Adjuncts, Repetition, and Learnability

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Learning

Blah blah...

Blah blah...

Photograph by Andrew Hetherington, Scientific American
July 20 2011
http://www.scientificamerican.com/article.cfm?id=benasich-baby-brains-signal-later-language-problems

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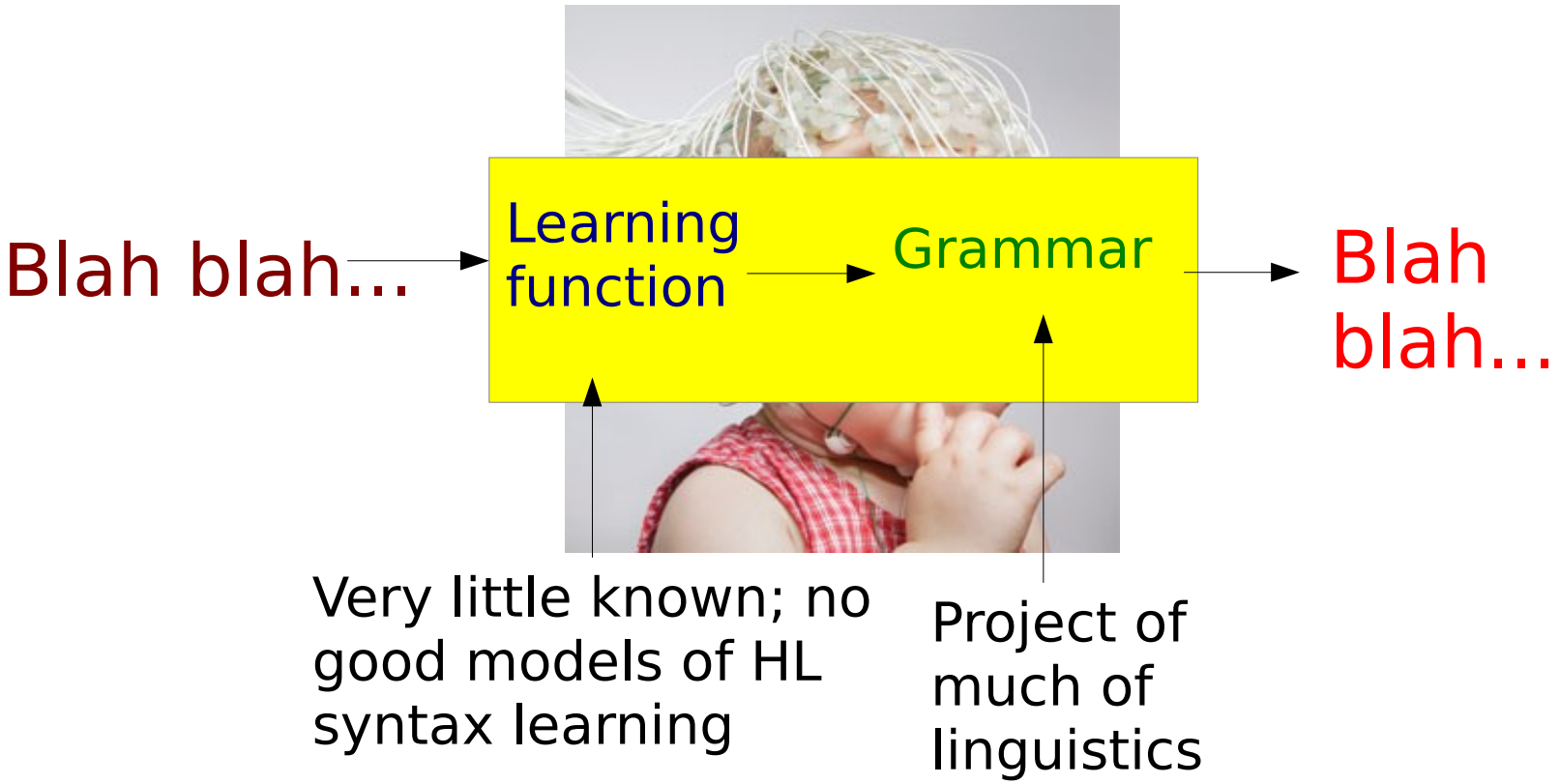
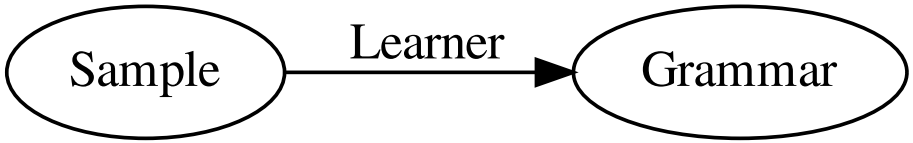
Learning


Blah blah...
Learning function
Grammar
Blah blah...
Very little known; no good models of HL syntax learning
Project of much of linguistics

Overview

How do people learn adjuncts?



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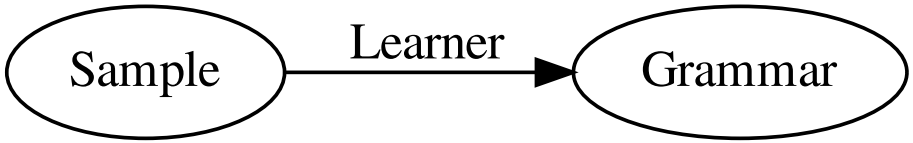

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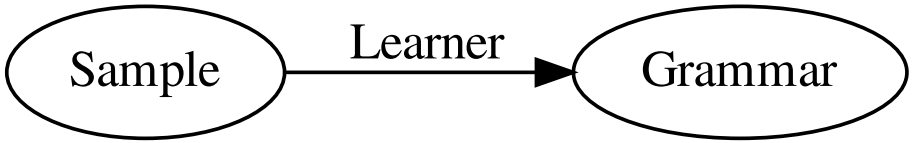

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2. **People**: How do people learn properties of adjuncts?
3. **Neural Networks**: How do neural networks learn properties of adjuncts?

Adjuncts

Generally adjectives, adverbs, prepositional phrases

(Almost) always **optional**, often **repeatable**

(1) a. My love is like a rose.
b. My love is like a red rose.
c. My love is like a red red rose.

(2) a. I'm tired!
b. I'm really tired!
c. I'm really really really really tired!

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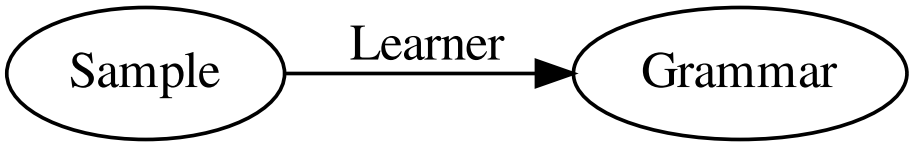
(3) He suddenly (*suddenly suddenly) smiled.

Learnability



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Learners we'll look at today

1. 0-reversible learner (Angluin, 1982)

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1. 0-reversible learner (Angluin, 1982)
2. Substitutable CFGs (Clark, 2010)
3. CFGs (with finite kernel and finite context) (Clark et al., 2010)

Learnability

A very weak claim *For some definition of "learn" and some definition of "language", humans learn language*

Learnability

Definition ((String) Language ($L \subseteq \Sigma^*$))

A set of sequences of symbols, with the symbols taken from a finite set

eg: words are built out of phonemes $\rightarrow$ language = the words
eg: sentences are built of out morphemes $\rightarrow$ language = the sentences

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A function from samples of a language to grammars

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Definition (Learn (in the limit from positive data) (Gold, 1967))

- A learner learns L if it eventually, after a finite number of samples, converges on a grammar that generates L
- A learner learns a class of languages if it distinguishes them from each other

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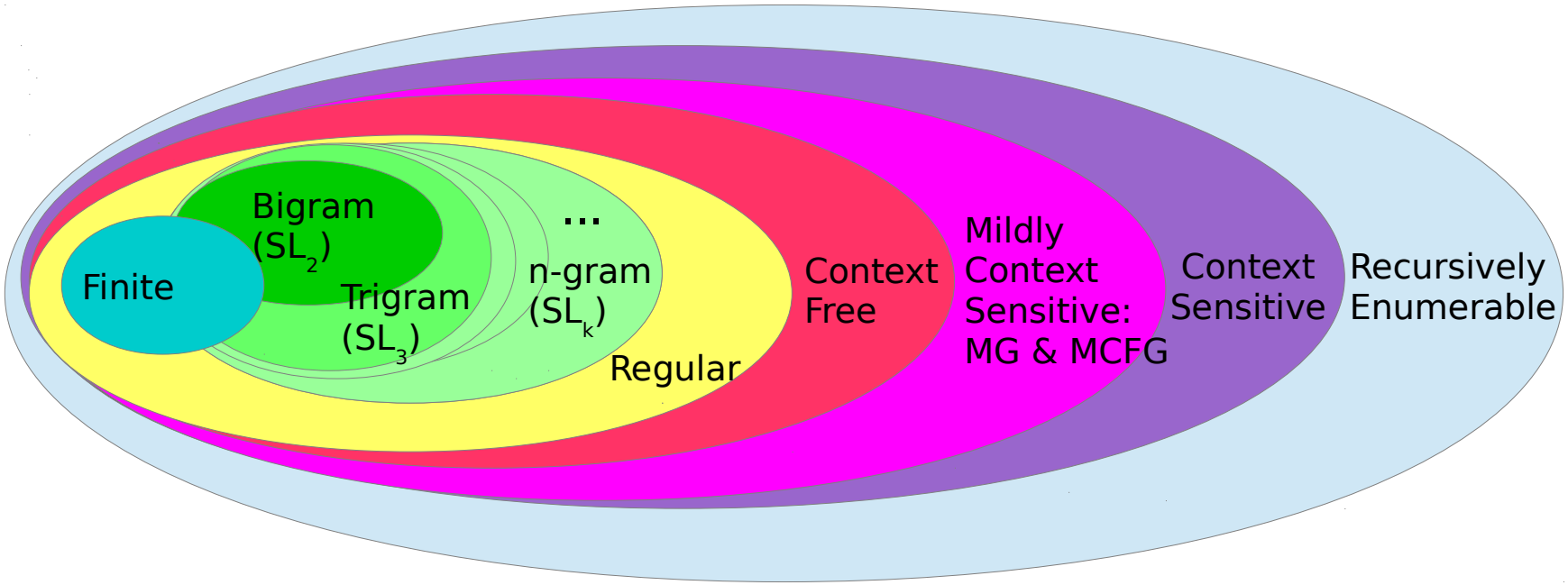
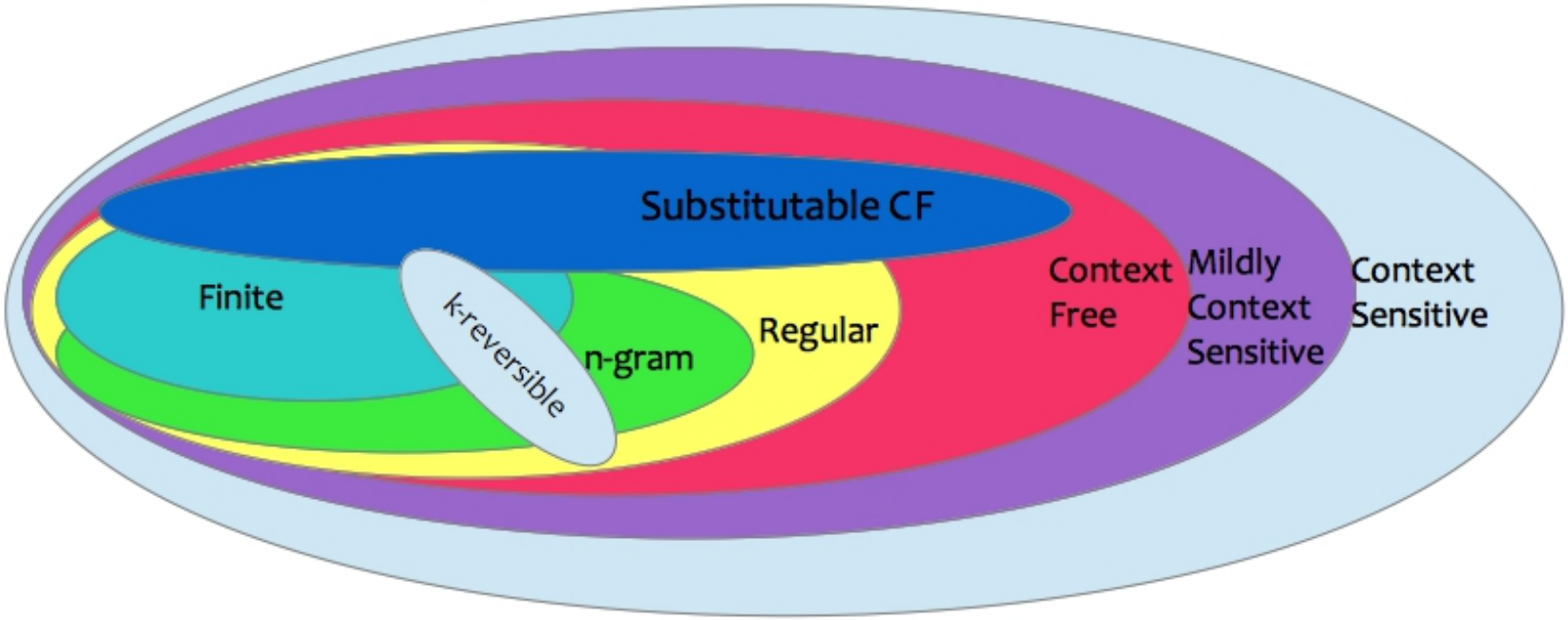
Huge (really bad?) abstraction: just samples, no meaning or context

Refined Chomsky hierarchy



Refined Chomsky hierarchy vs Learnable classes



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$\rightarrow$ We need *surface properties* of adjuncts to look at

Optionality and repetition (bad definitions)

Definition (Optional (try 1))

$x \in \Sigma^*$ is *optional* iff sentences in L can have x but don't have to

$\rightarrow$ *cat* is optional in English because *The cat slept on the mat* $\in$ English and *The dog slept on the mat* $\in$ English

Optionality and repetition (bad definitions)

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Definition (Repeatable (try 1))

$x \in \Sigma^*$ is *repeatable* iff you can say it more than once in a row

$\rightarrow$ *that* is repeatable in English because *I think that that is cool* $\in$ English

Optionality and repetition (good definitions)

Let $x, u, v \in \Sigma^*$

Definition (Optional)

x is *optional in context (u,v)* iff $uv \in L$ and $uxv \in L$

Optionality and repetition (good definitions)

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Definition (Optional)

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Definition (Repeatable)

x is *repeatable in context (u,v)* iff $ux^+v \subseteq L$

(4) Mary sniffed the (red red red) rose

We say *red* is repeatable and optional in context (Mary sniffed the, rose)

"How does this learner learn adjuncts?"

Lots of things this could mean, but I'm going to ask:

What generalisations will the learner make based on what samples?

Summary of learners

	0-rev	sub CFL	$CFL_{F,K}$
opt$\rightarrow$ rep	✓	✓	✗
rep$\rightarrow$ opt	✓	✓	✗
ac,abc,abbc$\rightarrow$ ab*c	✓	✓	✓
Learnable?	✓(Gold)	✓(Gold)	✓(MAT)
HL-like	no	somewhat	closer

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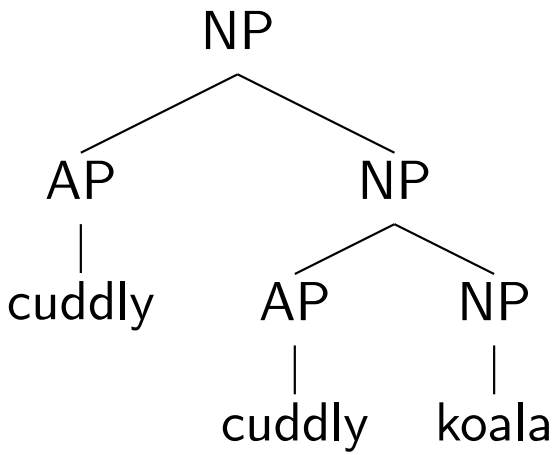
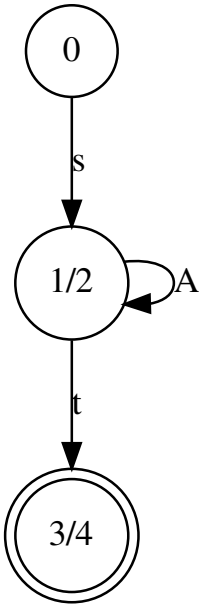


0-reversible learner (Angluin, 1982)

Definition

A FSA is 0-reversible iff it is deterministic both forward and backward

If L is 0-reversible then for all $u, v \in \Sigma^*$, if u and v share one suffix, they share all suffixes.



$L = sA^*t$

Note A is repeatable and optional in the context (s, t)

0-reversible learner

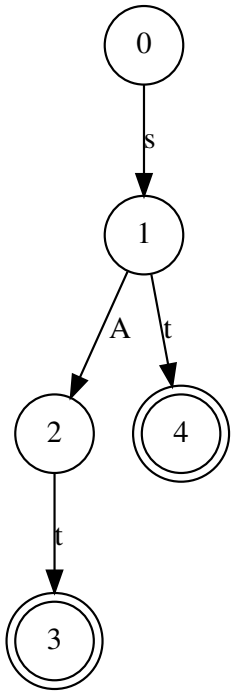
Optionality $\rightarrow$ Repetition

Sample: st, sAt

0-reversible learner

Optionality → Repetition

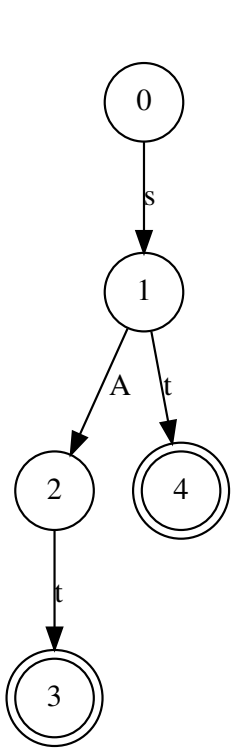
Sample: st, sAt

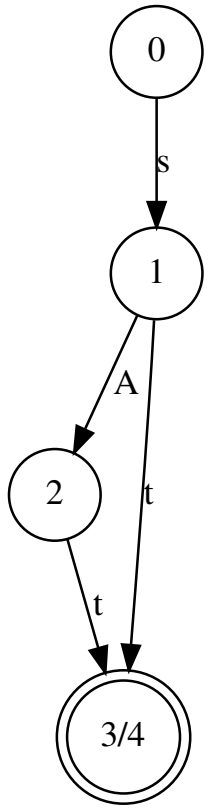


0-reversible learner

Optionality → Repetition

Sample: *st*, *sAt*





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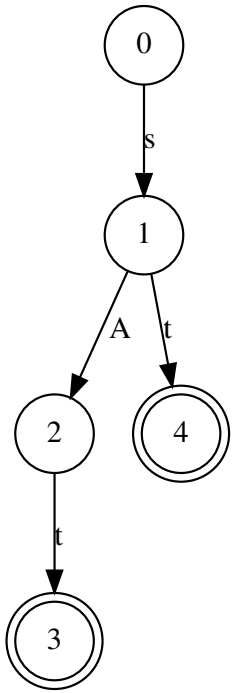

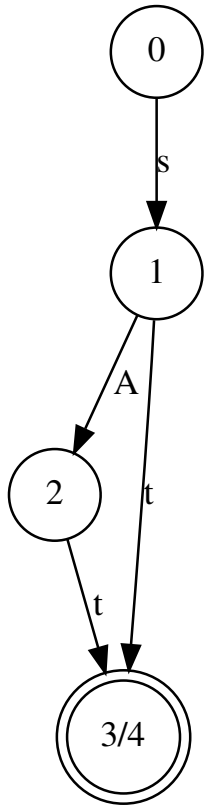

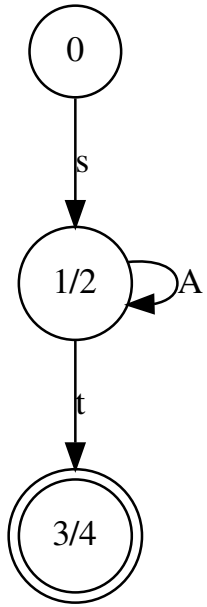

0-reversible learner

Theorem (Optionality → Repetition)

Let $u, v, x \in \Sigma^*$ and let $uv, uxv \in L$. Then $ux^*v \subseteq L$

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$uv \quad uxv$

$\quad\quad uxv \quad \rightarrow uxxv$

0-reversible learner: repetition $\rightarrow$ optionality

Theorem (repetition $\rightarrow$ optionality)

Let $ux^k v, ux^{k+1} \in L$ for some $k > 0$. Then $uv \in L$.

0-reversible learner: repetition $\rightarrow$ optionality

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uxv $uxxv$

$uxv \rightarrow uv$

0-reversible learner - summary

- Optionality $\leftrightarrow$ Repetition

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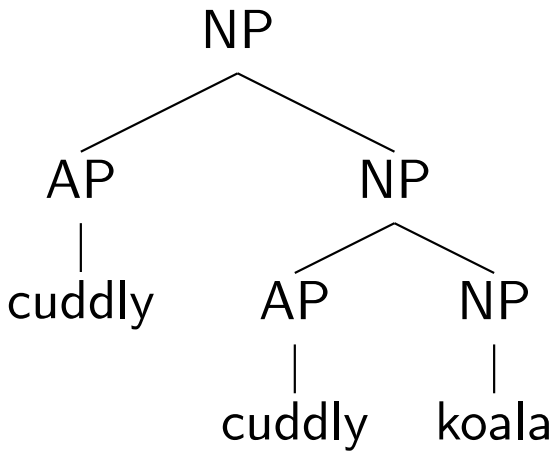

HL is not 0-reversible

(5) a. The students slept
b. You slept
c. You were kicking yourself
d. *The students were kicking yourself

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Substitutable Context Free languages (Clark, 2010)

- CF equivalent of 0-reversible
- Learnable! (No time for the learner today, sorry!)

Definition (Substitutable context free language)

L is SCF iff for all $u, v, s, t, x_1, x_2 \in \Sigma^*$, if
$ux_1v \in L$ and
$ux_2v \in L$ and
$sx_1t \in L$ then
$sx_2t \in L$
i.e if two strings share one **context**, they share all contexts

Substitutable Context Free learner

Theorem (Optionality → Repetition)

Let $u, v, x \in \Sigma^*$ *and* $uv, uxv \in L$. *Then* $ux^*v \subseteq L(G_i)$.

Substitutable Context Free learner

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Let $u, v, x \in \Sigma^*$ and $uv, uxv \in L$. Then $ux^*v \subseteq L(G_i)$.

uv $\quad$ uxv

$u\epsilon v$ $\quad$ $u\epsilon xv$

$\quad$ $\quad$ $u\epsilon xv \quad \rightarrow u\epsilon xxv$

$\quad$ $\quad$ $\quad \rightarrow uxxv$

Substitutable Context Free learner

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uxv $uxxv$

$u\epsilon xv$ $u\epsilon xxv$

$u\epsilon xv \rightarrow u\epsilon v$

$\rightarrow uv$

Substitutable CF – summary

- repetition $\leftrightarrow$ optionality
- one repetition $\rightarrow$ indefinite repetition

Human Language is not substitutable CF

Intersubstitutability is a big part of syntactic categories:

(6)
a. The kids watched a movie
b. The kids found a movie
c. ϵ All the kids in the neighourhood watched a movie
d. ϵ We watched a movie

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But the "one common context $\rightarrow$ all common contexts" idea is too strong:

(7)
a. I hear you slept
b. I hear the kids slept
c. I hear you were kicking yourself
d. *I hear the kids were kicking yourself

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$CFG_{F,K}$ Clark et al. (2010)

Context-free languages with the finite kernel and finite context properties

- Loosely, CF languages such that you can make a context-free grammar using just sets of contexts a substring can appear in.

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Context-free languages with the finite kernel and finite context properties

- Loosely, CF languages such that you can make a context-free grammar using just sets of contexts a substring can appear in.
- Similar learning algorithm to Substitutable CFG

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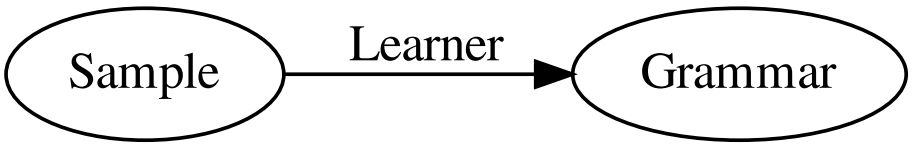

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Artificial language learning

The paradigm:

Training phase Participants are exposed to grammatical items from the target language

Testing phase Participants are tested on new items to see what they learned. Data like reaction time and grammaticality judgments are gathered to infer what the participants learned

Artificial language learning experiment: Tagalog

(8) natulog ang babae
sleep D woman
'The woman is sleeping/slept'

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(12) natulog siguro ang babae
sleep maybe D woman
'Maybe the woman is sleeping/slept'

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G1:

V (Adv) D Adj* N

G2:

V (Adv) D N Adj*

Artificial language learning experiment: Tagalog

Research Question: In learning language, do people generalise from limited to indefinite repetition?

Training stimuli V (Adv) D (Adj) (Adj) (Adj) N

Testing stimuli also ungrammatical and V (Adv) D Adj^4 (Adj) N

To answer the research question: compare responses to **ungrammatical** and **generalised** stimuli. If they like generalised stimuli more than ungrammatical, they've generalised repetition

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Testing stimuli

- 100 grammatical sentences

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- 78 ungrammatical sentences

Artificial language learning experiment: Tagalog

Testing stimuli

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  - 58 with the noun repeated instead of the adjective

Artificial language learning experiment: Tagalog

Testing stimuli

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- 78 ungrammatical sentences
  - 58 with the noun repeated instead of the adjective
  - 20 scrambled up grammatical sentences

Artificial language learning experiment 1: Tagalog

Training examples (Adj-medial grammar):

- natulog ang pusa'
- natulog siguro ang mapula kotse
- natulog siguro ang matanda matanda pusa'
- natulog ang masaya masaya masaya kotse

Artificial Language Learning experiment: Tagalog

Testing examples (Adj-medial grammar):
Generalised:

- umalis ang malaki malaki malaki malaki babae
- umalis ang malaki malaki malaki malaki malaki kotse
- umalis siguro ang mapula mapula mapula mapula babae

Repeated noun:

- *natulog ang malaki babae babae
- *umalis ang matanda kotse kotse kotse kotse

Scrambled:

- *siguro matanda matanda babe ang natulog
- *babae ang umalis

Artificial language learning experiment

Method:

- **Training:** Participants listen to randomised training stimuli over headphones

Artificial language learning experiment

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- **Training:** Participants listen to randomised training stimuli over headphones
- While they listen they see a red dot on the screen

Artificial language learning experiment

Method:

- **Training:** Participants listen to randomised training stimuli over headphones
- While they listen they see a red dot on the screen
- They respond with a keypress according to which side of the screen it's on. (distractor task)

Artificial language learning experiment

Method:

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Artificial language learning experiment

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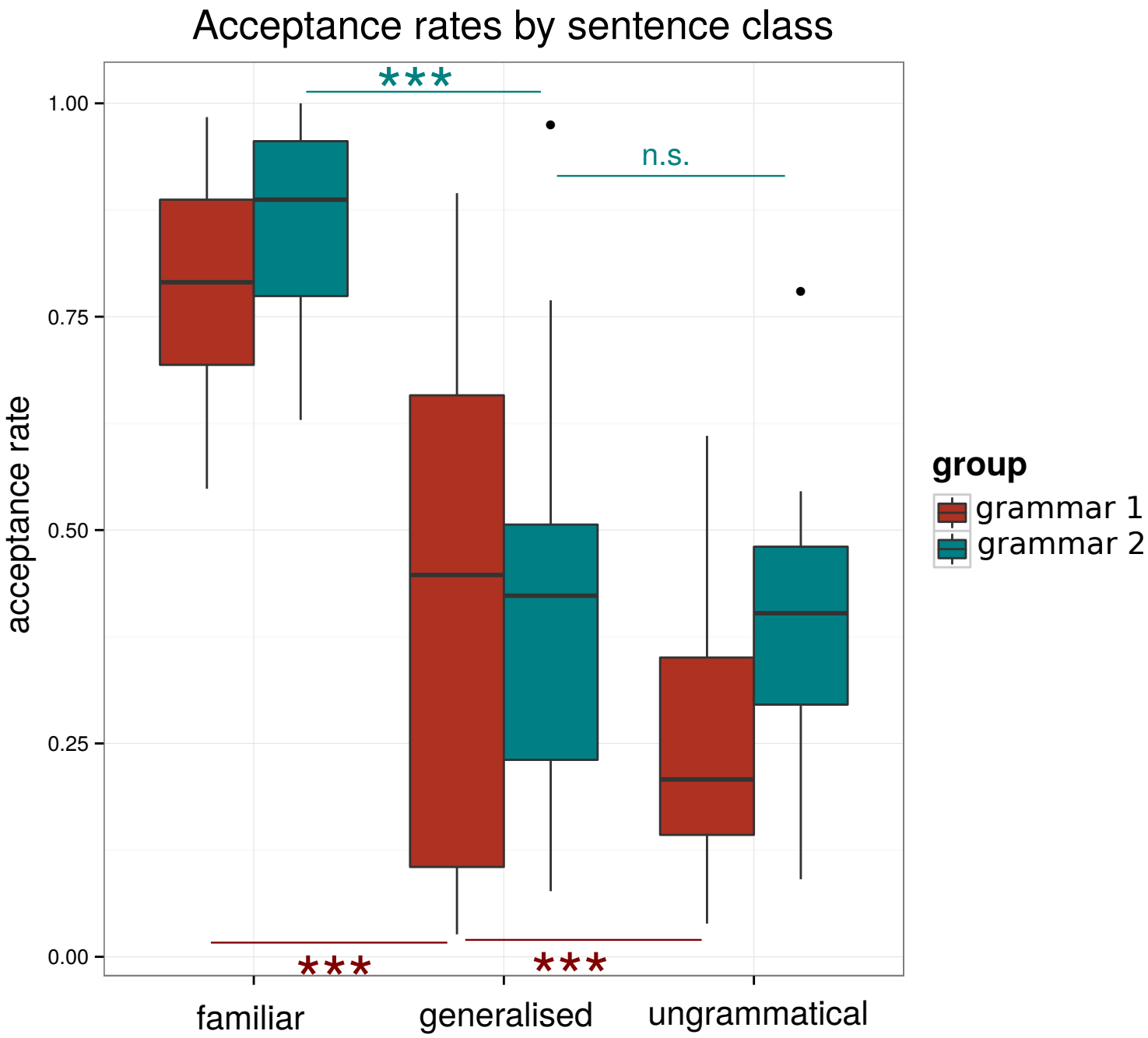
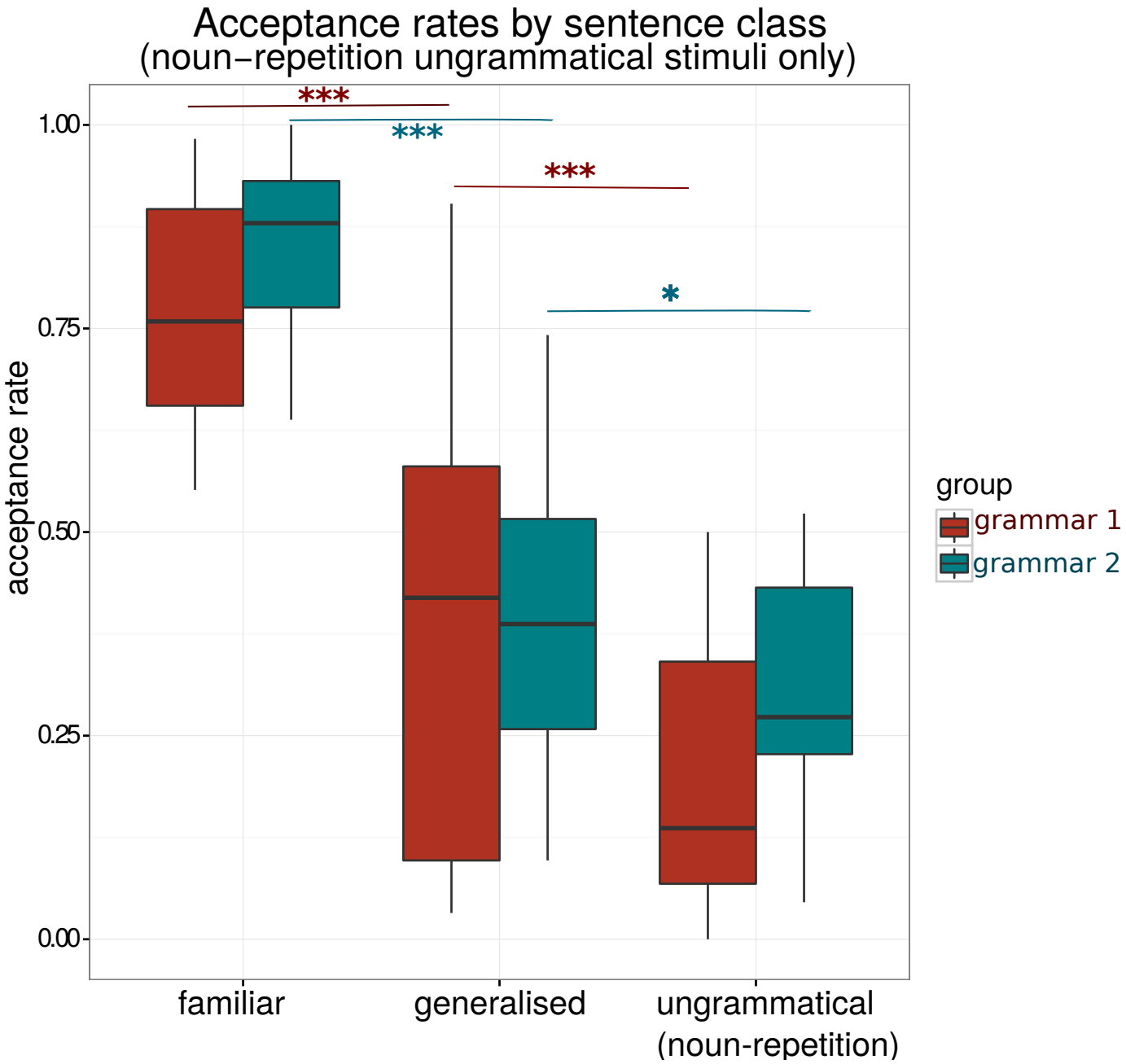

Acceptance rates by sentence class
***
n.s.
***
***
1.00
0.75
0.50
0.25
0.00
acceptance rate
familiar
generalised
ungrammatical
group
grammar 1
grammar 2

Ungrammatical types

- Repeated noun:
  - *natulog ang malaki babae babae
  - *umalis ang matanda kotse kotse kotse kotse
- Scrambled:
  - *siguro matanda matanda babe ang natulog
  - *babae ang umalis

- Adjective-final group's weird acceptance of ungrammatical items mostly driven by acceptance of Scrambled!
- Remove them, and everything's significant, but what on earth does that mean??


Acceptance rates by sentence class
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***
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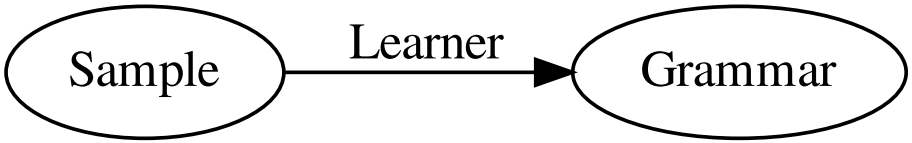

1. **Models**: How do formal models of language learning learn properties of adjuncts?
2. **People**: How do people learn properties of adjuncts?
3. **Neural Networks**: How do neural networks learn properties of adjuncts?

LSTMs generalise Tagalog repetition

1-layer LSTM encoder, trained to give grammaticality judgments

- **Training set:**
  - 200 grammatical (up to 3 adjectives)
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- **Development set:**
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  - 56 ungrammatical (28 noun rep, 28 scrambled)
- **Test set:**
  - all 1088 generalised to 4-20 adjectives
  - all 2176 ungrammatical (1088 scrambled generalised, 1088 4-20 noun rep)

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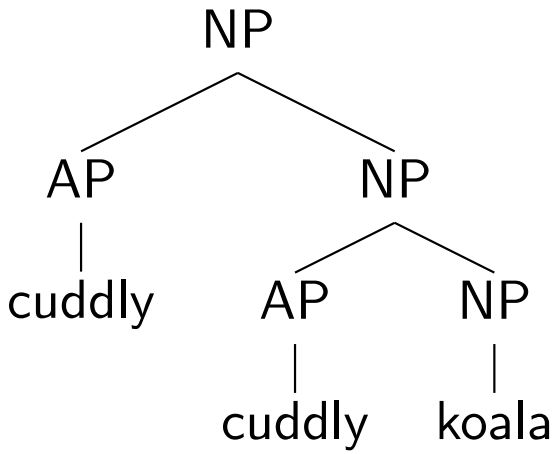
What does this mean??

Summary

- Formal learners we looked at see optionality and repetition as the same thing



- people can (mostly) generalise from limited to indefinite repetition
- LSTMs can generalise really well from limited to indefinite repetition

Thank you!

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   - Participants were trained on human-language-like sentences
   - In an MRI, participants listened to grammatical and ungrammatical sentences of the artificial language.
   - The higher their proficiency with the artificial language, the more the fMRI of their brains looked like they were processing their native language (Broca's area activation)

Experiment 1: Analysis

- I'm trying to get people to learn unconsciously, but maybe word repetition is just too salient

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- In English, some adjuncts are indefinitely repeatable, acceptance drops the more there are.

Experiment 2: English survey

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- 5 choices:
  1. Doesn't sound like English
  2. Sounds pretty weird
  3. Sounds a bit weird
  4. I wouldn't say it, but it does sound like English
  5. Definitely English

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- 11 fillers

Experiment 2: English survey results

People generally recognise lots of repetition as English, but the more repetition, the lower rating they give the sentence. (Lots of "4": *I wouldn't say it, but it does sound like English*)

Next

- Category repetition (*the big mean nasty bully*)

Next

- Category repetition (*the big mean nasty bully*)
- Embed repetition in a more complex grammar

$CFG_{F,K}$ learner

- Uses an *oracle*: the learner can ask *is this sentence ok?*

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- Clark et al conjecture that the oracle could be replaced by a probability distribution on the input
- Because of the oracle, the learner need only encounter the repeated string in the context in which it repeats to deduce repetition and optionality

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  - Try sticking s_2 into all the contexts in F and asking the oracle if you made a grammatical sentence. The list of all the usable contexts is the right daughter

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  - New rule: {(ϵ,ϵ)}$\rightarrow$ {(ϵ,bc),(ϵ,c)} {(ab,ϵ),(a,ϵ)}
  - ab and c get us the same rule

$CFG_{F,K}$

Hard-to-read Rules:

- $\{(\epsilon,c),(\epsilon,bc)\}\rightarrow a$
- $\{(a,c)\}\rightarrow b$
- $\{(a,\epsilon),(ab,\epsilon)\}\rightarrow c$
- $\{(\epsilon,c),(\epsilon,bc)\}\rightarrow \{(\epsilon,c),(\epsilon,bc)\}\ \{(a,c)\}$
- $\{(a,\epsilon),(ab,\epsilon)\}\rightarrow \{(a,c)\}\ \{(a,\epsilon),(ab,\epsilon)\}$
- $\{(\epsilon,\epsilon)\}\rightarrow \{(\epsilon,bc),(\epsilon,c)\}\ \{(ab,\epsilon),(a,\epsilon)\}$

$CFG_{F,K}$

Equivalent Rules:

- A$\rightarrow$ a
- B$\rightarrow$ b
- C$\rightarrow$ c
- A$\rightarrow$ A B
- C$\rightarrow$ B C
- S$\rightarrow$ A C

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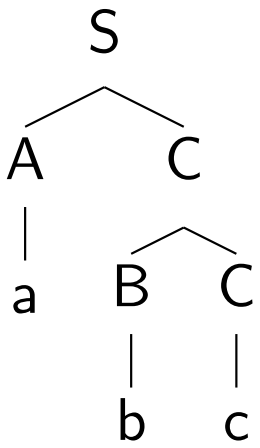

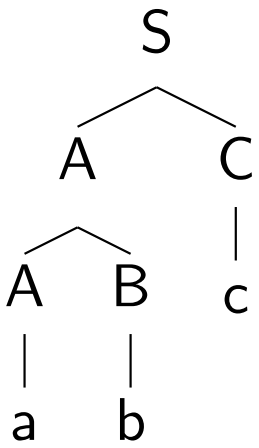

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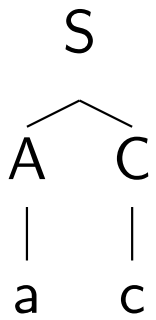

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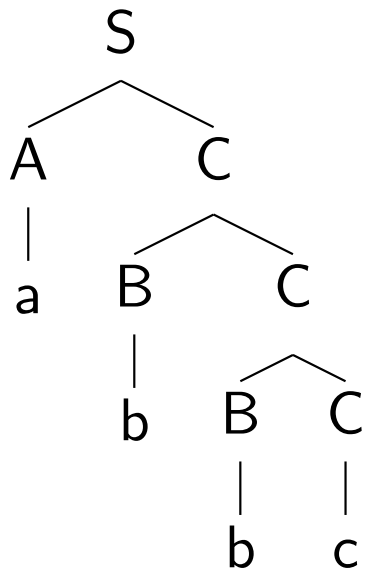

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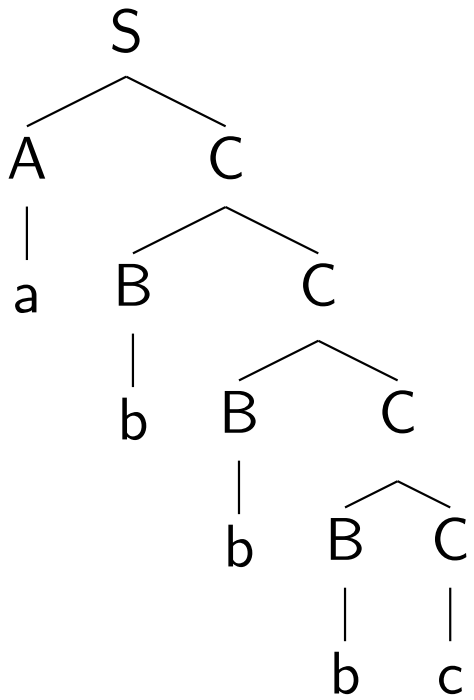

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- This means the baby only has to hear ac, abc, abbc to infer ab*c