How to know what’s necessary: Using computational modeling to specify Universal Grammar

Lisa Pearl
University of California, Irvine

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McGill University

Motivating Universal Grammar

The argument from acquisition: one explicit motivation that highlights the natural link between linguistic representation and language acquisition.


Motivating the contents of UG

Proposals have traditionally come from characterizing a specific acquisition problem for a particular linguistic phenomenon, and describing the (UG) solution to that specific characterization.
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Structure-dependent rules
(Chomsky 1980, Anderson & Lightfoot 2000; Fodor & Crowther 2002; Berwick et al. 2011; Anderson 2013)

Pirates who can dance can often fight well.
Can pirates who can dance __ often fight well?

Constraints on long-distance dependencies

Where did Jack think Lily bought the necklace from __?
*Where did Jack think the necklace from __ was too expensive?

Motivating the contents of UG

English anaphoric one representation
(Baker 1978, Pearl & Mis 2011, 2016)

Look – a red bottle! Do you see another one?

UG 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.

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)
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 (Alkus & Fodor 2005, Yang 2004, Pearl 2011, Dillon et al. 2013, Pearl & Sprouse 2013, Pearl et al. 2014, Pearl & Mis 2016, among many others).

We’ve also seen the development of more sophisticated acquisition frameworks that highlight the precise role of UG (Lidz & Gagliardi 2015).

Example: UG determines what data from the perceived input are relevant (acquisitional intake).

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

Are they necessarily both domain-specific and innate?

Note: We may use “innate” as a placeholder until we can determine if it’s impossible to derive the relevant component (Pearl 2014, Pearl & Mis 2016).
UG proposal refinement: Recent successful forays

Syntactic islands (constraints on wh-dependencies):
Pearl & Sprouse 2013a, 2013b, 2015

English anaphoric one:
Pearl & Mis 2011, 2016

Recurring themes:
(1) Broadening the set of relevant data in the acquisitional intake
(2) Evaluating output by how useful it is
(3) Not necessarily needing the prior knowledge we thought we did

Today’s Plan

Overview of how to characterize learning problems precisely enough

New modeling foray: The Linking Problem
(how and where event participants appear syntactically)
Characterizing learning problems

Initial state:
- initial knowledge state
  ex: grammatical 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

Data intake:
- encoding + acquisition intake = data perceived as relevant for learning
  (Fodor 1998, Lidz & Gagliardi 2015)
  ex: all wh-utterances for learning about wh-dependencies
  ex: all pronoun data when learning about anaphoric one
  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:
- 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

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: *Where did Jack think the necklace from ___ was too expensive?*
ex: one is category N' when it is not NP
ex: done-to
  The ice melted.
The penguin climbed.
done-to

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.

Informing UG (+ acquisition theory)

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

This identifies useful learning strategy components, which we can then examine to see where they might come from.

Today’s Plan

Overview of how to characterize learning problems precisely enough

New modeling foray: The Linking Problem
(how and where event participants appear syntactically)
The Linking Problem

- Why? About how conceptual information maps to syntactic structure, and tends to incorporate theoretical machinery to capture the empirical facts (e.g., [U]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.

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.

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 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.

The penguin climbed the hill.
The penguin climbed.
The hill was climbed.

She melted the ice.
The ice melted.
The ice was melted.

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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 young children have been shown to use this cue in experimental studies (Becker 2009, Becker 2014, Becker 2015).

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

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.

She seemed to melt the ice.
It seemed that she melted the ice.
Thematic roles & how to use them

Syntax
She melted the ice with a blow dryer.

Object
Subject
Indirect Object

How do we get from here to there?

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

Thematic roles & how to use them

Syntax
She melted the ice with a blow dryer.

Object
Subject
Indirect Object

Mapping to Syntax

The Uniformity of Theta Assignment Hypothesis:

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

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

Syntax
She melted the ice with a blow dryer.

Object
Subject
Indirect Object

Mapping to Syntax

The (relativized) Uniformity of Theta Assignment Hypothesis:
Larson 1988, Larson 1990

Intermediate representations
 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...

Thematic roles & how to use them

Syntax
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

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

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.

- exp-mapping

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

- exp-mapping: syntax mapping distributions are tracked

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.

Intermediate representations

Thematic roles are ordered with respect to each other.

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

Thematic roles map to one of three categories.

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

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

Thematic roles & how to use them

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 are ordered with respect to each other.

Thematic roles map to one of three categories.

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

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Potential learning strategies

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

Additional learner information: Syntactic options (+/- tense & aspect)

She melted the ice —> NP Vpast NP
The ice was melted —> NP Vparticiple
The ice was melting —> NP Vprogressive_participle

She melted the ice —> NP V NP
The ice melted —> NP V
The ice was melted —> NP V

All learners are sensitive to the animacy of NPs.

Learning strategy options

Syntax
She melted the ice with a blow dryer.

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

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

Choice 1
Choice 2
Choice 3

Mapping to Syntax

Intermediate representations

Thematic-roles

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

Initial state

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

Choice 1
Choice 2
Choice 3

All learners are sensitive to the animacy of NPs.
Acquisitional intake options
(From Brown-Eve corpus from CHILDES Treebank)

"it's falling off"

Possible perceptual intake

Acquisitional intake

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

FALL

animate subject: 1
Acquisitional intake options
(from Brown-Eve corpus from CHILDES Treebank)

Acquisitional intake

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

- animate subject: 1
- Patient-like as subject: 1
- NP V present participle PRT

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

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

- animate subject: 1
- Patient-like as subject: 1
- NP V PRT

Input Possible perceptual intake

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

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

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

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

- animate subject: 1
- movement: 1
- NP V present participle PRT

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

- animate subject: 1
- movement: 0
- NP V present participle PRT

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

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

Animate subject: 1
Highest role as subject: 1
NP V PRT

Comparison: 8 learners

Acquisitional intake

Possible perceptual intake

Animate subject: 1
NP V present_participle PRT

Comparison: 8 learners

Acquisitional intake

Possible perceptual intake

Animate subject: 1
NP V PRT

Comparison: 8 learners

Acquisitional intake

Possible perceptual intake

Animate subject: 1
NP V present_participle PRT

Comparison: 8 learners

Acquisitional intake

Possible perceptual intake

Animate subject: 1
NP V PRT

Comparison: 8 learners
Acquisitional intake options
(from Brown-Eve corpus from CHILDES Treebank)

Comparison: 8 learners
Possible
perceptual intake

Animate subject: 1
NP V present participle PRT
NP V PRT

Highest as subject
Patient like as subject

+ movement: 1
Patient like

Comparison: 8 learners

Acquisitional intake: Input data

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

This corpus contains speech directed at one child between the ages of 18 and 27 months.

There are 14,246 utterances total, comprised of 63,267 word tokens. Of the 289 verb lexical items that appear, 102 occur 10 or more times.

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?

Even more

Basic question: Is it possible for the child to use the acquisitional intake to achieve the target knowledge/behavior? Is 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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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 the goal of learnability approaches (often posed at the computational-level of analysis [Marr 1982]): Frank et al. 2009, Goldwater et al. 2009, Pearl et al. 2010, Pearl 2011, Li et al. 2012, Oritts et al. 2011, Orita et al. 2013

Even more

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 usable by children in real life.)

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?

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?

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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

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?

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

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So, that's why we've going to start with a computational-level model of the acquisition process.
Each verb is observed in a certain number of instances in the input.

\[
\text{"it's falling off"} \\
\text{"she fell down"} \\
\text{"don't fall!"} \\
\text{"is London Bridge falling down?"}
\]

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

\[
\text{unaccusatives}
\]

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.

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.
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.

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

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

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

Multinomial properties include:

- Agent-like/Highest role appears
- Patient-like/next-Highest role appears
- Goal-like/third-highest role appears

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.

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.

\[ p_0 = P(\theta, \phi | y) \] Gibbs sampling (method guaranteed to find optimal answer when sufficient time to search the hypothesis space)

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

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 conceptual and syntactic cues we're using?

Transitive, single object  
“Jack ___ it.”

Intransitive, single object  
“___”, “___”, “___”, “___”, “___”

Repetition, single object  
“bite, eat, forget, kick, understand, …”

Repetition, single object  
“cough, laugh, sleep, sneeze, …”
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 conceptual and syntactic cues we’re using?

**Transitive, single object**
- "Jack ___ it."
- "Jack ___ Lily the thing."

**Transitive, double object**
- "Jack ___ Lily the thing."

**Psych, subject experiencer**
- "Jack ___ it."
- "It ___ Jack."

**Psych, object experiencer**
- "It ___ Jack."
- "Jack ___ it."

**Unaccusative**
- "It ___ Jack."
- "Jack ___ it."

---

**Passivizable**
- "It ___ was ___-en."

---

**Agent-like**
- "Jack ___ it."

---

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

---

"love, miss
- "bite, eat, laugh, sleep, understand..."
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 conceptual and syntactic cues we’re using?

Transitive, single object  
Transitive, double object  
Psych, subject experience  
Psych, object experience  
Unergative  
Unaccusative  
Passivizable

**Psych, subject experiencer**

**Psych, object experiencer**

**Unaccusative**

**Unaccusative**

**Passivizable**

---

++ allow, like, love, understand...  
++ fall, go, happen, stare...

---

**Target state: Useful verb classes**

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Transitive, double object  
Psych, subject experience  
Psych, object experience  
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Passivizable

**Psycho, subject experiencer**

**Psych, object experiencer**

**Unaccusative**

**Unaccusative**

**Passivizable**

---

++ ask, forget, try, want...  
++ fall, go, happen, stare...

---

**Target state: Useful verb classes**

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---

++ ask, name, pick, tell...  
++ fall, go, happen, stare...

---

**Target state: Useful verb classes**

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---

++ come, happen, seem, use...  
++ fall, go, kick, stare...

---

**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 conceptual and syntactic cues we’re using?

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Passivizable

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**Passivizable**

---

++ care, hope, insist, wish...  
++ fall, go, kick, stare...

---

**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 conceptual and syntactic cues we’re using?

Transitive, single object  
Transitive, double object  
Psych, subject experience  
Psych, object experience  
Unergative  
Unaccusative  
Passivizable

**Psych, subject experiencer**

**Psych, object experiencer**

**Unaccusative**

**Unaccusative**

**Passivizable**

---

++ check, forget, tell, wonder...  
++ fall, go, kick, stare...

---
Target state: Children’s developing representations

Also, it may well be that some of these distinctions are more salient to children than others.

Transitive, single object

Passivizable

Unaccusative

Psych, object experiencer

Psych, subject experiencer

Ergative

Raising-to-object (ECM)

Raising-subject

Control-subject

Control-object

Unaccusative

Lidz & Gagliardi 2015

Pearl & Sprouse in progress

Goal-like

Agent-like

Raising-to-object (ECM)

Passivizable

Lidz & Gagliardi 2015

Unaccusative

Agent-like

Patient-like

Experiencer SubjectMatter

Psych, subject experiencer

Psych, object experiencer

Agent-like

Patient-like

Raising-to-object (ECM)

Control-subject

Control-object

Experiencer Causer

Patient-like

Raising-subject

Psych, subject experiencer

Psych, object experiencer

Agent-like

Patient-like

Raising-to-object (ECM)

Control-subject

Control-object

Experiencer Causer

Patient-like

Raising-subject

Psych, subject experiencer

Psych, object experiencer

Agent-like

Patient-like

Raising-to-object (ECM)

Control-subject

Control-object

Experiencer Causer

Patient-like

Raising-subject

Psych, subject experiencer

Psych, object experiencer

Agent-like

Patient-like

Raising-to-object (ECM)

Control-subject

Control-object

Experiencer Causer

Patient-like
Target state: Children’s developing representations

Give these developmental data, we may be particularly interested in these useful verb classes.

- Transitive, single object: "Jack ___ it.
- Transitive, double object: "Jack ___ Lily the thing.
- Psych, subject experiencer: "Jack ___ it.
- Psych, object experiencer: "It ___ Jack.
- Unergative: "Jack ___.
- Unaccusative: "Jack ___.
- Passivizable: "It was ___-en.

Raising-to-object (ECM): "Jack ___ been to win."
Control-object: "Jack ___ been to win."
Control-subject: "Jack ___ to win."
Raising-subject: "Jack ___ to win."

Example: Inferred class 6
- HAPPEN
- COME
- FALL
- WAKE
- CHIRP

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: Pairwise precision
- \# of pairs in inferred class that are the same kind
- Total \# of pairs in inferred class

Comparison class: unaccusatives
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.

Example: inferred class 6

Comparison class: unaccusatives

Not very homogeneous for unaccusatives

Total # of pairs in inferred class = 10

Comparison class: unaccusatives

Comparison class: transitive, double object
Target state: Evaluating the results

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: Pairwise precision
If of pairs in inferred class that are the same kind
\[
\text{total # of pairs in inferred class} = 10
\]
full-happens, full-comes, fall-wakes, fall-chirps, happen-comes, happen-wakes, happen-chirps, come-wakes, come-chirps, wake-chirps

Comparison class: transitive, double object

Example: inferred class 6

FALL
HAPPEN
COME
WAKE
CHIRP

Implementation: Pairwise precision
If of pairs in inferred class that are the same kind
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Comparison class: transitive, double object

When we randomly assign the verbs to classes of the same size as the inferred classes. This is how much utility there is in deciding to make this many classes and make them of these sizes.

When we assign all the verbs to a single class. This shows how much separation there is, using this adult distinction. If very few verbs are separated out (i.e. only 2 verbs are each object experience in our dataset out of 102), this baseline is near 1 for that distinction. Upshot: dividing into classes for that distinction isn’t terribly useful to begin with.

If the InferredClass pairwise precision is significantly higher than the random baseline, we know the classes inferred by this learner are more useful than just dividing verbs randomly into this many classes.

Upshot: There’s something useful about these particular inferred classes.
Each verb belongs to some class which determines its linguistic behavior.

It's also informative to know how the inferred classes compare to the One Class baseline — if their precision is better, it's useful to divide the verbs into classes this way. Otherwise, it isn't.

Similarly, it's also informative to know if the inferred classes precision isn't better (or is in fact lower) than the random baseline, we know the classes inferred by this learner aren't more useful than just dividing verbs randomly into this many classes.

For now, let's focus on the classes we know children distinguish.

Transitive (with a single object) seem to be recognized as early as 28 months old in English: Yuan & Fisher 2009, Scott & Fisher 2009.

Transitive, single object: "Jack ___ it," Agent-like, Patient-like


Transitive-Subj:

Target state: Evaluating the results

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### Target state: Evaluating the results

**Transitives** (with a single object) seem to be recognized as early as 28 months old in English: Yuan & Fisher 2009, Scott & Fisher 2009.

| Transitive object | Patient-like | 80 of 102: | drop, help, want ...
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**Agent-like**

| Unaccusative | 15 of 102: | break, drop, fall ...
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Target state: Evaluating the results


Unaccusative "Jack ___" 15 of 102: break, drop, fall, ...
Inferred
PairPrec
Baseline
One Class
Baseline

Inferred
Random baseline
One Class
Baseline

Inferred
Random baseline
One Class
Baseline

Inferred
Random baseline
One Class
Baseline

Unaccusatives seem to be distinguished early from unergatives: Hebrew (Friedmann 2007), Italian (Snyder et al. 1995), English (Pierce 1989, Pierce 1992, Deprez 1993, Deprez 1994): children under 2 years old. By 3 to 4 years old, English children have figured out that inanimate subjects can distinguish between raising-subject and control-subject verbs (Becker 2014). In particular, raising-subject verbs allow inanimate subjects. So, they’ve likely figured out these classes.

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Target state: Evaluating the results

Passives seem to be used appropriately by 4-year-olds (with the correct structural features available by 3 years old): Crain, Thornton & Murasugi, 1987; Budwig 1990; Tomaselli, Brooks, & Stern 1998, Huttonlocher et al. 2004.

Passivizable
Control-subject
Raising-subject
Unaccusatives
Unergatives
Transitives-L (N) P

PairPrec
Inferred Classes
Random baseline
One Class
Baseline

0.647 0.647 0.647 0.647 0.647 0.647 0.647 0.647

Pearl & Sprouse in progress

Target state: Evaluating the results

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Pearl & Sprouse in progress
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, subject-experiencer:* "It___Jack.*

Target state: Evaluating the results

<table>
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<tr>
<th>PairPrec</th>
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Pearl & Sprouse in progress
### Target state: Evaluating the results

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**Baseline**

- Target state: Evaluating the results

#### Learning strategy options

**Syntax**

- She melted the ice with a blow dryer.
- movement is salient because mapping to syntax is fixed

**Mapping to Syntax**

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

#### UG proposal refinement

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

Refining ideas about what implementations of Universal Grammar are consistently useful for acquisition (Ambridge et al. 2014, Pearl 2014): UTAH, expect the mapping to syntax a priori

Refining ideas about what needs to be true about the acquisitional intake for this implementation to be useful: abstract away from surface tense/aspect information

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

#### What next?

**Near future:**

- Test these learners on a larger data set to combat potential data sparseness issues. (In progress: annotating Valian corpus, which has ~25,000 utterances. Current studies with Brown-Ven corpus, which has ~14,000 utterances.)
Big picture:
Understanding how children make linguistic generalizations

Precisely defining the components of any learning problem is necessary for making progress on how children solve that learning problem, which requires insights from many different methods.

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

Computational methods
Theoretical methods
Experimental methods

Thank you!

Jon Sprouse

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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

UTAH: 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:
- door (Agent-like) > done-for/with (Goal-like) > done-to (Patient-like)

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An example implementation:
Agent = Cause > Experience > Possessor
Subject Matter = Cause > Theme > Patient
Object = Location, Goal, Benefactor, Instrument

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

Pearl & Sprouse in progress

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UG knowledge

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Thematic roles & how to use them

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

Syntax

Mapping to Syntax

Intermediate representations

UTAH

Thematic roles

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

UTAH

The (relativized) Uniformity of Theta Assignment Hypothesis: Larson 1988, Larson 1990

Agent > Experiencer > Theme = Participant
(Source, Goal, Instrument)

Target state: Evaluating the results

The different learners tend to infer different numbers of verb classes on average (results over 10 runs of each learner).

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

General tendency: When tense/aspect are ignored fewer classes are inferred. This makes intuitive sense, as there are fewer syntactic frames possible for each verb, so the syntactic distribution for different verbs can appear more similar.

Inferred Classes

Baseline

Random baseline

One Class

Baseline

<table>
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<th>Classes</th>
<th>Avg #</th>
<th>UTAH</th>
<th>13.4</th>
<th>10.8</th>
<th>10.8</th>
<th>38.5</th>
<th>40.4</th>
<th>32.6</th>
<th>43.8</th>
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<td>PairPrec inferred</td>
<td>-tense/aspect</td>
<td>10</td>
<td>UTAH</td>
<td>10.8</td>
<td>UTAH</td>
<td>38.5</td>
<td>40.4</td>
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<td>Random baseline</td>
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