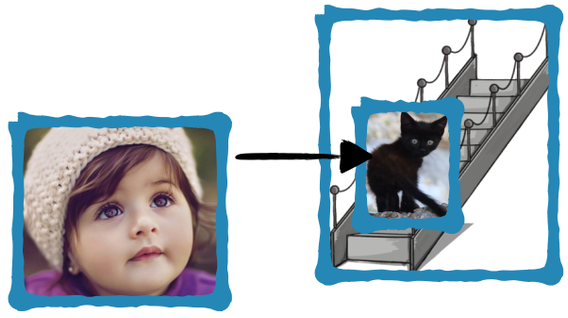
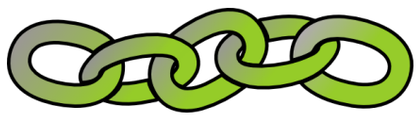




rUTAH

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

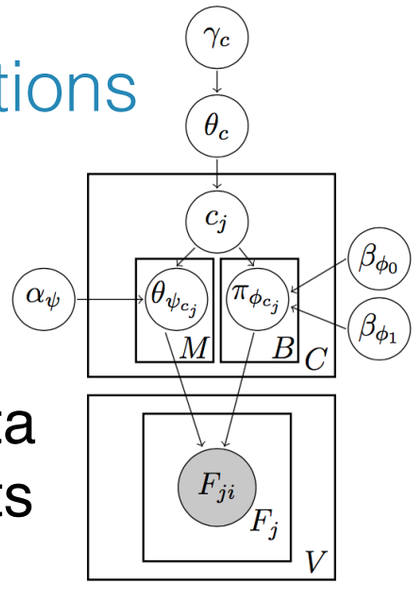
relative

UTAH

fixed

(2) Models incorporating more cognitively plausible assumptions

about target state:
+predicting behavioral data available from experiments



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Open questions

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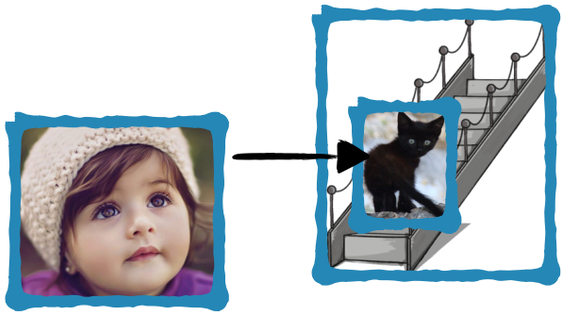

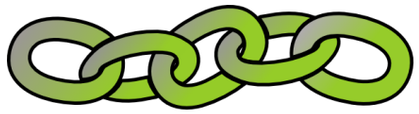

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(Source, Goal, Location)

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fixed

? ? ?

(3) Are there other theoretical options for linking thematic role information to syntactic structure that are compatible with what we know about development?

Open questions

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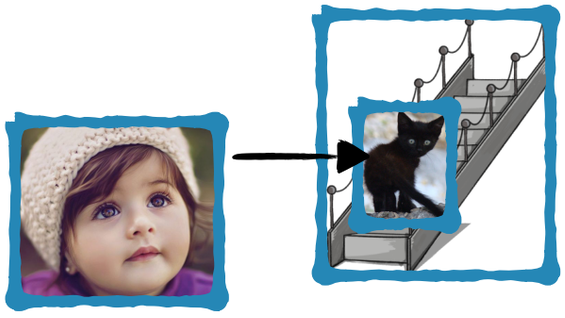

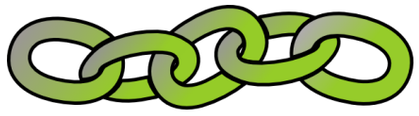

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(Source, Goal, Location)

rUTAH

relative

UTAH

fixed

? ? ?

(3) Are there other theoretical options for linking thematic role information to syntactic structure that are compatible with what we know about development?

We can use these quantitative approaches to investigate them.

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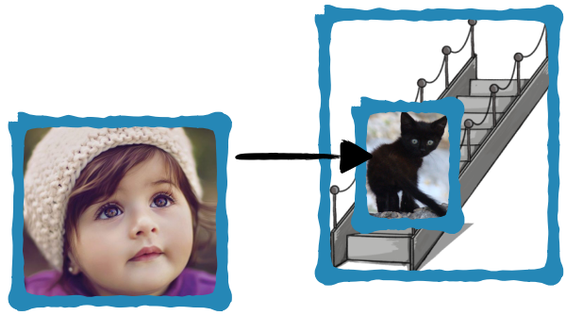

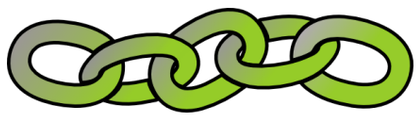

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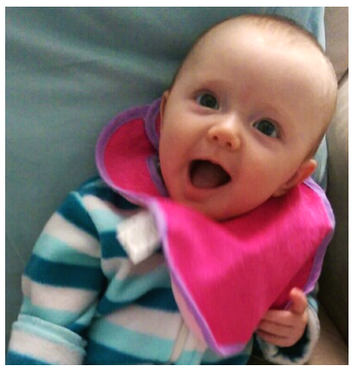
? ? ?

These quantitative approaches allow us to connect theories of linguistic representation with theories of language development and so understand more about both.



Thank you!

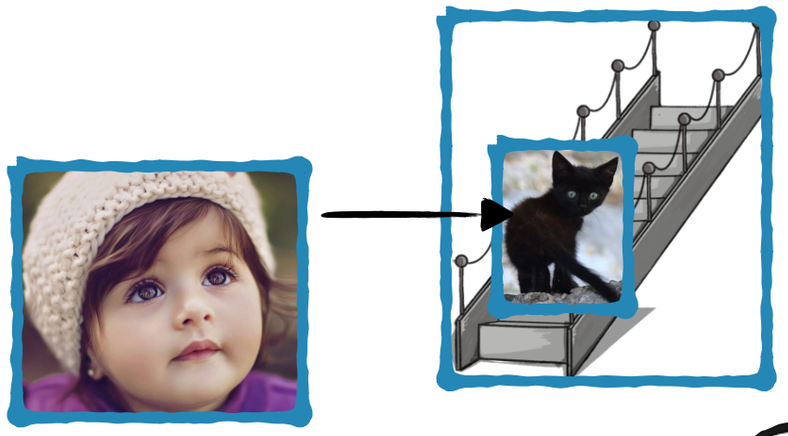
Jon Sprouse

MathPsych 2017

UCI Linguistics 2017

SynLinks workshop 2016

McGill Linguistics 2016



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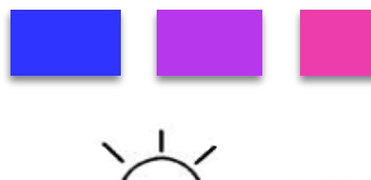

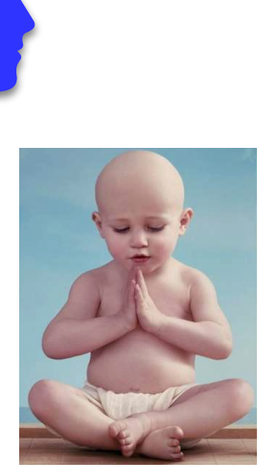

Computation of Language Laboratory

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