Psych 245A: Computational Models of Language Learning

Introduction to Language Acquisition
& the Linguist's Point of View

Knowledge of Language

It's so natural for us to produce and comprehend language that we often don't think about what an accomplishment this is.

Or how we learned language in the first place.

Language is Special


René Descartes

"It is a very remarkable fact that there are none … without even excepting idiots, that they cannot arrange different words together, forming of them a statement by which they make known their thoughts; while on the other hand, there is no other animal, however perfect and fortunately circumstanced it may be, which can do the same."

Language is Special

"What is so special about language? Maybe nothing if you are a snail or a camphor tree. But language is paramount among the capacities that characterize humans, setting us off from even the most perfectly formed and functioning of the other beasts on earth; so, as a matter of species pride – if nothing else – we would hold up language as a marker of our humanity and thus a focus of our scientific interest." (Gleitman & Liberman 1991: xix)


About Language

Language is a complex system of knowledge that all children learn by listening to native speakers in their surrounding environment.

It includes sound structure, word structure, word meaning, sentence structure, mapping from sentence structure to meaning, unspoken rules of conversation…

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Stress pattern → gob lins

Individual sounds (in IPA) → g a b l ɪ n z

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goblin (plural) = goblin + s

gob lins

g a b l ɪ n z

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Goblins like children.

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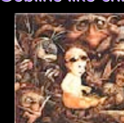
Don't goblins like children?

Goblins like children.



goblins

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gob lins

g a b l ɪ n z

Some Terminology

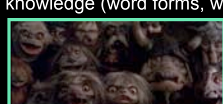
Phonology: sounds and sound system of the language

g a b l ɪ n z   gob lins

Lexicon: Words and associated knowledge (word forms, word meanings, etc.)

goblins =

(not koblins)



Morphology: system for combining units of meaning together (goblin + [plural] = goblins)

Some Terminology

Syntax: system for combining words into sentences

Goblins like children.

Pragmatics: knowledge of language use

Don't goblins like children?
(expresses prior belief that goblins do like children)
Use this question form if you have this prior belief

Kids Do Amazing Things

Much of the linguistic system is already known by age 3.

…when kids can't tie their own shoes or reliably recognize "4".

What kids are doing: extracting patterns and making generalizations from the surrounding data mostly without explicit instruction. They usually only get examples of what's allowable in the language, rather than explicit instruction about what's allowable.

"Rules" of language = grammar

Knowledge of Language & Hidden Rules

Some examples from language:

You know that…

…*strop* is a possible word of English, while *stvop* isn't.

Knowledge of Language & Hidden Rules

Some examples from language:

You know that…

…"Who did you see who did that?" is not a grammatical question in English

(Instead: "Who did you see do that?")

Knowledge of Language & Hidden Rules

Some examples from language:

You know that…

…In "She ate the peach while Sarah was reading", *she ≠ Sarah*

but *she* can be *Sarah* in all of these:

Sarah ate the peach while she was reading.
While she was reading, Sarah ate the peach.
While Sarah was reading, she ate the peach.

Knowledge of Language & Hidden Rules

Some examples from language:

You know that…

…the 's' in 'cats' sounds different from the 's' in goblins

cats: 's' = /s/

goblins: 's' = /z/

Linguistic Productivity Means We Need Rules

"The expressive variety of language use implies that a language user's brain contains unconscious grammatical principles" - Jackendoff (1994)

Example: Most sentences we have never seen or used before, but we can still understand them.

The argument for mental grammar

"In short, in order for us to be able to speak and understand novel sentences, we have to store in our heads not just the words of our language but also the patterns of sentences possible in our language. These patterns, in turn, describe not just patterns of *words* but also patterns of *patterns*. Linguists refer to these patterns as the *rules* of language stored in memory; they refer to the rules as the *mental grammar* of the language, or *grammar* for short." - Jackendoff (1994)

Possible objection to an unconscious rule set

"When I talk, the talk just comes out - I'm not consulting any rule set."

Possible objection to an unconscious rule set

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Analogy: wiggling your fingers

When you want to wiggle your fingers, you "just wiggle them".

But your finger-wiggling intention was turned into commands sent by your brain to your muscles, and you're never conscious of the process unless something interferes with it.
Nonetheless, there *is* a process, even if you're not aware of it.

Learning

Learning patterns

Not so clear that children learn grammatical patterns from their parents

(From Martin Braine)

Child: Want other one spoon, Daddy.
Father: You mean, you want the other spoon.
Child: Yes, I want other one spoon, please Daddy.
Father: Can you say "the other spoon"?
Child: Other…one…spoon.
Father: Say "other".
Child: Other.
Father: "Spoon."
Child: Spoon.
Father: "Other spoon."
Child: Other…spoon. Now give me other one spoon?

Children's Mistakes

From Edward Klima & Ursula Bellugi

Wh-questions

Stage 1
- What book name?
- Why you smiling?
- What soldier marching?

Stage 2
- What he can ride in?
- Which way they should go?
- Why kitty can't stand up?

Stage 3
- Where will you go?
- Why can't kitty see?
- Why don't you know?

Children's Mistakes

From Edward Klima & Ursula Bellugi

Use of negative elements (not, n't)

Stage 1
No the sun shining.
No a boy bed.
No sit there.

Stage 2
He no bite you.
I no want envelope.
I no taste them.

Stage 3
I didn't did it.
You didn't caught me.

Children don't just imitate what they've heard

From Edward Klima & Ursula Bellugi

Use of past tense verbs
(U-shaped curve of performance)

Stage 1
walked
played
came
went

Stage 2
walked
played
comed
goed
holded

Stage 3
walked
played
camed
wented

Stage 4
walked
played
came
went
held

Time/Age

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Time/Age

Main points

The patterns children produce during learning are often stripped-down versions of the adult pattern, but they make mistakes that cannot be attributed directly to the input.

Children don't just imitate what they've heard - they're trying to figure out the patterns of their native language. Also, they may not notice or respond to explicit correction.

Standard Theory

The Standard Theory, according to Chomsky (summarized by Seidenberg (1997))

Big Questions of Language Acquisition:

What constitutes knowledge of language?

How is this knowledge acquired?

How is this knowledge used?

Standard Theory

Knowledge of language, according to Chomsky

Knowledge of language = grammar

Grammar = complex set of rules and constraints that gives speakers intuitions that some sentences belong in the language while others do not

Standard Theory

Knowledge of language, according to Chomsky

Competence Hypothesis: Grammar is separate from "performance factors", like dysfluencies (she said…um..wrote that), errors (I bringed it), memory capacity (The boy that the dog that the cat chased bit ran home.), and statistical properties of language (frequency of transitive (Sarah ate the peach) vs. intransitive use (Sarah ate))

"I think we are forced to conclude that…probabilistic models give no particular insight into some of the basic problems of syntactic structure" - Chomsky, 1957

Standard Theory

Properties of language, according to Chomsky

Grammar is generative: it can be used to produce and comprehend an infinite number of sentences

Grammar involves abstract structures: information that speakers unconsciously used is not overtly available in the observable data

Standard Theory

Properties of language, according to Chomsky

Grammar is modular: there are separate components with different types of representations governed by different principles

Grammar is domain-specific: language exhibits properties not seen in other areas of cognition, so it cannot be the product of our general ability to think and learn

Standard Theory

Language acquisition, according to Chomsky

How does a child acquire a grammar that has those properties (generative, involving abstract structures, modular, domain-specific)?

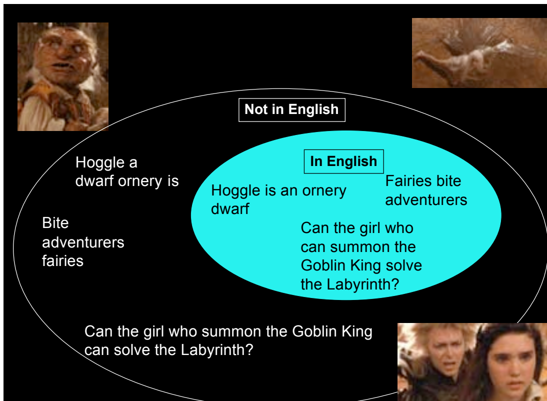
Poverty of the stimulus problem

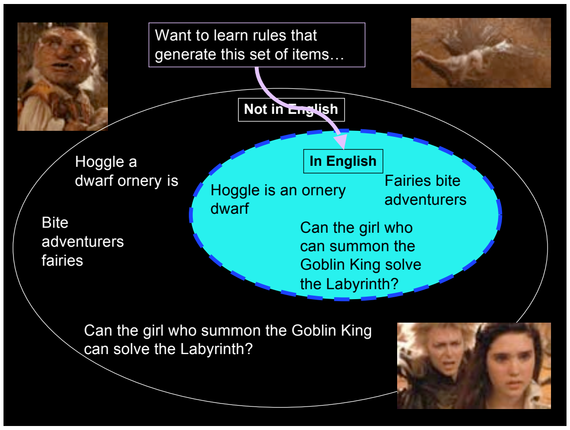
The Child's Job

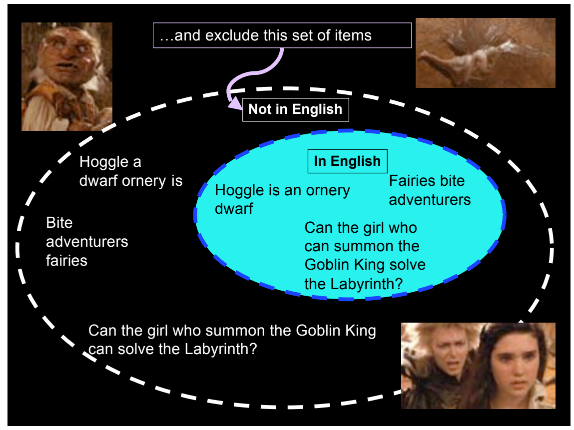
Adult knowledge: rules & patterns that generate the items that are part of the language. (mental grammar)

The child's job: figure out the rules that generate the items that belong in the language and that don't generate items that don't.

For example, the child wants rules to generate "Hoggle is definitely an ornery dwarf" but not "Hoggle an dwarf definitely ornery is".




Want to learn rules that generate this set of items…
Not in English
In English
Hoggle a dwarf ornery is
Hoggle is an ornery dwarf
Fairies bite adventurers
Bite adventurers fairies
Can the girl who can summon the Goblin King solve the Labyrinth?
Can the girl who summon the Goblin King can solve the Labyrinth?


…and exclude this set of items
Not in English
In English
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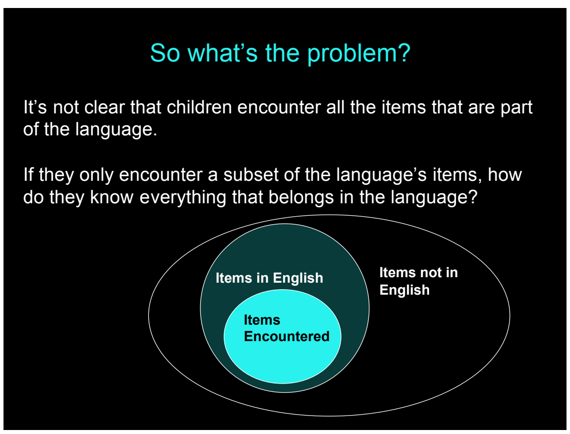
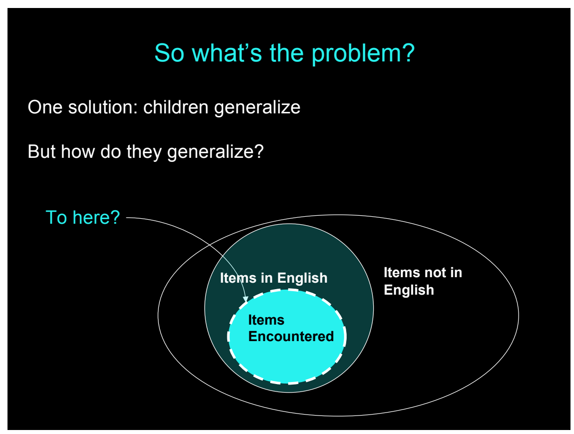
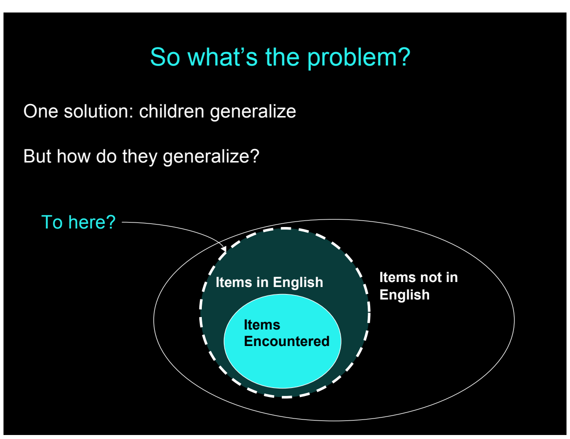

So what's the problem?
It's not clear that children encounter all the items that are part of the language.
If they only encounter a subset of the language's items, how do they know everything that belongs in the language?
Items in English
Items not in English
Items Encountered


So what's the problem?
One solution: children generalize
But how do they generalize?
To here?
Items in English
Items not in English
Items Encountered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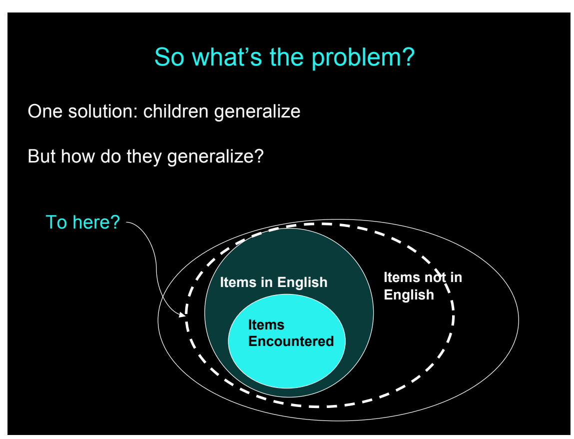
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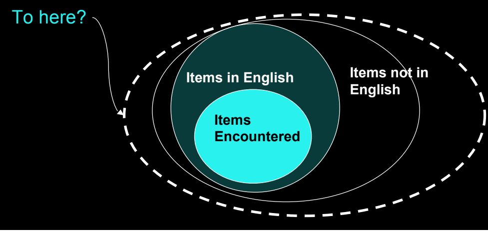
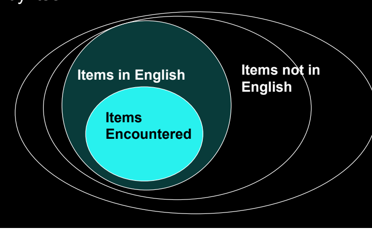
One solution: children generalize

But how do they generalize?



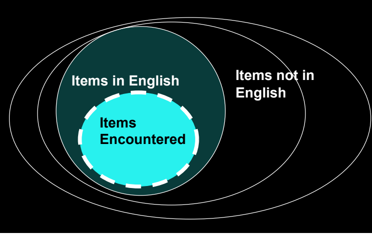
So what's the problem?

The problem is that children must make the right generalization from data that is compatible with multiple generalizations. In this sense, the data (stimulus) encountered is impoverished. It does not single out the correct generalization by itself.



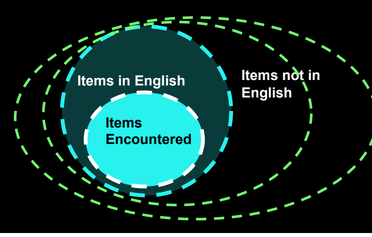
Poverty of the Stimulus: Logic

Children encounter data that is compatible with many hypotheses about the correct rules and patterns of the language.



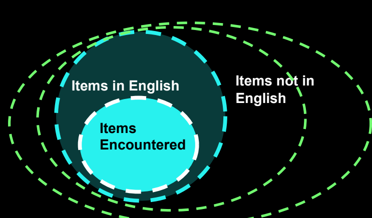
Poverty of the Stimulus: Logic

Specifically, the data encountered is compatible with both the correct hypothesis and other, incorrect hypotheses about the rules and patterns of the language.



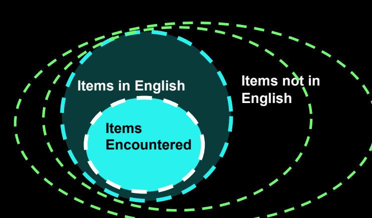
Poverty of the Stimulus: Logic

A rational learner would consider all compatible hypotheses, and perhaps make errors before choosing the correct hypothesis.



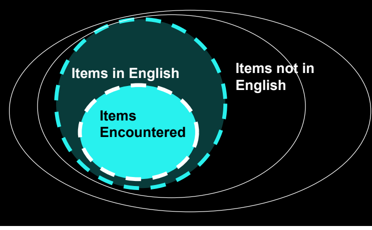
Poverty of the Stimulus: Logic

Expectation for rational learners: errors in performance. Children will behave as if they think ungrammatical items are part of the language at some point.



Argument about Innate Knowledge

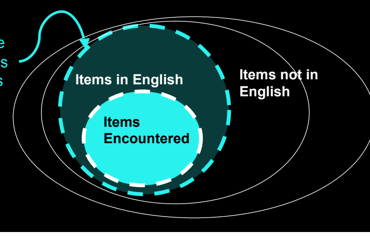
But what if children never behave as if they consider the incorrect hypotheses? That is, they never produce errors compatible with the incorrect hypotheses. They only seem to produce items that are compatible with the correct hypothesis.



Argument about Innate Knowledge

Nativist conclusion: children have some prior knowledge (possibly innate) that causes them never to consider the incorrect hypotheses. Instead, they only consider the correct hypothesis for what the rules and patterns of the language might be.

Innate knowledge restricts children's hypothesis to this



Specific Example: Yes/No Question Formation

Jareth can alter time.

↓

Can Jareth alter time?

To turn the sentence into a yes/no question, move the auxiliary verb ("can") to the front.

The child's task: figure out a rule that will form yes/no questions from their corresponding sentences.

Specific Example: Yes/No Question Formation

Jareth can alter time.
Can Jareth alter time?

Rule?

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Jareth can alter time.
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Rule: Move first auxiliary?

Specific Example: Yes/No Question Formation

Jareth can alter time.
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Rule: Move first auxiliary?

Anyone who <u>can</u> wish away their brother would be tempted to do it.
Would anyone who <u>can</u> wish away their brother be tempted to do it?

Specific Example: Yes/No Question Formation

Jareth can alter time.
Can Jareth alter time?

Rule: Move first auxiliary?

Rule?

Anyone who can wish away their brother would be tempted to do it.
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Rule: Move first auxiliary?

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Someone who can solve the labyrinth can show someone else who can't how.
Can someone who can solve the labyrinth show someone else who can't how?

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Rule???

Someone who can solve the labyrinth can show someone else who can't how.
Can someone who can solve the labyrinth show someone else who can't how?

Need a rule that is compatible with *all* of these, since they're all grammatical English questions.

Specific Example: Yes/No Question Formation

Jareth can alter time.
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Someone who can solve the labyrinth can show someone else who can't how.
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Idea: Try looking at the sentence structure, not just the linear order of the words in the sentences.

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embedded clauses = additional descriptive sentences that are not part of the main clause

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Let's look just at the main clauses in these examples

Specific Example: Yes/No Question Formation

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Let's look just at the main clauses in these examples

Specific Example: Yes/No Question Formation

Jareth can alter time.
Can Jareth alter time?

Anyone would be tempted to do it.
Would anyone be tempted to do it?

Someone can show someone else how.
Can someone show someone else how?

Rule that works for all of these examples (and all English examples): Move the auxiliary verb in the main clause to make a yes/no question.

This is a rule dependent on the structure of the sentences.

Children's Knowledge

Children seem to know this rule by the age of 3. (Crain & Nakayama 1987)

Learning problem: Children don't encounter all the examples we saw. They encounter a subset of the possible yes/no questions in English.

Most of the data they encounter (particularly before the age of 3) consists of simple yes/no questions.

Jareth can alter time.
Can Jareth alter time?

Learning Difficulties: Yes/No Questions

The problem is that these simple yes/no questions are compatible with a lot of different rules.

Jareth can alter time.
Can Jareth alter time?

Rule: Move first auxiliary?

Rule: Move last auxiliary?

Rule: Move main clause auxiliary?

Rule: Move auxiliary in even-numbered position in sentence?

Rule: Move auxiliary closest to a noun?

Learning Difficulties: Yes/No Questions

Rational learner prediction: if children considered all these hypotheses, they should make mistakes on more complex yes/no questions. Let's look at two hypotheses in detail.

Rule: Move first auxiliary?

Rule: Move main clause auxiliary?

Learning Difficulties: Yes/No Questions

The girl who can solve the labyrinth is happy.

Predictions of questions generated

Rule: Move first auxiliary?

* Can the girl who solve the labyrinth is happy?

Learning Difficulties: Yes/No Questions

The girl who can solve the labyrinth is happy.

Predictions of questions generated

Rule: Move first auxiliary?

* Can the girl who solve the labyrinth is happy?

Rule: Move main clause auxiliary?

Correct rule = grammatical question

Is the girl who can solve the labyrinth happy?

Learning Difficulties: Yes/No Questions

Crain & Nakayama (1987) showed that children as young as 3 years old don't make these mistakes. They use the right rule for this complex yes/no question.

Predictions of questions generated

Rule: Move first auxiliary?

* Can the girl who solve the labyrinth is happy?

Rule: Move main clause auxiliary?

Is the girl who can solve the labyrinth happy?

Learning Difficulties: Yes/No Questions

But the simple questions they see are compatible with both of these hypotheses (along with many others). How do children choose the right rule from all the possible rules that are compatible? That is, how do they generalize the right way from the subset of the data they encounter?

Rule: Move main clause auxiliary?

Is the girl who can solve the labyrinth happy?

Learning Difficulties: Yes/No Questions

Nativist position: Children have an innate bias to look for rules that make use of sentence structure. Specifically, they only consider rules that are structure-dependent.

Rule: Move first auxiliary?

Rule: Move last auxiliary?

Rule: Move auxiliary in even-numbered position in sentence?

Rule: Move auxiliary closest to a noun?

Rule: Move main clause auxiliary?

Is the girl who can solve the labyrinth happy?

Learning Difficulties: Yes/No Questions

It is this structure-dependent learning bias that allows children to generalize the correct way from "impoverished" data.

Poverty of the Stimulus leads to Innate Knowledge about Language: Summary of Logic

1) Suppose there is some data.
2) Suppose there is an incorrect hypothesis compatible with the data.
3) Suppose children behave as if they never entertain the incorrect hypothesis.

Conclusion: Children possess prior (innate) knowledge ruling out the incorrect hypothesis from the hypotheses they do actually consider.

Standard Theory

Language acquisition, according to Chomsky

How does a child acquire a grammar that has those properties (generative, involving abstract structures, modular, domain-specific)?

Poverty of the stimulus problem: Available data insufficient to determine all these properties of the grammar. Therefore, children must bring innate knowledge to the language learning problem that guides them to the correct instantiation of grammar.

Standard Theory

Language acquisition, according to Chomsky

Available data properties leading to this inductive problem:
- noisy (degenerate): sometimes there are incorrect examples in the input
- variable: no child's input is the same as another's, but all converge
- no reliable negative evidence: no labeled examples of what's not in the language
- no positive evidence for some generalizations: yet children still converge on them

Specificity of Innate Knowledge

"Innate capacities may take the form of biases or sensitivities toward particular types of information inherent in environmental events such as language, rather than a priori knowledge of grammar itself." - Seidenberg (1997)

Levels of Representation Marr (1982)

On Explaining (Marr 1982)

"But the important point is that if the notion of different types of understanding is taken very seriously, it allows the study of the information-processing basis of perception to be made *rigorous*. It becomes possible, by separating explanations into different levels, to make explicit statements about what is being computed and why…"

On Explaining (Marr 1982)

"But the important point is that if the notion of different types of understanding is taken very seriously, it allows the study of the information-processing basis of perception to be made *rigorous*. It becomes possible, by separating explanations into different levels, to make explicit statements about what is being computed and why…"

Our goal: Substitute "language learning" for "perception".

The three levels

Computational
What is the goal of the computation? What is the logic of the strategy by which is can be carried out?

Algorithmic
How can this computational theory be implemented? What is the representation for the input and output, and what is the algorithm for the transformation?

Implementational
How can the representation and algorithm be realized physically?

The three levels: An example with the cash register

Computational
What does this device do?
Arithmetic (ex: addition).
Addition: Mapping a pair of numbers to another number.

(3,4) ⟶ 7 (often written (3+4=7))
Properties: (3+4) = (4+3) [commutative], (3+4)+5 = 3+(4+5) [associative], (3+0) = 3 [identity element], (3+ -3) = 0 [inverse element]

True no matter how numbers are represented: this is what is being computed

The three levels: An example with the cash register

Computational
What does this device do?
Arithmetic (ex: addition).
Addition: Mapping a pair of numbers to another number.

Algorithmic
What is the input, output, and method of transformation?
Input: arabic numerals (0,1,2,3,4…)
Output: arabic numerals (0,1,2,3,4…)
Method of transformation: rules of addition, where least significant digits are added first and sums over 9 have their next digit carried over to the next column

```
  99
+  5
```

The three levels: An example with the cash register

Computational
What does this device do?
Arithmetic (ex: addition).
Addition: Mapping a pair of numbers to another number.

Algorithmic
What is the input, output, and method of transformation?
Input: arabic numerals (0,1,2,3,4…)
Output: arabic numerals (0,1,2,3,4…)
Method of transformation: rules of addition, where least significant digits are added first and sums over 9 have their next digit carried over to the next column

```
  99
+  5
  14
```

The three levels: An example with the cash register

Computational
What does this device do?
Arithmetic (ex: addition).
Addition: Mapping a pair of numbers to another number.

Algorithmic
What is the input, output, and method of transformation?
Input: arabic numerals (0,1,2,3,4…)
Output: arabic numerals (0,1,2,3,4…)
Method of transformation: rules of addition, where least significant digits are added first and sums over 9 have their next digit carried over to the next column

```
  1
  99
+  5
   4
```


The three levels: An example with the cash register

Computational
What does this device do?
Arithmetic (ex: addition).
Addition: Mapping a pair of numbers to another number.

Algorithmic
What is the input, output, and method of transformation?
Input: arabic numerals (0,1,2,3,4…)
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Method of transformation: rules of addition, where least significant digits are added first and sums over 9 have their next digit carried over to the next column


```
  1
  99
+  5
 104
```


The three levels: An example with the cash register

Computational
What does this device do?
Arithmetic (ex: addition).
Addition: Mapping a pair of numbers to another number.

Algorithmic
What is the input, output, and method of transformation?
Input: arabic numerals (0,1,2,3,4…)
Output: arabic numerals (0,1,2,3,4…)
Method of transformation: rules of addition

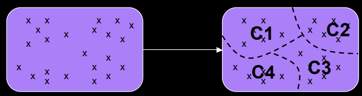
Implementational
How can the representation and algorithm be realized physically?
A series of electrical and mechanical components inside the cash register.

Mapping the Framework: Algorithmic Theory of Language Learning

Goal: Understanding the "how" of language learning

First, we need a computational-level description of the learning problem.

Computational Problem: Divide sounds into contrastive categories



Mapping the Framework: Algorithmic Theory of Language Learning

Goal: Understanding the "how" of language learning

First, we need a computational-level description of the learning problem.

Computational Problem: Divide spoken speech into words

húwzəfɹéjdəvðəbígbǽdwə́lf

↓

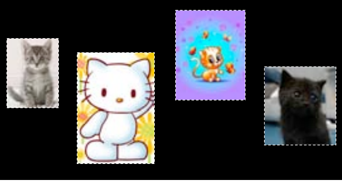
húwz əfɹéjd əv ðə bíg bǽd wə́lf
who's afraid of the big bad wolf

Mapping the Framework: Algorithmic Theory of Language Learning

Goal: Understanding the "how" of language learning

First, we need a computational-level description of the learning problem.

Computational Problem: Learn the meaning of word forms



kitty = ?

animal = ?

Mapping the Framework: Algorithmic Theory of Language Learning

Goal: Understanding the “how” of language learning

First, we need a computational-level description of the learning problem.

Computational Problem: Identify grammatical categories

“This is a DAX.” 

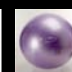
DAX = noun

Mapping the Framework: Algorithmic Theory of Language Learning

Goal: Understanding the “how” of language learning

First, we need a computational-level description of the learning problem.

Computational Problem: Identify what words refer to in sentences.

“Jack likes this red ball. Lily likes that one.”  

one = *red ball* or *ball*?

Mapping the Framework: Algorithmic Theory of Language Learning

Goal: Understanding the “how” of language learning

First, we need a computational-level description of the learning problem.

Computational Problem: Identify the rules of word order for sentences.

Jareth juggles crystals
Subject Verb Object

Kannada
Subject t_{Object} Verb Object

German
Subject Verb $t_{Subject}$ Object t_{Verb}

English
Subject Verb Object

Mapping the Framework: Algorithmic Theory of Language Learning

Goal: Understanding the “how” of language learning

Second, we need to be able to identify the algorithmic-level description:

Input = sounds, syllables, words, phrases, …

Output = sound categories, words, words with affixes, grammatical categories, sentences, …

Method = statistical learning, prior knowledge about how human languages work, …

Recap: Levels of Representation

Language acquisition can be viewed as an information-processing task where the child takes the native language input encountered and uses it to construct the adult rule system (grammar) for the language.

Main idea: The point is not just to describe what children know about their native language and when they know it, but also how they learned it.

Three levels:

- computational: what is the problem to be solved
- algorithmic: what procedure will solve the problem, transforming input to desired output form
- implementational: how is that procedure implemented/instantiated in the available medium