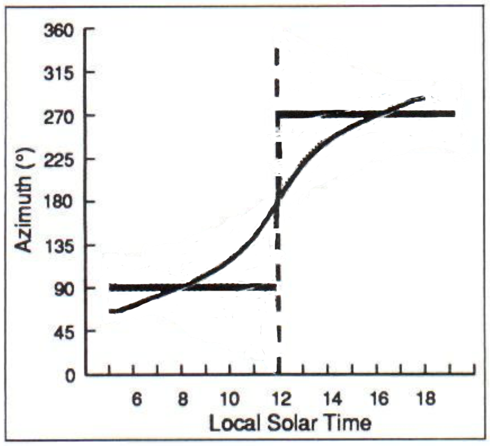
6.S077 Lecture 2

- For animals: Biology+Experience = what you know
- A general research strategy: How “poverty of stimulus” argument for bees extends to baby talk
- You can’t learn something unless…
- How babies learning to talk is like/unlike honeybee learning to navigate
- How to combine statistics with biology

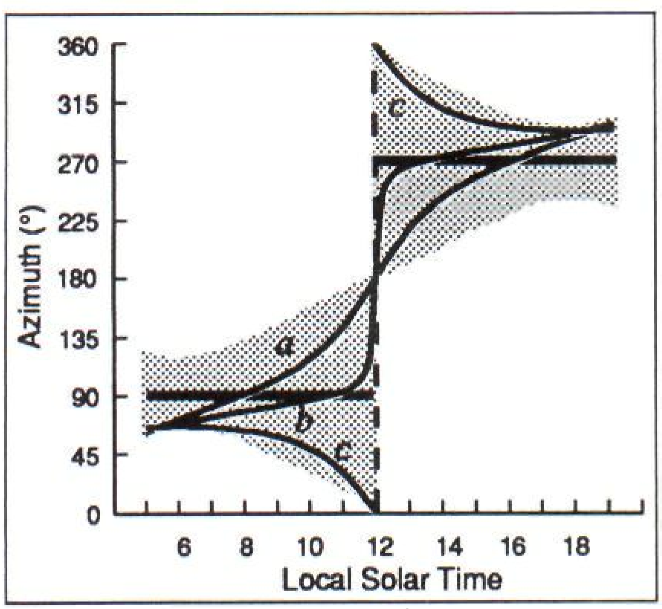
- Infant = in+fant = ”no language”
- By end of the hour, you’ll learn part of how infants learn (part of) language – the language sound system and something about how infants learn (part of) the sound system of their language
- Like honeybees, and unlike honeybees: combine methods from statistics, and a universal, apparently pre-existing innate constraint
- In general, babies are like songbirds, at least for learning a sound system

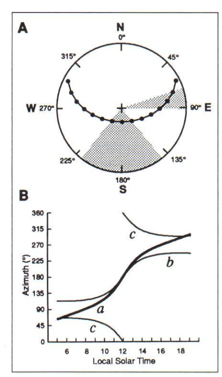
Learning from Small (or almost no) Data Method Honeybee (*Apis*), solar ephemeris function

Azimuth (direction of sun in sky), degrees (North=0, East=90)



Local solar time (hour of day)

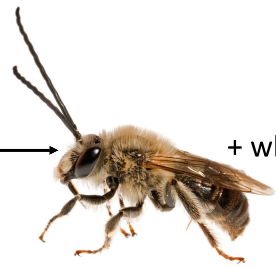




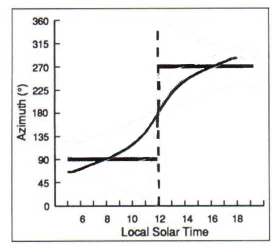
Shaded= space of <u>all</u> physically possible
Solar ephemeris functions

The honeybee learning picture

Experience from flight →



+ what's initially in brain =



Final state = Biology + Experience

Key q: How <u>much</u> biology? How <u>much</u> experience?

How is this any different?

(sounds) →

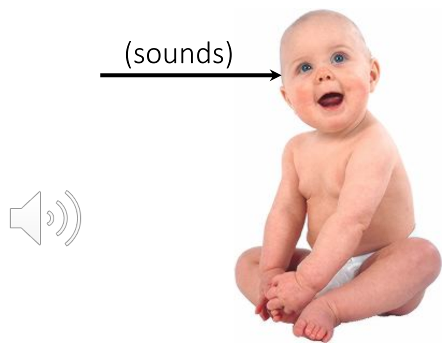
+ what's in brain?

<u>Any Learning System</u>

1. Initial State
2. Final State
3. External experience
4. Learning algorithm

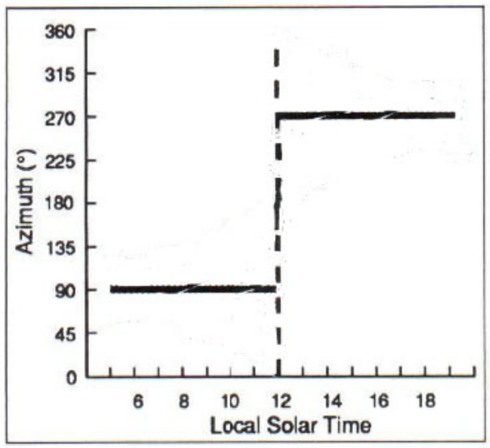
Is language acquisition experience driven?
Biology driven? How <u>much</u> experience? How <u>much</u> bio?

Biology + Experience = Final State suggests a research strategy…

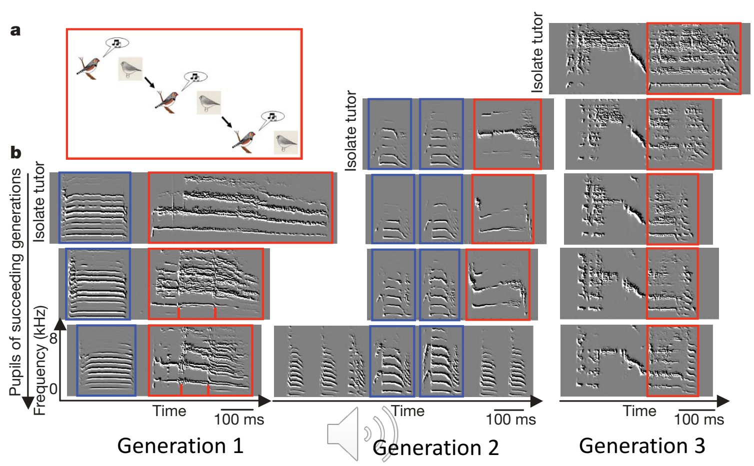


(Pharoah Psamtik I did the experiment….)
[without IRB approval…]

If no experience, revert to "ground genomic state" or "wild type"; this tells us what's there at the start



Reversion to "Wild type" without experiential input: Zebra finch

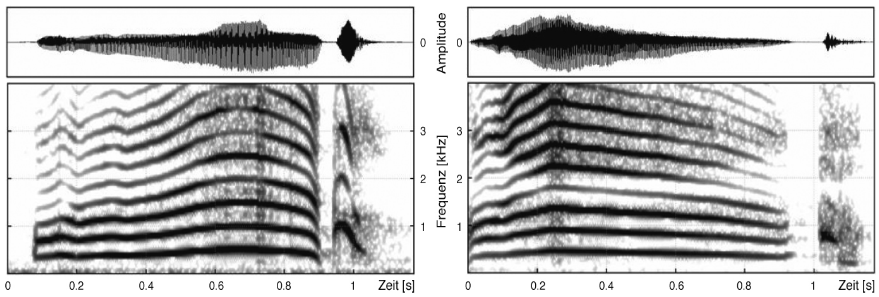


O Fehér *et al.* *Nature* **000**, 1-5 (2009) doi:10.1038/nature07994

nature

Initial state, human babies

typical French cry | typical German cry



Source: Mampe, Friederici, Christophe & Wermke, Current Biology, 2009

Human stages sound system

1. Reflex to Cooing: 'vegetative' sounds, crying (in rhythmic pattern of mother's language), …
2. Precanonical: Syllables ma, …
3. Canonical: Repetitive babbling: na-na
4. First words

Let's illustrate.

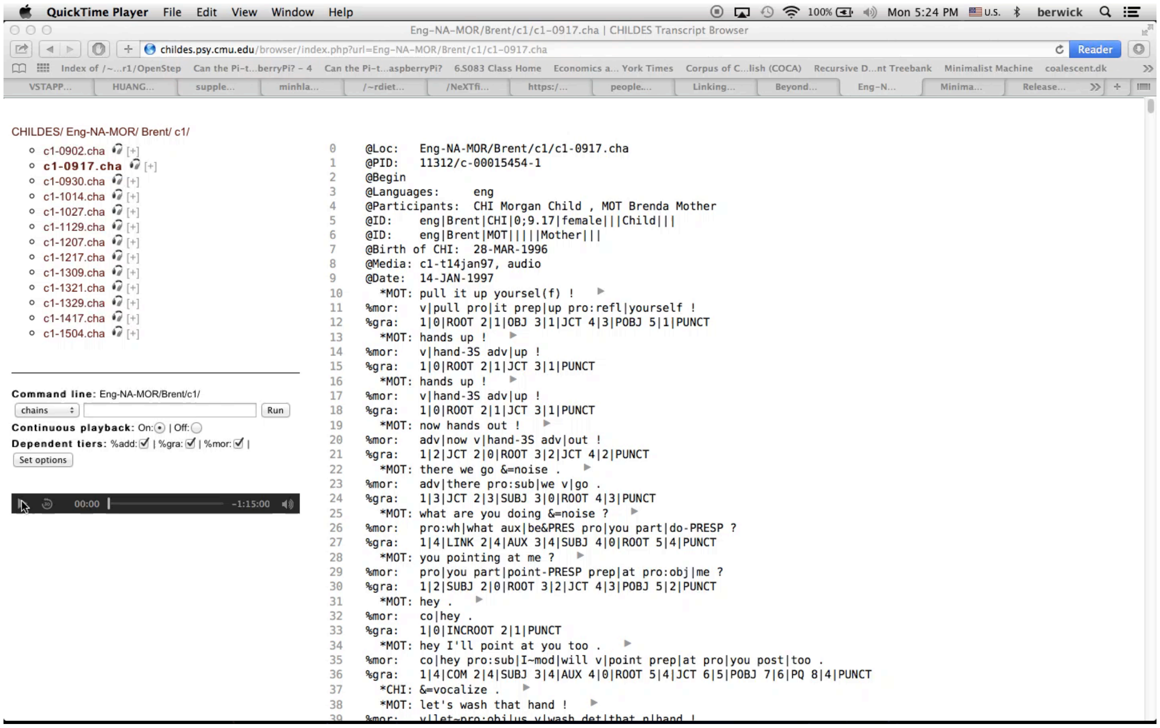
Stages of prespeech vocal development

0 weeks	reflexive crying, biological-based sounds
6-8 weeks	cooing
16 weeks	vocal play begins
36 weeks	reduplicated/canonical babbling
48 weeks	nonreduplicated babbling

First Word


SPEECH
EXPOSED
CHILD


HANDSPEAK.COM



Compression of conversational speech– Poverty of the lexical (word) stimulus

Play first

Play second

Play third

Play fourth

Courtesy Warner and Tucker

Compression of conversational speech– Poverty of the lexical (word) stimulus

Gonna hafta =
Going to have to

Chillinn'the =
Chilling in the

Courtesy Warner and Tucker

Notice that this small "four word" excerpt becomes totally clear from the speech that <u>follows</u> it

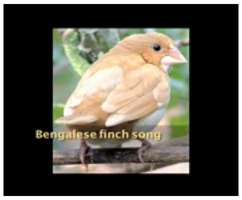
Yet our conscious percept is that we analyzee the initial fragment, *as we hear it*

This rehabilitates the notion of "psychological moment", in which unconscious processes move back and forth, but the percept is linear

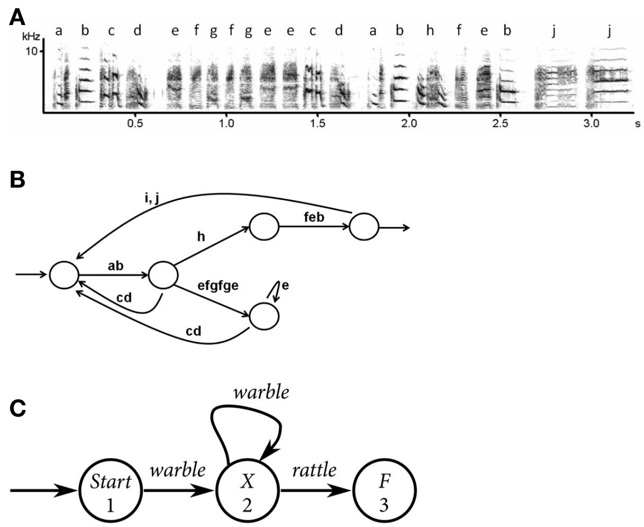
Play first

Courtesy Warner and Tucker

An animal model for human learning?

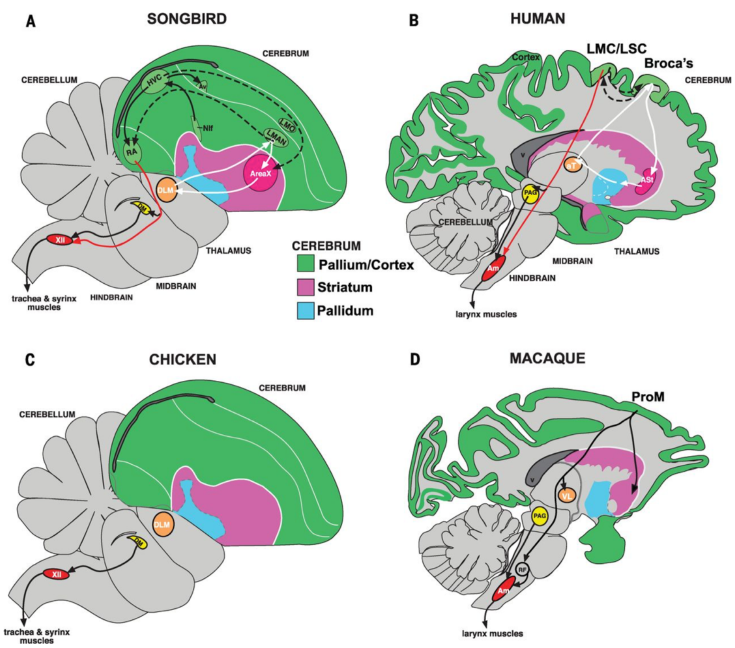


Bengalese finch
(*Lonchura striata domestica*)
Source: K. Okanoya, 2003

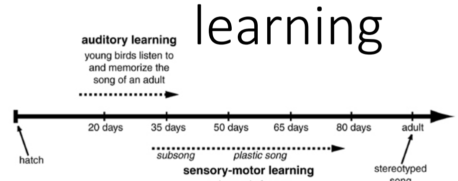


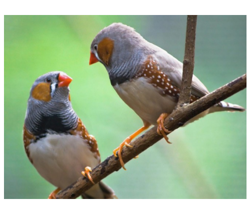
What's the same?

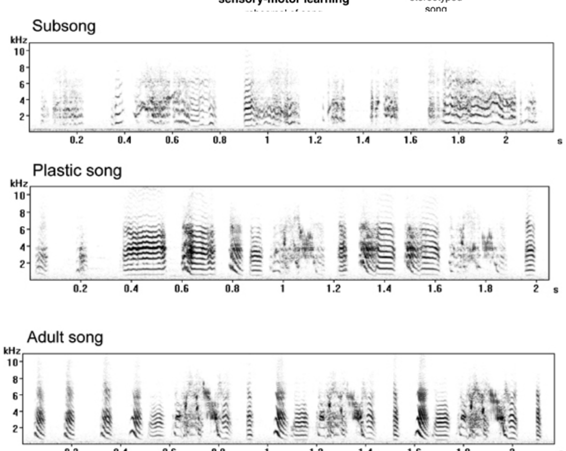
- "Critical period" for learning from external experience
- Babbling (subsong), practice & self-practice
- Plasticity frozen at puberty (by hormonal change – testosterone)
- Left-lateralization for system
- Brain circuitry control
- Beads on a string structure



Songbirds – Zebra finch "critical period" learning



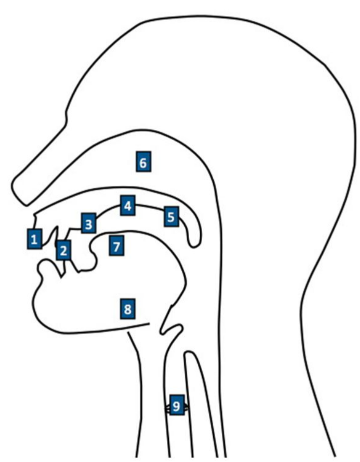




Human (and animal?) sound system like a "tweaked template" system – 8 "dials"

The Articulatory System

1. Lips
2. Teeth
3. Alveolar ridge (tooth ridge/ gum ridge)
4. Hard palate (roof of the mouth)
5. Soft palate (velum)
6. Nasal passage
7. Tongue
8. Jaw
9. Vocal cords



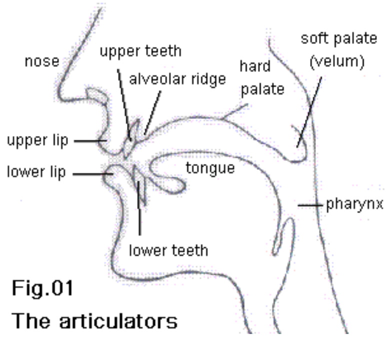


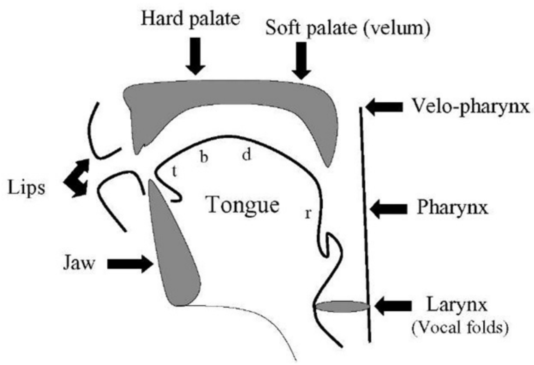
Fig.01
The articulators

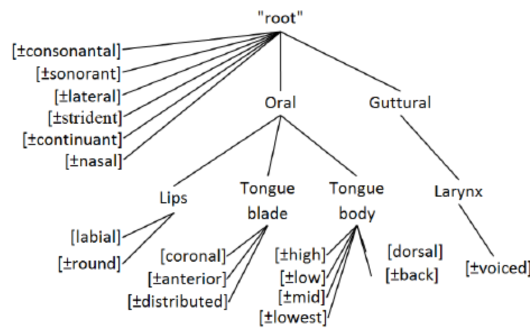
Table 1. Distinctive Features of American English Consonants

	p	b	m	f	v	θ	ð	t	d	n	s	z	l	r	ʃ	ʒ	ʧ	ʤ	j	ɹ	k	g	ŋ	w	ʔ	h
Back	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+
High	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-
Coronal	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-
Anterior	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Labial	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Continuant	-	-	-	+	+	+	+	-	-	-	+	+	+	-	+	+	-	-	+	+	-	-	-	+	-	+
Lateral	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Nasal	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Sonorant	-	-	+	-	-	-	-	-	-	+	-	-	+	+	-	-	-	-	+	+	-	-	+	+	-	-
Strident	-	-	-	+	+	-	-	-	-	-	+	+	-	-	+	+	+	+	-	-	-	-	-	-	-	-
Voiced	-	+	+	-	+	-	+	-	+	+	-	+	+	+	-	+	-	+	+	+	-	+	+	+	-	-

Table 2. Distinctive Features of American English Vowels

i	ɪ	e	ɛ	æ	u	ʊ	o	ɔ	a	ʌ	ə	
+	+	-	-	-	+	+	-	-	-	-	-	high
-	-	-	-	+	-	-	-	-	+	+	-	low
-	-	-	-	-	+	+	+	+	+	-	-	back
-	-	-	-	-	+	+	+	+	-	-	-	rounded
+	-	+	-	-	+	-	+	-	-	-	-	ATR





All English sounds

Table 1. Distinctive Features of American English Consonants

	p	b	m	f	v	θ	ð	t	d	n	s	z	l	r	ʃ	ʒ	ʧ	ʤ	j	ɹ	k	g	ŋ	w	ʔ	h
Back	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+
High	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-
Coronal	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-
Anterior	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Labial	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Continuant	-	-	-	+	+	+	+	-	-	-	+	+	+	-	+	+	-	-	+	+	-	-	-	+	-	+
Lateral	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Nasal	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Sonorant	-	-	+	-	-	-	-	-	-	+	-	-	+	+	-	-	-	-	+	+	-	-	+	+	-	-
Strident	-	-	-	+	+	-	-	-	-	-	+	+	-	-	+	+	+	+	-	-	-	-	-	-	-	-
Voiced	-	+	+	-	+	-	+	-	+	+	-	+	+	+	-	+	-	+	+	+	-	+	+	+	-	-

Table 2. Distinctive Features of American English Vowels

i	ɪ	e	ɛ	æ	u	ʊ	o	ɔ	a	ʌ	ə	
+	+	-	-	-	+	+	-	-	-	-	-	**high**
-	-	-	-	+	-	-	-	-	+	+	-	**low**
-	-	-	-	-	+	+	+	+	+	-	-	**back**
-	-	-	-	-	+	+	+	+	-	-	-	**rounded**
+	-	+	-	-	+	-	+	-	-	-	-	**ATR**

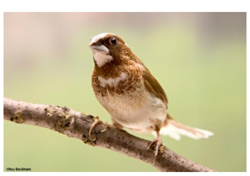
The simplest linear patterns = regular

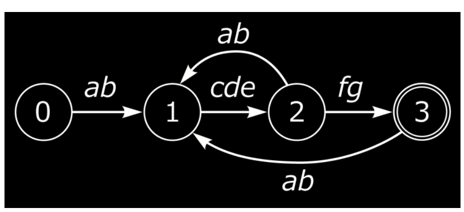
ba:d → bat; de:g → dek (Heinz, 2007)

ʃi:tʒ, *ʃi:te:z
(Chandlee & Jardine, 2013)

Lonchura striata domestica. Source: K. Okanoya, 2003

Birdsong & human sound systems: what's the same?





Bengalese finch
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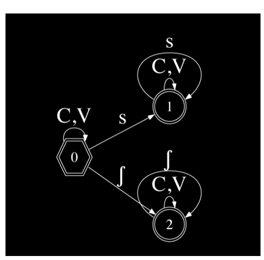


In well formed words, sibilants agree in the feature [anterior].

1. [s,z,ts,ts',dz] are never preceded by [ʃ,ʒ,tʃ,tʃ',dʒ].
2. [ʃ,ʒ,tʃ,tʃ',dʒ] are never preceded by [s,z,ts,ts',dz].

Examples (Sapir and Hojier 1967):

1. ʃi:te:ʒ 'we (dual) are lying'
2. dasdo:lis 'he (4th) has his foot raised'
3. *ʃi:te:z (hypothetical)
4. *dasdo:liʃ (hypothetical)

Sound system components: birds & people

"Beads on a string" model:

1. Beads – chunks or "states" that are <u>categorical</u> classes (remember: "s-sh"
2. Linear sequence – one state follows another, in constrained way

(e.g., "slo" starts a possible English word, but "rdz" does not)

= A <u>finite-state</u> automaton

Categorical <u>production</u> and <u>perception</u>

Today: Let's address just one part of that: how do we find the "chunks" in the input at all?

twasbrilligandtheslithytovesdidgyreandgimbleinthewabe
ekalaloakapaiiaokekahikolamuölelokanakamalokoonänüpepe
czarnelubrdzawegontowestrzechyiarkikryjącewsobiezakopcone

twas brillig and the slithy toves did gyre and gimble in the wabe
e kala loa ka pai ia o kekahi kolamu ölelo kanaka ma loko o nä nüpepa
czarne lub rdzawe, gontowe strzechy i arki kryjące w sobie zakopcone

Challenge: segmentation twasbrilligandtheslithytovesdidgyre

{pabiku,tibudo,golatu,daropi}

```
pabikutibudodaropipabiku
tibudodaropitibudodaropi
pabikudaropipabikugolatu
tibudogolatutibudogolatu
golatudaropipabikutibudo
daropigolatudaropipabiku
tibudogolatudaropigolatu
daropigolatupabikutibudo
pabikutibudodaropigolatu…
```

Question: What are the words?????

pigola daropi tudaro

Challenge: Combining Inference with Cognitive Constraints (How real people solve real problems can help real computers)

Problem: *twasbrilligandtheslithytovesdidgyreandgimble*

"Standard" solution: *prettybaby* *pre-ty-ba-by*

Graph of transition probabilities (tp): $Pr(x_{i+1}|x_i)$ & look for local minima or threshold

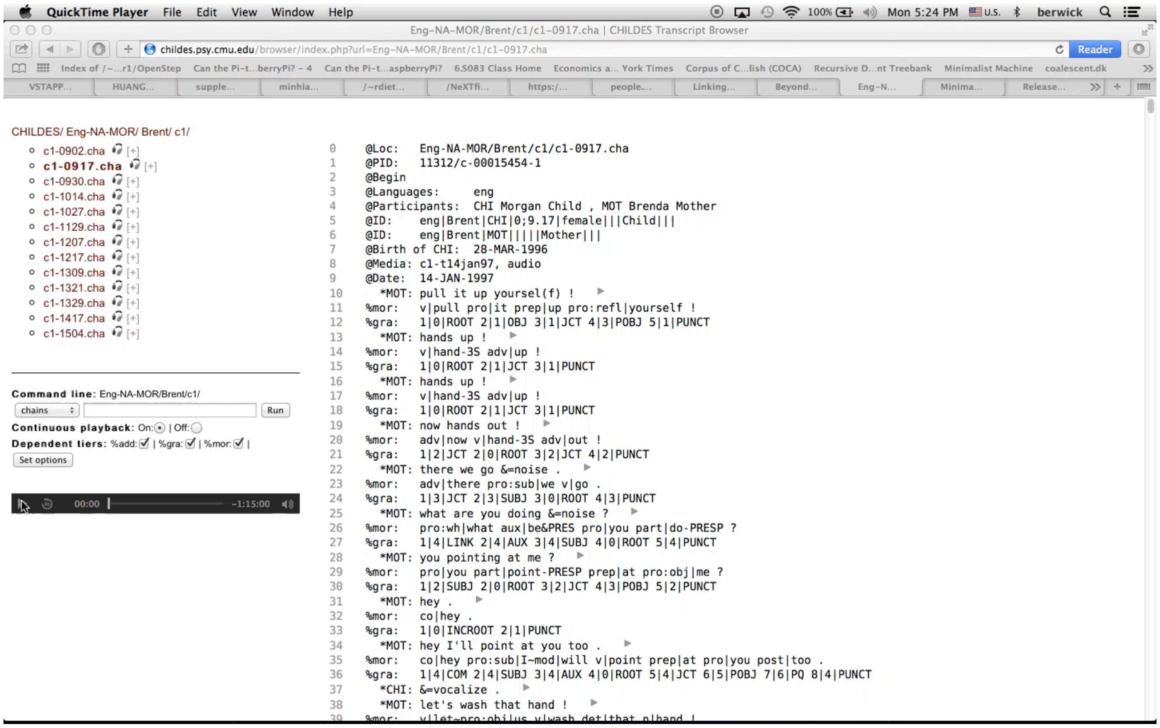
"Standard" claim: works great; "stats is all you need" (*Science*, 1996)

```
                          pabiku tibudo daropi golatu daropi
pabikutibudodaropigolatu…
Pr(bi|pa)=1.0; Pr(ku|bi)=1.0; Pr(ti|ku)=0.3,
Pr(bu|ti)=1; Pr(do|bu)=1.0; Pr(da|do)=0.3
Pr(ro|da)=1; Pr(pi|ro)=1.0; Pr(go|pi)=0.3
Pr(la|go)=1.0; Pr(tu|la)=1.0 …
```

Works great? NO!!!

pabiku

pigola→ pi golatu

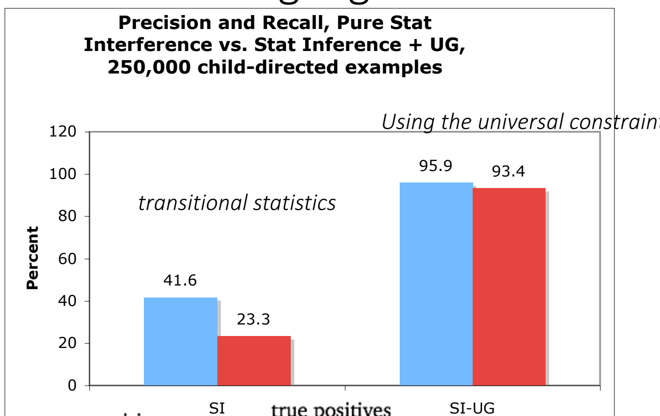


Phonetically transcribed mother's speech to "Adam" fed to segmentation program

"CMU pronunication dict":
http://www.speech.cs.cmu.edu/cgi-bin/cmudict
1= primary stress
U= utterance end

Big drum.
Horse.
Those are checkers
bih1gdrah1mU
hhao1rsU
dhow1zaa1rcheh1kerzU

Actual results on actual speech to children? works lousy! What's the answer? But, add a ONE universal constraint about human language and it works GREAT!



- $\text{precision} = \dfrac{\text{true positives}}{\text{true positives} + \text{false positives}}$
- $\text{recall} = \dfrac{\text{true positives}}{\text{true positives} + \text{false negatives}}$

What IS this ONE universal constraint???? HINT: you all know it!

Summary for today

- Small data for small minds: Statistics can be profitably combined with pre-existing ("innate") constraints, even in humans
- Sound system for language looks like a (bit more complex version) of "tweaked template" as in honeybee navigation
- Correct representation key to learning success