Integrating conceptual and structural cues: Theories for syntactic acquisition

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Syntactic acquisition

While syntactic acquisition is (by definition) about learning linguistic structure, children use information of different kinds in order to accomplish it.
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prior knowledge (Universal Grammar or otherwise)
Syntactic acquisition

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prior knowledge (Universal Grammar or otherwise)
syntactic cues

[Diagram of syntactic structure]
Syntactic acquisition

While syntactic acquisition is (by definition) about learning linguistic structure, children use information of different kinds in order to accomplish it.

- Prior knowledge (Universal Grammar or otherwise)
- Syntactic cues
- Conceptual cues

+animate

-animate

![Example of animate (animal) and non-animate (ice)]
Syntactic acquisition

While syntactic acquisition is (by definition) about learning linguistic structure, children use information of different kinds in order to accomplish it.

prior knowledge (Universal Grammar or otherwise)
syntactic cues
conceptual cues
semantic-syntactic cues

She melted the ice with a blow dryer.
Syntactic acquisition

Given this, it seems useful to consider learning theories that leverage these different information types.

prior knowledge (Universal Grammar or otherwise)
syntactic cues
conceptual cues
semantic-syntactic cues

It’s even more useful to be concrete, so let’s look at a specific case study:

The Linking Problem (where event participants appear syntactically)
Today’s plan

Linking Problem overview & some theories for handling it

Theory evaluation with computational modeling: A primer

Theory evaluation: The Linking Problem
Today’s plan

Linking Problem overview & some theories for handling it

Theory evaluation with computational modeling: A primer

Theory evaluation: The Linking Problem
The Linking Problem

- **Why?** About how conceptual information maps to syntactic structure, and we have some proposals for how to capture the empirical facts (e.g., (r)UTAH, Case Theory)
The Linking Problem

- **Why?** About how conceptual information maps to syntactic structure, and we have some proposals for how to capture the empirical facts (e.g., (r)UTAH, Case Theory)

- **What?** Predicates such as verbs allow a variety of syntactic options for where and how their arguments appear and *each predicate has certain linguistic patterns of behavior.*

*The penguin seemed to climb the hill.*

*She tried to melt the ice.*

*It tried that she melted the ice.*
The Linking Problem: Acquisition

One way to figure out how a new predicate will behave is to determine what kind of predicate it is (i.e., what predicate category it belongs to) with the idea that predicates in the same category behave similarly.
The Linking Problem: Acquisition

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The Linking Problem: Acquisition

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The Linking Problem: Acquisition

Knowledge transfer: Once you figure out how one predicate in the category behaves, you know something about how all the predicates in the category behave. This helps you predict how the conceptual arguments will surface syntactically for that new predicate.

The ice froze.
She melted the ice.
The ice melted.
The ice was melted.
The penguin climbed the hill.
The penguin climbed.
The hill was climbed.

She tried to melt the ice.

*It tried that she melted the ice.

The penguin seemed to climb the hill.
It seemed that the penguin climbed the hill.

Pearl & Sprouse in progress
The Linking Problem: Acquisition

Important foundation: Making **useful predicate categories**. What cues are available to do this?

- The ice **froze**.
- She **melted** the ice.
- The penguin **climbed** the hill.
- *It** **tried** that she **melted** the ice.
- It **seemed** that the penguin **climbed** the hill.

**unaccusative**

**unergative**

**The ice froze.**

**She melted the ice.**

**The penguin climbed the hill.**

**She tried to melt the ice.**

**The penguin seemed to climb the hill.**

---

*Pearl & Sprouse in progress*
The Linking Problem: Available cues

One type of cue: Syntactic cues

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

Relevant cue: syntactic structure

May be shallow “syntactic skeleton” (Gutman et al. 2015) that includes tense and aspect information or not.

<table>
<thead>
<tr>
<th>unaccusative</th>
<th>unergative</th>
</tr>
</thead>
<tbody>
<tr>
<td>She melted the ice.</td>
<td>The penguin climbed the hill.</td>
</tr>
<tr>
<td>The ice melted.</td>
<td>The penguin climbed.</td>
</tr>
<tr>
<td>The ice was melted.</td>
<td>The hill was climbed.</td>
</tr>
</tbody>
</table>
The Linking Problem: Available cues

One type of cue: Syntactic cues

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Relevant cue: syntactic structure

May be shallow “syntactic skeleton” (Gutman et al. 2015) that includes tense and aspect information or not.

+ some available tense and aspect information

She melted the ice \(\rightarrow\) NP \(V_{\text{past}}\) NP
The ice melted \(\rightarrow\) NP \(V_{\text{past}}\)
The ice was melted \(\rightarrow\) NP \(V_{\text{past\_participle}}\)
The ice was melting \(\rightarrow\) NP \(V_{\text{progressive\_participle}}\)

Pearl & Sprouse in progress
The Linking Problem: Available cues

One type of cue: Syntactic cues

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

Relevant cue: *syntactic structure*

May be shallow “syntactic skeleton” (Gutman et al. 2015) that includes tense and aspect information or not.

+ *some available tense and aspect information*

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>unaccusative</td>
<td>She <em>melted</em> the ice.</td>
<td>The ice <em>melted</em>.</td>
</tr>
<tr>
<td>unergative</td>
<td>The penguin <em>climbed</em> the hill.</td>
<td>The hill <em>was climbed</em>.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tense &amp; Aspect</th>
<th>Sentence 1</th>
<th>Sentence 2</th>
<th>Sentence 3</th>
<th>Sentence 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>past</td>
<td>She <em>melted</em> the ice.</td>
<td>The ice <em>melted</em>.</td>
<td>The ice <em>was melted</em>.</td>
<td>The ice <em>was melting</em>.</td>
</tr>
<tr>
<td>past participle</td>
<td>The ice <em>melted</em>.</td>
<td>The ice <em>was melted</em>.</td>
<td>The ice <em>was melting</em>.</td>
<td></td>
</tr>
<tr>
<td>progressive_participle</td>
<td>The ice <em>was melting</em>.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Linking Problem: Available cues

One type of cue: Syntactic cues

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

Relevant cue: syntactic structure

Why include tense and aspect information? Tenny’s (1987 1994) Aspectual Interface Hypothesis suggests that aspect may be a useful cue to verb class (telic = unaccusative, atelic = unergative). Tense and aspect affect telicity and are sometimes easily observable in the morphology.

+ some available tense and aspect information

She melted the ice —> NP V_{past} NP
The ice melted —> NP V_{past}
The ice was melted —> NP V_{past_participle}
The ice was melting —> NP V_{progressive_participle}

ignore available tense and aspect information

She melted the ice —> NP V NP
The ice melted —> NP V
The ice was melted —> NP V
The ice was melting —> NP V
The Linking Problem: Available cues

Another type of cue: Conceptual cues (non-linguistic)

Example: Animacy is useful for distinguishing predicate classes like raising vs. control verbs, and psych-object-experiencer verbs. Young children have been shown to use this cue in experimental studies (Becker 2009, Kirby 2009, Kirby 2010, Becker 2014, Becker 2015, Hartshorne et al. 2015).

- animate

She tried to melt the ice.

*It tried that she melted the ice.

+ animate

The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.
The Linking Problem: Available cues

Another type of cue: Conceptual cues (non-linguistic)

Example: Thematic roles (e.g., Agent, Patient) that indicate participant roles in an event are salient to very young children [<10 months: Gordon 2003; 6 months: Hamlin, Wynn, & Bloom 2007, Hamlin, Wynn, Bloom, & Mahajan 2011].

She tried to melt the ice.

It tried that she melted the ice.

The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.
Thematic roles & how to use them:
semantic-syntactic information

Syntax

She melted the ice with a blow dryer.

Subject       Object       Indirect Object

How do we get from here to here?

(likely derived from lower-level conceptual info) =
Agent, Experiencer, Patient, Theme, Goal, Source, Instrument...
Thematic roles & how to use them: semantic-syntactic information

**Syntax**

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

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

**Mapping to Syntax**

**The Uniformity of Theta Assignment Hypothesis:**


**Thematic roles map to one of three categories.**

(likely derived from lower-level conceptual info) = Agent, Experiencer, Patient, Theme, Goal, Source, Instrument...
Thematic roles & how to use them: semantic-syntactic information

Syntax

She melted the ice with a blow dryer.

Subject

Object

Indirect Object

Intermediate representations

Thematic roles map to one of three categories.

Thematic roles are ordered with respect to each other.

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

Mapping to Syntax

The (relativized) Uniformity of Theta Assignment Hypothesis:

Larson 1988, Larson 1990

rUTAH

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

UG knowledge

The UTAH approach includes:

- Relativized Uniformity of Theta Assignment
- Larson 1988, Larson 1990

thematic-roles

Thematic roles are:

- Agent
- Experiencer
- Patient
- Theme
- Goal
- Source
- Instrument

Object
Thematic roles & how to use them: semantic-syntactic information

She melted the ice with a blow dryer.

Standard UTAH and rUTAH implementations typically assume this part is included.

Mapping to Syntax

Intermediate representations

Thematic roles map to one of three categories.
(likely derived from lower-level conceptual info) = Agent, Experiencer, Patient, Theme, Goal, Source, Instrument...

Syntax

Thematic roles are ordered with respect to each other.

Agent > Experiencer > Theme > Patient > (Source, Goal, Instrument)
Thematic roles & how to use them: semantic-syntactic information

If children expect the mapping to hold, it may be especially salient to them when it doesn’t. Such instances would be accounted for by movement.

- **UG knowledge**
- **UTAH**
  - Agent > Experiencer > Theme > Patient > (Source, Goal, Instrument)
- **rUTAH**

+exp-mapping
Thematic roles & how to use them: semantic-syntactic information

If children expect the mapping to hold, it may be especially salient to them when it doesn’t. Such instances would be accounted for by movement.

The ice was \textit{melted} by the girl.
If children expect the mapping to hold, it may be especially salient to them when it doesn’t. Such instances would be accounted for by movement.

Thematic roles & how to use them: semantic-syntactic information

The ice was melted by the girl.

\[
\text{Subject} \quad \text{done-to} \quad \text{Indirect Object}
\]
Thematic roles & how to use them:
semantic-syntactic information

Syntax

She melted the ice with a blow dryer.

Subject

Object

Indirect Object

But we could also look at implementations that don’t assume this mapping is fixed a priori. This would be a weaker version of standard (r)UTAH implementations.

Thematic roles map to one of three categories.

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

Thematic roles are ordered with respect to each other.

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

Mapping to Syntax

UTAH

rUTAH

Intermediate representations

thematic-roles
The ice was melted by the girl.

The thematic roles and how to use them:

*semantic-syntactic information*

Alternatively, children could simply track the distributions of where intermediate representation roles appear with respect to grammatical positions. *(No absolute expectation yet that the mapping will hold. This is something children would have to infer through exposure to the input.)*
Thematic roles & how to use them: semantic-syntactic information

Alternatively, children could simply track the distributions of where intermediate representation roles appear with respect to grammatical positions. (No absolute expectation yet that the mapping will hold. This is something children would have to infer through exposure to the input.)
Thematic roles & how to use them: semantic-syntactic information

Syntax

She melted the ice with a blow dryer.

Subject       Object       Indirect Object

+exp-mapping:
movement is salient
because mapping to
syntax is fixed

-exp-mapping:
syntax mapping
distributions are
tracked

Mapping to Syntax

UTAH

rUTAH

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

Thematic roles map to one
of three categories.

Thematic roles are ordered
with respect to each other.

(likely derived from lower level conceptual info) =
Agent, Experiencer, Patient, Theme, Goal, Source, Instrument...
**Thematic roles & how to use them:**

semantic-syntactic information

**Syntax**

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

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

+**exp-mapping:**

movement is salient because mapping to syntax is fixed

-**exp-mapping:**

syntax mapping distributions are tracked

**Mapping to Syntax**

**UTAH**  |  **Choice 1**  |  **rUTAH**

**Intermediate representations**

Thematic roles map to one of three categories.

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

Thematic roles are ordered with respect to each other.

*(likely derived from lower-level conceptual info)* = Agent, Experiencer, Patient, Theme, Goal, Source, Instrument...
Potential learning strategies

**UG knowledge options**
- UTAH, -exp-mapping
- UTAH, +exp-mapping
- rUTAH, -exp-mapping
- rUTAH, +exp-mapping
Potential learning strategies

**UG knowledge options**

UTAH, -exp-mapping
UTAH, +exp-mapping
rUTAH, -exp-mapping
rUTAH, +exp-mapping

Additional learner information: Syntactic options (+/- tense & aspect in the surface morphology)

* + some available tense and aspect information
  
  She melted the ice → NP \( V_{\text{past}} \) NP
  The ice melted → NP \( V_{\text{past}} \)
  The ice was melted → NP \( V_{\text{past}\_\text{participle}} \)
  The ice was melting → NP \( V_{\text{progressive\_participle}} \)

* ignore available tense and aspect information
  
  She melted the ice → NP \( V \) NP
  The ice melted → NP \( V \)
  The ice was melted → NP \( V \)
  The ice was melting → NP \( V \)
Potential learning strategies

UG knowledge options
UTAH, -exp-mapping
UTAH, +exp-mapping
rUTAH, -exp-mapping
rUTAH, +exp-mapping

+ some available tense and aspect information
The ice was melted —> NP $V_{\text{past_participle}}$

8 different learning strategy variants

ignore available tense and aspect information
The ice was melted —> NP $V$
Potential learning strategies

**UG knowledge options**
- UTAH, -exp-mapping
- UTAH, +exp-mapping
- rUTAH, -exp-mapping
- rUTAH, +exp-mapping

+ some available tense and aspect information
The ice was melted $\rightarrow$ NP $V_{\text{past\_participle}}$

8 different learning strategy variants

- UTAH, -exp-mapping
- UTAH, +exp-mapping
- rUTAH, -exp-mapping
- rUTAH, +exp-mapping

*ignore available tense and aspect information*
The ice was melted $\rightarrow$ NP $V$

All learners are sensitive to the animacy of NPs.

*animate*  

*rUTAH, animate*
Learning strategy options

Syntax: She melted the ice with a blow dryer.

- Subject: She
- Object: The ice
- Indirect Object: A blow dryer

- Thematic roles map to one of three categories.
- Thematic roles are ordered with respect to each other.

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

UG knowledge:

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

Mapping to Syntax:

- Choice 1: UTAH → rUTAH
  - Intermediate representations
  - Thematic roles map to one of three categories.

- Choice 2: +exp-mapping: syntax mapping distributions are tracked
  - movement is salient because mapping to syntax is fixed

- Choice 3: -tense/aspect info
  - -exp-mapping: +tense/aspect info

(Choice 1, 2, and 3 are connected with arrows indicating the flow of information).
Today’s plan

Linking Problem overview & some theories for handling it

Theory evaluation with computational modeling: A primer

Theory evaluation: The Linking Problem
Learning theory proposals: Generation & evaluation

How to generate a learning theory proposal:
Characterize the learning problem precisely and identify a potential solution.

8 different learning strategy variants
Learning theory proposals: Generation & evaluation

How to generate a learning theory proposal:
Characterize the learning problem precisely and identify a potential solution.

Benefit of computational modeling:
We can make sure the learning problem is characterized precisely enough to implement. It’s not always obvious what pieces are missing until you try to build a model of the learning process.
(Pearl 2014, Pearl & Sprouse 2015)
Learning theory proposals: Generation & evaluation

How to generate a learning theory proposal:
Characterize the learning problem precisely and identify a potential solution.

How to evaluate a learning theory proposal:
See if it’s successful when embedded in a model of the acquisition process for that learning problem.
Learning theory proposals: Generation & evaluation

How to generate a learning theory proposal:
Characterize the learning problem precisely and identify a potential solution.

How to evaluate a learning theory proposal:
See if it’s successful when embedded in a model of the acquisition process for that learning problem.

Recently, in computational modeling, we’ve seen the integration of rich hypothesis spaces with probabilistic/statistical learning mechanisms (Sakas & Fodor 2001, Yang 2004, Pearl 2011, Dillon et al. 2013, Pearl & Sprouse 2013, Pearl et al. 2014, Pearl & Mis 2016, among many others).
Learning theory proposals: Generation & evaluation

How to generate a learning theory proposal:
Characterize the learning problem precisely and identify a potential solution.

How to evaluate a learning theory proposal:
See if it’s successful when embedded in a model of the acquisition process for that learning problem.

We’ve also seen the development of more sophisticated acquisition frameworks that highlight the precise role of different components (Lidz & Gagliardi 2015, Omaki & Lidz 2015).
The Lidz & Gagliardi (2015) acquisition framework
Learning theory proposals: Generation & evaluation

How to *generate* a learning theory proposal:
Characterize the learning problem precisely and identify a potential solution.

How to *evaluate* a learning theory proposal:
See if it’s *successful when embedded in a model of the acquisition process* for that learning problem.

This computational modeling approach helps us refine our theories about both *the knowledge representation* the learning theory relies on and *the acquisition process* that uses that representation.
Characterizing learning problems

Initial state:

Pearl & Sprouse 2015, Pearl & Mis 2016
Characterizing learning problems

Initial state:

- initial knowledge state
  ex: syntactic categories exist and can be identified
  ex: phrase structure exists and can be identified
  ex: participant roles can be identified

N, V, Adj, P, ...

Agent, Patient, Goal, ...

Pearl & Sprouse 2015, Pearl & Mis 2016
Characterizing learning problems

Initial state:

- initial knowledge state
  ex: syntactic categories exist and can be identified
  ex: phrase structure exists and can be identified
  ex: participant roles can be identified

- learning biases & capabilities
  ex: frequency information can be tracked
  ex: distributional information can be leveraged

Pearl & Sprouse 2015, Pearl & Mis 2016
Characterizing learning problems

**Initial state:** initial knowledge state + learning biases & capabilities

**Data intake:**

Lidz & Gagliardi 2015
Characterizing learning problems

**Initial state:** initial knowledge state + learning biases & capabilities

**Data intake:**

- input + encoding + acquisitional intake = data perceived as relevant for learning

(Fodor 1998, Lidz & Gagliardi 2015)

ex: syntactic and conceptual data for learning syntactic knowledge that links with conceptual knowledge

[defined by knowledge & biases/capabilities in the initial state]
Characterizing learning problems

**Initial state:** initial knowledge state + learning biases & capabilities

**Data intake:** data perceived as relevant for learning

**Learning period:**

---

*Pearl & Sprouse 2015, Pearl & Mis 2016*
Characterizing learning problems

**Initial state:** initial knowledge state + learning biases & capabilities

**Data intake:** data perceived as relevant for learning

**Learning period:**
- how long children have to reach the target knowledge state
  (when inference & iteration happen)

ex: 3 years, ~1,000,000 data points
ex: 4 months, ~36,500 data points

Pearl & Sprouse 2015, Pearl & Mis 2016
Characterizing learning problems

**Initial state:** initial knowledge state + learning biases & capabilities

**Data intake:** data perceived as relevant for learning

**Learning period:** how long children have to learn

**Target state:**

Lidz & Gagliardi 2015

Pearl & Sprouse 2015, Pearl & Mis 2016
Characterizing learning problems

**Initial state:** initial knowledge state + learning biases & capabilities

**Data intake:** data perceived as relevant for learning

**Learning period:** how long children have to learn

**Target state:**
- the knowledge children are trying to attain (as indicated by their behavior)

ex: *done-to*
   - The ice melted.
   - The penguin climbed.

*doer*
Characterizing learning problems

**Initial state:** initial knowledge state + learning biases & capabilities

**Data intake:** data perceived as relevant for learning

**Learning period:** how long children have to learn

**Target state:** the knowledge children must attain

Once we have all these pieces specified, we should be able to implement an informative model of the learning process.

*Lidz & Gagliardi 2015*
Informing theories of knowledge & learning

When we identify a successful learning strategy via modeling, this is an existence proof that children could solve that learning problem using the knowledge, learning biases, and capabilities comprising that strategy.

This identifies useful learning strategy components, which include both the knowledge components (= theories of representation) and the biases & capabilities that must exist for that knowledge to be successfully deployed during acquisition (= theories of the learning process).
Today’s plan

Linking Problem overview & some theories for handling it

Theory evaluation with computational modeling: A primer

Theory evaluation: The Linking Problem
Potential learning strategies revisited

**UG knowledge options**
- UTAH, -exp-mapping
- UTAH, +exp-mapping
- rUTAH, -exp-mapping
- rUTAH, +exp-mapping

+ some available tense and aspect information

The ice was melted —> NP V_{past_participle}

8 different learning strategy variants

- animate
- +animate

ignore available tense and aspect information

The ice was melted —> NP V

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Lidz & Gagliardi 2015

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Pearl & Sprouse in progress
The ability to identify and extract all relevant information reliably (syntactic + conceptual + semantic-syntactic cues) + sufficient statistical learning abilities to track and use this information.

+ some available tense and aspect information

The ice was melted $\rightarrow$ NP $V_{\text{past participle}}$

8 different learning strategy variants

ignore available tense and aspect information

The ice was melted $\rightarrow$ NP $V$
Initial state

The ability to identify and extract all relevant information reliably (syntactic + conceptual + semantic-syntactic cues) + sufficient statistical learning abilities to track and use this information.

+ some available tense and aspect information

The ice was melted —> NP V_{past_participle}

8 different variants, which all cause different *acquisitional intakes*

*ignore available tense and aspect information*

The ice was melted —> NP V

- animate

+ animate

---

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

“it’s falling off”

Input

Lidz & Gagliardi 2015

Pearl & Sprouse in progress
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

Possible perceptual intake

“it’s falling off”

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

Possible perceptual intake

"it’s falling off"

(1) UTAH, -exp-mapping, +some available tense and aspect information

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

Possible perceptual intake

“it’s falling off”

Acquisitional intake

(1) UTAH, -exp-mapping,+some available tense and aspect information

FALL

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

Possible perceptual intake

“it’s falling off”

Acquisitional intake

(1) UTAH, -exp-mapping, +some available tense and aspect information

FALL

-animate subject: 1

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

Possible perceptual intake

“it’s falling off”

Acquisitional intake

(1) UTAH, -exp-mapping,+some available tense and aspect information

FALL

-animate subject: 1

Patient-like as subject: 1

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

"it’s falling off"

Acquisitional intake

(1) UTAH, -exp-mapping, +some available tense and aspect information

FALL

- animate subject: 1

Patient-like as subject: 1

NP V_{present\_participle} PRT

Note: CHILDES Treebank syntactic encoding captures these distinctions:
(i) present (VBP) vs. past tense (VBD)
(ii) present participle (VBG) vs. past participle (VBN)
(iii) non-finite usage (VB)

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

"it's falling off"

Possible perceptual intake

Acquisitional intake

(2) UTAH, -exp-mapping, -some available tense and aspect information

FALL

-animate subject: 1

Patient-like as subject: 1

NP V PRT

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

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

Possible perceptual intake

“it’s falling off”

Acquisitional intake

(3) UTAH, +exp-mapping, -some available tense and aspect information

FALL
- animate subject: 1
+ movement: 1
NP V PRT

Lidz & Gagliardi 2015

Pearl & Sprouse in progress
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

```
Acquisitional intake

(4) UTAH, +exp-mapping, +some available tense and aspect information

FALL
- animate subject: 1
+ movement: 1
NP V_{present participle} PRT
```

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

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

Possible perceptual intake

“it’s falling off”

Input

Acquisitional intake

(5) rUTAH, +exp-mapping, +some available tense and aspect information

FALL

-animate subject: 1
+movement: 0

NP V_{present_participle} PRT

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

"it’s falling off"

Possible perceptual intake

Acquisitional intake

(6) rUTAH, +exp-mapping, -some available tense and aspect information

FALL

-animate subject: 1
+movement: 0
NP V PRT

Lidz & Gagliardi 2015

Pearl & Sprouse in progress
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

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

Possible perceptual intake

“it’s falling off”

(7) rUTAH, -exp-mapping, -some available tense and aspect information

FALL

-animate subject: 1

Highest role as subject: 1

NP V PRT

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

Possible perceptual intake

(8) rUTAH, -exp-mapping, +some available tense and aspect information

FALL

-animate subject: 1

Highest role as subject: 1

NP V_{present_participle} PRT

Lidz & Gagliardi 2015
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

Comparison: 8 learners
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

“it’s falling off”

Possible perceptual intake

Comparison: 8 learners

-FALL

animacy

-animate subject: 1

All 8 learners

Comparison: 8 learners
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

"it’s falling off"

Comparison: 8 learners

-animate subject: 1

+tense/aspect

NP V_{present_participle} PRT

-4 learners

-tense/aspect

NP V PRT

-4 learners
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

"it’s falling off"

Possible perceptual intake

Comparison: 8 learners

Patient-like as subject
2 learners

Highest as subject
2 learners

Patient-like as subject
2 learners

Highest as subject
2 learners

Pearl & Sprouse in progress
Acquisitional intake options

(from Brown-Eve corpus from CHILDES Treebank)

“it’s falling off”

Possible perceptual intake

Comparison: 8 learners

Input

Patient-like as subject: 1

Highest as subject

Patient-like as subject: 1

Highest as subject

Patient-like as subject: 1

Highest as subject

Patient-like as subject: 1

Highest as subject

Patient-like as subject: 1

Highest as subject

Patient-like as subject: 1

Highest as subject

1 learner 1 learner 1 learner 1 learner 1 learner 1 learner 1 learner 1 learner

Pearl & Sprouse in progress
Acquisitional intake: Input data

Brown-Eve+Valian

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

This corpus (Brown-Eve+Valian) contains speech directed at 22 children between the ages of 18 and 32 months.

There are ~40,000 utterances total, comprised of ~193,000 word tokens. Of the 553 verb lexical items that appear, 239 occur 5 or more times.
Acquisitional intake: Input data
Brown-Eve+Valian

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

This corpus (Brown-Eve+Valian) contains speech directed at 22 children between the ages of 18 and 32 months.

There are ~40,000 utterances total, comprised of ~193,000 word tokens. Of the 553 verb lexical items that appear, 239 occur 5 or more times.

Focus on learning the predicate categories for these for now. Intuition: Frequent enough to be useful to distributionally learn from.

Lidz & Gagliardi 2015

Pearl & Sprouse in progress
Basic question: Is it possible for the child to use the **acquisitional intake** to achieve the **target knowledge/behavior** in the **amount of time** children typically get to do it, given the incremental nature of learning and children’s cognitive constraints?
Learning period

Basic question: Is it possible for the child to use the **acquisitional intake** to achieve the **target knowledge/behavior** in the **amount of time** children typically get to do it, given the incremental nature of learning and children’s cognitive constraints?

However, before we try to answer this, there’s an **even more basic question** that’s often worth asking.
Learning period

Even more

Basic question: Is it possible for the child to use the **acquisitional intake** to achieve the **target knowledge/behavior** in the amount of time children typically get to do it, given the incremental nature of learning and children’s cognitive constraints?

However, before we try to answer this, there’s an **even more basic** question that’s often worth asking.

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Lidz & Gagliardi 2015
Learning period

Even more

Basic question: Is it possible for the child to use the **acquisitional intake** to achieve the **target knowledge/behavior**? in the amount of time children typically get to do it, given the incremental nature of learning and children’s cognitive constraints?


Lidz & Gagliardi 2015
Learning period

Even more

Basic question: Is it possible for the child to use the **acquisitional intake** to achieve the **target knowledge/behavior**? in the amount of time children typically get to do it, given the incremental nature of learning and children’s cognitive constraints?


This kind of analysis is very helpful for determining if this implementation of the acquisition task is the right one. In particular, if children are sensitive to this information in the perceptual intake, is that enough to yield the target knowledge/behavior? Are these useful learning assumptions for children to have to create the **acquisitional intake**? Are these useful representations?

Lidz & Gagliardi 2015
Even more

Basic question: Is it possible for the child to use the **acquisitional intake** to achieve the **target knowledge/behavior**? in the amount of time children typically get to do it, given the incremental nature of learning and children’s cognitive constraints?


This is typically implemented as an **ideal learner model**, which isn’t concerned with the cognitive limitations and incremental learning restrictions children have.

(That is, **useful** for children is different from **useable** by children in real life.)
Learning period

Even more

Basic question: Is it possible for the child to use the *acquisitional intake* to achieve the *target knowledge/behavior*? in the amount of time children typically get to do it, given the incremental nature of learning and children’s cognitive constraints?


So, for an *ideal learner*, learning period considerations aren’t as important as considerations about the *initial state*, *data intake*, and *target knowledge/behavior*.

Lidz & Gagliardi 2015
Learning period

Even more

Basic question: Is it possible for the child to use the **acquisitional intake** to achieve the **target knowledge/behavior**? in the amount of time children typically get to do it, given the incremental nature of learning and children’s cognitive constraints?


Practical note: Doing a computational analysis is often a really good idea to make sure we’ve got the right conceptualization of the **acquisition task** (see Pearl 2011 for the trouble you can get into when you don’t do this first).
Learning period

Even more
Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior? in the amount of time children typically get to do it, given the incremental nature of learning and children’s cognitive constraints?


So, that’s why we’re going to start with a computational-level model of the acquisition process.

Lidz & Gagliardi 2015
Learning process: Computational-level

Generative model of how the observable data for each verb are created.

Lidz & Gagliardi 2015
Each verb is observed in a certain number of instances in the input.

“it’s falling off”
“she fell down”
“don’t fall!”
“is London Bridge falling down?”

Lidz & Gagliardi 2015

Pearl & Sprouse in progress
Learning process: Computational-level

Each instance is observed some number of times.

FALL

(3x) “it’s falling off”
“she fell down”
“don’t fall!”
“is London Bridge falling down?”

Lidz & Gagliardi 2015
Learning process: Computational-level

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

(3x) “it’s falling off”

“she fell down”

“don’t fall!”

“is London Bridge falling down?”

Lidz & Gagliardi 2015
Learning process: Computational-level

The class is the main thing the learner is trying to figure out for each verb. The learner doesn’t know how many classes there are beforehand, or which verbs belong to which.

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

(3x) “it’s falling off”
“she fell down”
“don’t fall!”
“is London Bridge falling down?”

Lidz & Gagliardi 2015
Learning process: Computational-level

However, the learner does begin with a bias for fewer classes, rather than more classes. This can be adjusted automatically during the learning process.

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

(3x) “it’s falling off”
“she fell down”
“don’t fall!”
“is London Bridge falling down?”

Lidz & Gagliardi 2015
Learning process: Computational-level

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

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

(3x) “it’s falling off”
“she fell down”
“don’t fall!”
“is London Bridge falling down?”

Lidz & Gagliardi 2015
Learning process: Computational-level

These characteristics can include binary choices, such as whether the subject is animate or not. Each class has a probability of preferring each option.

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

(3x) “it’s falling off”

“she fell down”

“don’t fall!”

“is London Bridge falling down?”

Lidz & Gagliardi 2015
Learning process: Computational-level

Binary properties include:

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

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

<table>
<thead>
<tr>
<th>FALL</th>
<th>unaccusatives</th>
</tr>
</thead>
</table>

(3x) “it's falling off”

“she fell down”
“don’t fall!”
“is London Bridge falling down?”

Lidz & Gagliardi 2015
The learner doesn’t know these probabilities beforehand, and begins with no bias towards either. This can be adjusted automatically during the learning process.

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

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

Lidz & Gagliardi 2015
Learning process: Computational-level

These characteristics also include multinomial choices, such as which syntactic frame (of however many there are) a verb appears in. Each class has a probability of preferring each option.

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

These characteristics also include multinomial choices, such as which syntactic frame (of however many there are) a verb appears in. Each class has a probability of preferring each option.

Each verb belongs to some class which determines its linguistic behavior.
Learning process: Computational-level

Multinomial properties include:

- which syntactic frame is used (if -exp-mapping)
- where the Agent-like/Highest role appears
- where the Patient-like/next-Highest role appears
- where the Goal-like/third-highest role appears

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

FALL
unaccusatives

(3x) “it’s falling off”
“she fell down”
“don’t fall!”
“is London Bridge falling down?”

Lidz & Gagliardi 2015
Learning process: Computational-level

The learner doesn’t know these probabilities beforehand, and begins with no bias towards any of them. This can be adjusted automatically during the learning process. Each verb belongs to some class which determines its linguistic behavior.

Lidz & Gagliardi 2015
Learning process: Computational-level

All the characteristics for each class can be inferred during the learning process.

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

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

(3x) “it’s falling off”

“she fell down”

“don’t fall!”

“is London Bridge falling down?”

Lidz & Gagliardi 2015
Summary: 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, and what the characteristics are of each class. The best answer will be the one that maximizes the probability of the observed data.

$$p_{c_j} = P(c_j|c_{-j}, \gamma_c, F_{-j}, \lambda) = P_{\text{cat}_j} * P_{\text{binary}_{c_j}} * P_{\text{multinomial}_{c_j}}$$

+ Gibbs sampling (method guaranteed to find optimal answer, given sufficient time to search the hypothesis space)
Learning process: Computational-level

Goal: Determine if the information provided (syntactic, conceptual, and semantic-syntactic cues) is sufficient to identify useful verb classes this way.

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

-anim

(3x) “it’s falling off”

“she fell down”

“don’t fall!”

“is London Bridge falling down?”

Lidz & Gagliardi 2015

Pearl & Sprouse in progress
Target state: Useful verb classes

Adult knowledge is the eventual target state for acquisition, and there are a variety of verb distinctions that have different syntactic and/or thematic role implications. Do some of these distinctions fall out directly by using the syntactic, conceptual, and semantic-syntactic cues we’re using?
Target state: Useful verb classes

Adult knowledge is the eventual target state for acquisition, and there are a variety of verb distinctions that have different syntactic and/or thematic role implications. Do some of these distinctions fall out directly by using the syntactic, conceptual, and semantic-syntactic cues we’re using?

Given the input data we have from the Brown-Eve+Valian corpus (which is directed at children age 2;8 and younger), we should probably focus on distinctions children seem to have made by age three.
Target state: Useful verb classes

Cues to transitives (allowing a single object) seem to be recognized as early as two years old in English: Naigles 1990, Naigles & Kako 1993, Yuan & Fisher 2009.

Transitive, single object  “Jack ___ it.”

+= bite, eat, forget, kick, understand, …
-= cough, laugh, sleep, sneeze, …

Lidz & Gagliardi 2015
Target state: Useful verb classes

Verbs that can be used *transitively* (aren’t purely intransitive) can be *passivized*, though children in English seem to only be able to recognize verbs in passives around age three: Gordon & Chafetz 1990, O’Brien et al. 2006, Crain et al., 2009, Nguyen et al. 2016.

Transitive, single object      “Jack ___ it.”

Passivizable                “It was ___-en.” Patient-like ___-en.

+= bite, eat, forget, kick, understand, ...
-= cough, laugh, sleep, sneeze, ...

Lidz & Gagliardi 2015
Target state: Useful verb classes

Verbs allowing the intransitive use (no object) are recognized as early as 28 months: Scott & Fisher 2009.

Transitive, single object  “Jack ___ it.”

Passivizable  “It was ___-en.”

Intransitive  “Jack ___.”

+= chirp, eat, jump, understand, ...
-= buy, give, thank, want ...

Lidz & Gagliardi 2015
Target state: Useful verb classes


**Transitive, single object**  
“Jack ___ it.”

**Passivizable**  
“It was ___-en.” *Patient-like*

**Intransitive**  
“Jack ___ .”

**Transitive, double object**  
“Jack ___ Lily the thing.”

+= allow, bring, pour, send, ...
-= bite, eat, laugh, sleep, understand...

Lidz & Gagliardi 2015
TARGET STATE: USEFUL VERB CLASSES

Children seem to begin forming a class of verbs used as unaccusatives by age two: Déprez & Pierce 1993, Snyder & Stromswold 1997, Bunger & Lidz 2004.

Transitive, single object  “Jack ___ it.”
Passivizable  “It was ___-en.”
Intransitive  “Jack ___ .”
Transitive, double object  “Jack ___ Lily the thing.”

+= bounce, break, freeze, melt,...
-= call, find, help, see,...

Lidz & Gagliardi 2015

Pearl & Sprouse in progress
### Target state: Useful verb classes

Children seem to begin forming a class of verbs used as **unergatives** by age two: Bunger & Lidz 2008.

<table>
<thead>
<tr>
<th>Verb Class</th>
<th>Example</th>
<th>Patient-like</th>
<th>Agent-like</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transitive, single object</td>
<td>“Jack ___ it.”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passivizable</td>
<td>“It was ___-en.”</td>
<td>Patient-like</td>
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<tr>
<td>Intransitive</td>
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<tr>
<td>Transitive, double object</td>
<td>“Jack ___ Lily the thing.”</td>
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<td></td>
</tr>
</tbody>
</table>

+= cry, dance, listen, play,...
-= bounce, follow, push, shake,...
Target state: Useful verb classes

Children seem to begin forming a class of verbs that take *that*-complements by age three: Kidd, Lieven, & Tomasello 2006.

<table>
<thead>
<tr>
<th>Verb Class</th>
<th>Example Sentence</th>
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</thead>
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<td>“Jack ___.”</td>
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<tr>
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</tr>
<tr>
<td>Unaccusative</td>
<td>“Jack ___.”</td>
</tr>
<tr>
<td>Unergative</td>
<td>“Jack ___.”</td>
</tr>
</tbody>
</table>

*Patient-like*

+= care, decide, know, learn...
-= bounce, follow, push, shake,...

Lidz & Gagliardi 2015
Target state: Evaluating the results

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

Remember: The class is the main thing the learner is trying to figure out for each verb. The learner doesn’t know how many classes there are beforehand, or which verbs belong to which.
Each verb belongs to some class which determines its linguistic behavior.

**Question:** How homogeneous are the verb classes each learner infers?

That is, when we look at the verbs grouped together into an inferred class, are they often the same kind of verb? It’s useful to group together verbs of the same kind.
Target state: Evaluating the results

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

Question: How homogeneous are the verb classes each learner infers?

That is, when we look at the verbs grouped together into an inferred class, are they often the same kind of verb? It’s useful to group together verbs of the same kind.

Implementation: Random Index

Intuition: Get credit for putting things together that belong together and keeping things apart that don’t belong together.
Target state: Evaluating the results

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Implementation:
Random Index

For each pair of verbs in the inferred classes:

\[
\begin{align*}
\text{verb}_i & \quad \text{verb}_j \\
\end{align*}
\]

**Inferred Class**

<table>
<thead>
<tr>
<th>True Class</th>
<th>Same class</th>
<th>Different class</th>
</tr>
</thead>
<tbody>
<tr>
<td>True</td>
<td>True Positive</td>
<td>False Negative</td>
</tr>
<tr>
<td>Different class</td>
<td>False Positive</td>
<td>True Negative</td>
</tr>
</tbody>
</table>

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

\[
0.0 \leq RI \leq 1.0
\]
Target state: Evaluating the results

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

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Implementation:
Random Index

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

True

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

FALL unaccusatives

\[ 0.0 \leq RI \leq 1.0 \]
Question: How **homogeneous** are the verb classes each learner infers?

That is, when we look at the verbs grouped together into an inferred class, are they often the same kind of verb? It’s **useful** to group together verbs of the same kind.

**Implementation:**
Random Index

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

But how do we know we’re doing better than chance?
Target state: Evaluating the results

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

Question: How **homogeneous** are the verb classes each learner infers?

That is, when we look at the verbs grouped together into an inferred class, are they often the same kind of verb? It’s **useful** to group together verbs of the same kind.

Implementation:

Adjusted Random Index

\[-1.0 \leq \text{ARI} \leq 1.0\]

Compared against the expected value of the Random Index:

- **1.0** = perfect classification
- **>0** = better than chance
- **0** = chance performance
- **<0** = worse than chance
- **-1.0** = perfectly awful performance
Target state: Evaluating the results

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

Question: How homogeneous are the verb classes each learner infers?

That is, when we look at the verbs grouped together into an inferred class, are they often the same kind of verb? It’s useful to group together verbs of the same kind.

Implementation:
Adjusted Random Index

\[-1.0 \leq ARI \leq 1.0\]

Compared against the expected value of the Random Index:

- Useful
  - 1.0 = perfect classification
  - >0 = better than chance
- Not useful
  - 0 = chance performance
  - <0 = worse than chance
  - -1.0 = perfectly awful performance
Target state: Evaluating the results

Distinctions made by two to three years of age, based on behavioral data.

PEARL & SPROUSE in progress
Target state: Evaluating the results

Distinctions made by two to three years of age, based on behavioral data.

**ARI**

<table>
<thead>
<tr>
<th>ARI</th>
<th>UTAH</th>
<th>rUTAH</th>
<th>UTAH</th>
<th>rUTAH</th>
</tr>
</thead>
<tbody>
<tr>
<td>+exp-mapping</td>
<td>-exp-mapping</td>
<td>+exp-mapping</td>
<td>-exp-mapping</td>
<td>+exp-mapping</td>
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<tr>
<td>-tense/aspect</td>
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<td></td>
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**Transitive-double obj**

- 93 verbs
- AoA = 3

**Intransitives**

- 183 verbs
- AoA = 2

**Transitive-single obj/Passivizable**

- 204 verbs
- AoA = 2-3

*Pearl & Sprouse in progress*
Target state: Evaluating the results

Distinctions made by two to three years of age, based on behavioral data.

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**Intransitives**
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Pearl & Sprouse in progress
Target state: Evaluating the results

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Transitive-

double obj

93 verbs
AoA = 3

Intransitives

183 verbs
AoA = 2

Transitive-
single obj/
Passivizable

204 verbs
AoA = 2-3

Learning which verbs allow a single object (and so are passivizable) is easy no matter which assumptions you use.

But learning which verbs allow no objects or two objects is hard, no matter which assumptions you use.
Target state: Evaluating the results

Distinctions made by two to three years of age, based on behavioral data.

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</table>

**that-comp**
55 verbs
AoA = 3

**Unergative**
105 verbs
AoA = 2

**Unaccusative**
82 verbs
AoA = 2
**Target state: Evaluating the results**

Distinctions made by two to three years of age, based on behavioral data.

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*that-comp*
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*Unaccusative*
82 verbs
AoA = 2

*Pearl & Sprouse in progress*
Target state: Evaluating the results

Distinctions made by two to three years of age, based on behavioral data.

Now we see some differences:

While distinguishing unaccusatives is hard no matter what, distinguishing unergatives is fine if the rUTAH intermediate representation is used with surface tense/aspect morphology in the syntactic frames.
**Target state: Evaluating the results**

Distinctions made by two to three years of age, based on behavioral data.

<table>
<thead>
<tr>
<th>ARI</th>
<th>+tense/aspect</th>
<th>-tense/aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTAH</td>
<td>+exp-mapping</td>
<td>-exp-mapping</td>
</tr>
<tr>
<td>rUTAH</td>
<td>+exp-mapping</td>
<td>-exp-mapping</td>
</tr>
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</tr>
</tbody>
</table>

**that-comp**
- 55 verbs
- AoA = 3

**Unergative**
- 105 verbs
- AoA = 2

**Unaccusative**
- 82 verbs
- AoA = 2

Now we see some differences:

However, only using the UTAH intermediate representation with an expectation of mapping between that representation and syntactic positions as well as ignoring surface tense/aspect morphology will allow a learner to distinguish *that*-complement verbs from these data.
Target state: Evaluating the results

Distinctions made by two to three years of age, based on behavioral data.

Big picture:

Three of these eight strategies seem to have a leg up on the rest when it comes to making the distinctions children should from these data.

Implication: These combinations of learning assumptions may be more on the right track than the others.

- rUTAH, +exp-mapping, +tense/aspect
- rUTAH, -exp-mapping, +tense/aspect
- UTAH, +exp-mapping, -tense/aspect

---

Pearl & Sprouse in progress
Learning strategy options

Syntax: She melted the ice with a blow dryer.

Subject: She
Object: the ice
Indirect Object: with a blow dryer

-tense/aspect info
+exp-mapping: movement is salient because mapping to syntax is fixed
Choice 2

Choice 3
+tense/aspect info
-exp-mapping: syntax mapping distributions are tracked

Mapping to Syntax

Intermediate representations

Thematic roles map to one of three categories.

Thematic roles are ordered with respect to each other.

Thematic roles

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

UTAH

Choice 1

rUTAH

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

Two good variants

UG knowledge

Pearl & Sprouse in progress
Thematic roles are ordered with respect to each other.

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

Another good variant

Thematic roles map to one of three categories.

Intermediate representations

- tense/aspect info
- exp-mapping:
  movement is salient because mapping to syntax is fixed

- tense/aspect info
- exp-mapping:
syntax mapping distributions are tracked

Mapping to Syntax

UG knowledge

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

Syntax

She melted the ice with a blow dryer.

Subject Object Indirect Object

Choice 1

Choice 2

Choice 3

Learning strategy options

UTAH

rUTAH

UTAH knowledge

Pearl & Sprouse in progress
Target state: Evaluating the results

But wait! Maybe children haven’t figured out every verb in these classes by age three...

<table>
<thead>
<tr>
<th>Category</th>
<th>Verbs</th>
<th>AoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>that-comp</td>
<td>55</td>
<td>3</td>
</tr>
<tr>
<td>Unergative</td>
<td>105</td>
<td>2</td>
</tr>
<tr>
<td>Unaccusative</td>
<td>82</td>
<td>2</td>
</tr>
<tr>
<td>Transitive-double obj</td>
<td>93</td>
<td>3</td>
</tr>
<tr>
<td>Intransitives</td>
<td>183</td>
<td>2</td>
</tr>
<tr>
<td>Transitive-single obj/</td>
<td>204</td>
<td>2-3</td>
</tr>
</tbody>
</table>
Target state: Evaluating the results

Perhaps we should focus on the specific ones that have been behaviorally attested in children by age three...

But wait! Maybe children haven’t figured out every verb in these classes by age three...

that-comp
7 verbs
AoA = 3

Unergative
105 verbs
AoA = 2

Unaccusative
5 verbs
AoA = 2

Transitive-
double obj
13 verbs
AoA = 3

Intransitives
183 verbs
AoA = 2

Transitive-
single obj/
Passivizable
24 verbs
AoA = 2-3

Lidz & Gagliardi 2015
Target state: Evaluating the results

Matching the specific distinctions attested in behavioral studies (experimental & spontaneous speech).

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Unaccusative
5 verbs

Transitive-2obj
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Passivizable
24 verbs

Pearl & Sprouse in progress
Target state: Evaluating the results

Matching the specific distinctions attested in behavioral studies (experimental & spontaneous speech).

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*Pearl & Sprouse in progress*
**Target state: Evaluating the results**

Matching the specific distinctions attested in behavioral studies (experimental & spontaneous speech).

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that-comp
- 7 verbs

Unaccusative
- 5 verbs

Transitive-2obj
- 13 verbs

Passivizable
- 24 verbs

Things don’t look so hard anymore (except for passivizable verbs for one strategy variant). That’s probably the only one we would rule out.

Pearl & Sprouse in progress
Seven out of eight good variants

Learning strategy options

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

-tense/aspect info
+exp-mapping: movement is salient because mapping to syntax is fixed
Choice 2

+exp-mapping: syntax mapping distributions are tracked
Choice 3

-tense/aspect info

Mapping to Syntax

UTAH Choice 1 rUTAH

Intermediate representations

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

Thematic roles map to one of three categories.

Thematic roles are ordered with respect to each other.

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

Pearl & Sprouse in progress
Learning strategy options

How do we winnow this down?
Learning strategy options

How do we winnow this down?

Maybe we need more behavioral data about which specific verb distinctions children make at this age. This could then distinguish between these strategies.

Lidz & Gagliardi 2015
Maybe we need more *behavioral data* about which specific verb distinctions children make at this age. This could then distinguish between these strategies.

Example:
Verbs that are *ditransitive* and *passivizable* like *feed* and *give*
Seven out of eight good variants

Learning strategy options

How do we winnow this down?

Maybe we need more behavioral data about which specific verb distinctions children make at this age. This could then distinguish between these strategies.

Example:
Verbs that are ditransitive and passivizable like feed and give

Do three-year-olds treat them the same?

If yes, compatible with these:
- tense/aspect, rUTAH, +exp-mapping
- tense/aspect, rUTAH, -exp-mapping
- tense/aspect, UTAH, +exp-mapping
- tense/aspect, UTAH, -exp-mapping

If no, compatible with these:
- tense/aspect, UTAH, +exp-mapping
- tense/aspect, UTAH, -exp-mapping

NP V-ing NP

- exp-mapping: movement is salient because mapping to syntax is fixed
- exp-mapping: syntax mapping distributions are tracked

NP V NP

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

+exp-mapping: movement is salient because mapping to syntax is fixed
-exp-mapping: syntax mapping distributions are tracked

Lidz & Gagliardi 2015
Learning strategy options

How do we winnow this down?

Near future:

Test these learners on a larger data set to combat potential data sparseness issues. (In progress: annotating the Brown-Adam corpus, which has about 20,000 more utterances.)

This also allows a larger age range of child-directed speech, extending up through age four. We can then investigate performance on predicate distinctions children make at later ages.
Learning strategy options

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Teaser: Even on these data directed at children under three, one strategy consistently does better at capturing the distinctions children will make at older ages. (psych-subject experiencer verbs, psych-object experiencer verbs, raising-object verbs, raising-subject verbs, control-subject verbs, non-finite to complement verbs)

This is the same one that did better on that-complementizer verbs.

UTAH, +exp-mapping, -tense/aspect

Pearl & Sprouse in progress
What next?

Further future:

Alternative theories: Are there other options for linking thematic role information to syntactic structure that we can explore in this framework? What about linking conceptual information, if we’re not so sure thematic roles are there?

thematic-roles (likely derived from lower-level conceptual info) = Agent, Experiencer, Patient, Theme, Goal, Source, Instrument...
What next?

Further future:

More sophisticated syntactic cues: What kind of structure is necessary for children to know in order to capture some of the more sophisticated distinctions they make at later ages? (It’s likely a simple syntactic skeleton won’t be enough...)

She melted the ice → NP V\textsubscript{past} NP
The ice melted → NP V\textsubscript{past}
The ice was melted → NP V\textsubscript{past\_participle}
The ice was melting → NP V\textsubscript{progressive\_participle}

Pearl & Sprouse in progress
What next?

Further future:

More realistic assumptions about children:

- What if children only have some thematic roles available initially (and some syntactic structure), which they later build on? Do these theories still work/not work?

- What happens when we embed these theories in a learning model that learns incrementally (or at least in stages) and has cognitive constraints? For example, children might have one set of assumptions at age two, but a different set at age three based on the knowledge they’ve acquired.

*Lidz & Gagliardi 2015*
Big picture:
Understanding how children make syntactic generalizations

Precisely defining the components of a learning problem is necessary for making progress on how children solve that learning problem, which requires insights from many different empirical methods. This approach allows us to connect theories of linguistic representation and theories of language acquisition.

Given a specific initial state, a learner must use the data intake to reach the target state by the end of the learning period.

Lidz & Gagliardi 2015
Biggest picture:
Computational acquisition modeling for building integrated theories of acquisition

This technique is a useful tool — so let’s use it to inform our theories of syntactic representation and acquisition!
Thank you!

This work was supported in part by NSF grant BCS-1347028.

Special thanks to Abbie Thornton, Alandi Bates, Emily Yang, and BreAnna Silva for CHILDES Treebank corpus annotation.
Brown-Eve+Valian+Adam4yrs
**Acquisitional intake: Input data**

*Brown-Eve+Valian+Adam4yrs*

Data come from the Brown-Eve corpus (Brown 1973), the Valian corpus (Valian 1991), and the Brown-Adam corpus (Brown 1973) directed at age four, with syntactic & thematic annotations provided by the CHILDES Treebank (Pearl & Sprouse 2013).

This corpus (Brown-Eve+Valian+Adam4yrs) contains speech directed at 23 children between the ages of 18 and 58 months.

There are ~45,000 utterances total, comprised of ~224,000 word tokens. Of the 603 verb lexical items that appear, 253 occur 5 or more times.

---

![Diagram](https://example.com/diagram.png)

*Lidz & Gagliardi 2015*
Acquisitional intake: Input data
Brown-Eve+Valian+Adam4yrs

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There are ~45,000 utterances total, comprised of ~224,000 word tokens. Of the 603 verb lexical items that appear, 253 occur 5 or more times.

Focus on learning the predicate categories for these for now. Intuition: Frequent enough to be useful to distributionally learn from.
Target state: Useful verb classes

Adult knowledge is the eventual target state for acquisition, and there are a variety of verb distinctions that have different syntactic and/or thematic role implications. Do some of these distinctions fall out directly by using the syntactic, conceptual, and semantic-syntactic cues we’re using?

Given the input data we have from the Brown-Eve-Valian+Adam corpus (which is directed at children age 4;10 and younger), we can include distinctions children seem to have made by age five when we learn from those data.
Target state: Useful verb classes

Children seem to figure out **object-experiencer psych verbs** before **subject-experiencer psych verbs** in English, though they seem to sort them both out by age 4 or 5 (Hartshorne, Pogue, & Snedeker 2015).

Psych, object experiencer  "It ___ Jack."

Causer   Experiencer

+= bother, confuse, scare, worry...
-= fall, go, kick, stare...

Lidz & Gagliardi 2015
Target state: Useful verb classes

Children seem to figure out object-experiencer psych verbs before subject-experiencer psych verbs in English, though they seem to sort them both out by age 4 or 5 (Hartshorne, Pogue, & Snedeker 2015).

Psych, object experiencer  “It ___ Jack.”
  Causer  Experiencer

Psych, subject experiencer  “Jack ___ it.”
  Experiencer SubjectMatter

+= like, love, miss, want...
-= fall, go, kick, stare...

Lidz & Gagliardi 2015
Target state: Useful verb classes

By 4 to 5 years old, English children can use animacy information when distinguishing between control-object and raising-object verbs (Kirby 2009, 2010, 2011).

Psych, object experiencer  "It ___ Jack."
 Causer  Experiencer

Psych, subject experiencer  "Jack ___ it."
 Experiencer  SubjectMatter

Control-object  "Jack ___ her to win."
 Agent-like  Goal-like

+= ask, tell, teach, thank...
-= fall, go, kick, stare...
Target state: Useful verb classes

By 4 to 5 years old, English children can use animacy information when distinguishing between control-object and raising-object verbs (Kirby 2009, 2010, 2011).

Psych, object experiencer  “It ___ Jack.”  
Causer  Experiencer

Psych, subject experiencer  “Jack ___ it.”  
Experiencer SubjectMatter

Control-object  “Jack ___ her to win.”  
Agent-like Goal-like

Raising-object (ECM)  “Jack ___ her to win.”  
Agent-like

+= knew, mean, need, take...
-= fall, go, kick, stare...

Lidz & Gagliardi 2015
Target state: Useful verb classes

By 4 to 5 years old, English children have figured out that inanimate subjects can distinguish between raising-subject and control-subject verbs (Becker 2006, 2007, 2009, 2014). In particular, raising-subject verbs allow inanimate subjects. So, they’ve likely figured out these classes.

Psych, object experiencer  “It ___ Jack.”
Causer  Experiencer

Psych, subject experiencer  “Jack ___ it.”
Experiencer  SubjectMatter

Control-object  “Jack ___ her to win.”
Agent-like  Goal-like

Raising-object (ECM)  “Jack ___ her to win.”
Agent-like

+= begin, happen, seem, use...
-= fall, go, kick, stare...

Lidz & Gagliardi 2015
Target state: Useful verb classes

By 4 to 5 years old, English children have figured out that inanimate subjects can distinguish between raising-subject and control-subject verbs (Becker 2006, 2007, 2009, 2014). In particular, raising-subject verbs allow inanimate subjects. So, they’ve likely figured out these classes.

Psych, object experiencer  “It ___ Jack.”
                      Causer  Experiencer

Psych, subject experiencer  “Jack ___ it.”
                          Experiencer SubjectMatter

Control-object  “Jack ___ her to win.”
                    Agent-like
                      Goal-like

Raising-object (ECM)  “Jack ___ her to win.”
                      Agent-like

+= decide, like, try, want...
-= fall, go, kick, stare...

Lidz & Gagliardi 2015
**Target state: Useful verb classes**

By 5 years old, English children use *whether/if*-complement taking verbs in their spontaneous speech (Diessel & Tomasello 2001), which may indicate they’ve formed a class of these verbs.

Psych, object experiencer  
“*It ___ Jack.*”

Control-object  
“*Jack ___ her to win.*”

Raising-object (ECM)  
“*Jack ___ her to win.*”

Psych, subject experiencer  
“*Jack ___ it.*”

Raising-subject  
“*Jack ___ to win.*”

Control-subject  
“*Jack ___ to win.*”

Psych, subject experiencer  
“*Jack ___ it.*”

Control-subject  
“*Jack ___ to win.*”

Raising-subject  
“*Jack ___ to win.*”

=+ decide, forget, know, wonder...

=– fall, go, kick, stare...

---

Lidz & Gagliardi 2015
Thematic roles & how to use them

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

The (relativized) Uniformity of Theta Assignment Hypothesis


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

- **control**
  
  She tried to melt the ice.
  
  *It tried that she melted the ice.*

- **raising**
  
  The penguin seemed to climb the hill.
  
  It seemed that the penguin climbed the hill.
Thematic roles & how to use them

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Agent-like = grammatical subject

Agent
Causer
Experiencer
Possessor

("internal cause" = Rappaport-Hovav 1995)
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Agent-like = grammatical subject

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

("internal cause" = Rappaport-Hovav 1995)

She fears spiders. Experiencer
Spiders frighten her. Experiencer

The penguin seemed to climb the hill. It seemed that the penguin climbed the hill.

She tried to melt the ice. It tried that she melted the ice.

Agent
Causer
Experiencer
Possessor

She fears spiders. Experiencer
Spiders frighten her. Experiencer

The penguin seemed to climb the hill. It seemed that the penguin climbed the hill.

She fears spiders. Experiencer
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control

She tried to melt the ice.

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

*Patient
Theme
Experiencer
Subject Matter

(“external cause”)

---

She **tried to melt the ice.**

*It **tried that she melted the ice.**

The penguin **seemed to climb the hill.**

It **seemed that the penguin climbed the hill.**

---

* control

She **tried to melt the ice.**

*It **tried that she melted the ice.**

The penguin **seemed to climb the hill.**

It **seemed that the penguin climbed the hill.**

---

Pearl & Sprouse in progress
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Agent-like = grammatical subject
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Patent
Theme
Experiencer (*Baker: only when not subject)
Subject Matter

(“external cause”)

**She fears spiders.**
Experiencer

**Spiders frighten her.**
Experiencer

**She tried to melt the ice.**

*It tried that she melted the ice.*

**The penguin seemed to climb the hill.**

*It seemed that the penguin climbed the hill.*

*Pearl & Sprouse in progress*
Thematic roles & how to use them

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

The (relativized) Uniformity of Theta Assignment Hypothesis


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

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Source</th>
<th>Goal</th>
<th>Benefactor</th>
<th>Instrument</th>
</tr>
</thead>
</table>

She tried to melt the ice with a blow dryer.

*It tried that she melted the ice with a blow dryer.

The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.
Thematic roles & how to use them

Syntax

She melted the ice with a blow dryer.

Subject Object Indirect Object

Mapping to Syntax

The Uniformity of Theta Assignment Hypothesis:

Intermediate representations

Thematic roles map to one of three categories.

(likely derived from lower level conceptual info) = Agent, Experiencer, Patient, Theme, Goal, Source, Instrument...
Thematic roles & how to use them

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

The (relativized) Uniformity of Theta Assignment Hypothesis

rUTAH: Larson 1988, Larson 1990

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

She tried to melt the ice with a blow dryer.

\[
\begin{array}{ccc}
\text{doer} & \text{done-to} & \text{done-with} \\
\text{doer} & \text{melt} & \text{ice} \\
\end{array}
\]

*It tried that she melted the ice with a blow dryer.

The penguin seemed to climb the hill.

\[
\begin{array}{ccc}
\text{doer} & \text{done-to} & \\
\text{doer} & \text{climb} & \text{hill} \\
\end{array}
\]

It seemed that the penguin climbed the hill.

Pearl & Sprouse in progress
Thematic roles & how to use them

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

The (relativized) Uniformity of Theta Assignment Hypothesis

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

Basic intuition:

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

She tried to melt the ice with a blow dryer.

*It tried that she melted the ice with a blow dryer.

The penguin seemed to climb the hill.

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Basic intuition:

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

An example implementation:

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

She tried to melt the ice with a blow dryer.

*It tried that she melted the ice with a blow dryer.

The penguin seemed to climb the hill.

It seemed that the penguin climbed the hill.
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rUTAH: Larson 1988, Larson 1990

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

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

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

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

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

The (relativized) Uniformity of Theta Assignment Hypothesis

rUTAH: Larson 1988, Larson 1990

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

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

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

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

She fears spiders.
Experiencer Subject Matter
Experiencer Subject Matter
Subject Object

Spiders frighten her.
Causer Experiencer
Causer Experiencer
Subject Object

Pearl & Sprouse in progress
Near-ish future:

Other ways to evaluate the output of the modeled learners.

(1) **Qualitative analysis**: Which verbs of each class is a learner consistently getting right? Are these more important/more useful in some respect? What do the errors look like, and do they look like the kind of thing children do? (Behavioral data on specific verbs gets at this somewhat already.)

(2) **Utility of inferred classes**: Can we identify a specific acquisition task that depends on verb classes, and see if the inferred classes are useful for that task (Phillips & Pearl 2015, Bar-Sever & Pearl 2016)? This can tell us if they’re good classes, even if they don’t match adult verb classes.
Learning strategy option refinement: The bigger picture

The Linking Problem: Pearl & Sprouse in progress

Refining ideas about what implementations of prior knowledge are consistently useful for acquisition (Ambridge et al. 2014, Pearl 2014):

*Not: UTAH & -exp-mapping if using surface tense/aspect information*

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Lidz & Gagliardi 2015
The Linking Problem: Pearl & Sprouse in progress

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Lidz & Gagliardi 2015
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Refining ideas about what needs to be true about the **acquisitional intake** for this implementation to be useful: may be useful to abstract away from surface tense/aspect information if UTAH & -exp-mapping

Larger point: Connection between theories of **linguistic representation** and theories of language acquisition

Lidz & Gagliardi 2015