The Logical Nature of Phonology Across Speech and Sign

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Computational Perspective

- Mathematically precise representational claims
- Mathematically restricted grammars
- Efficient, provably correct learning algorithms

Schlenker 2018

"investigating Universal Semantics from the standpoint of sign language might help reconsider foundational questions about the logical core of language, and its expressive power"

What about Universal Phonology?

Today's Question

Do the computational properties of phonology hold across modalities?

Two Major Camps

- "Continuity View": phonology depends on/emerges from the properties of the phonetic system (grounded)
  - Hayes et al 2004, Steriade 1997, a.o.
- "Algebraic View" : Abstract computational system that gets to peek at the phonetics, but is largely independent
  - Berent 2013, Sandler 2012, Sandler and Lillo-Martin 2006, Hale & Reiss 2000
  - "overwhelmingly, lesion and neuroimaging studies indicate that the neural systems supporting signed and spoken language are very similar. Recent studies have also highlighted processing differences between languages in these different modalities." (MacSweeney et al. 2008)

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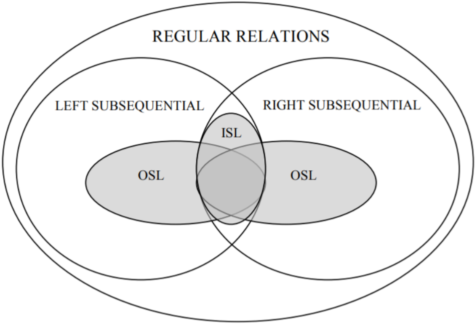
Types of Modality Differences

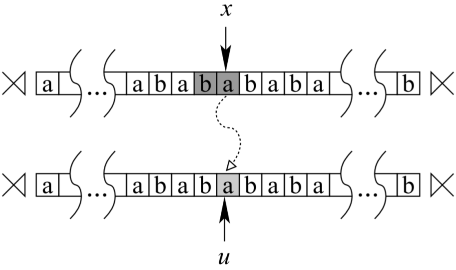
		Representation	
		Same	Different
Grammar	Same		
	Different		

Phonology is Subregular



- Regular/finite-state: Memory does not grow with input size
- Sufficient for phonology (Johnson 1972, Kaplan & Kay 1994)
  - Underlying/Surface pairs: (ba:d, ba:t),
  - Rewrite Rules: -son → -voice / _#,
  - Constraint Interaction: *[-son,+voice]# >> IDENT(voi)
- New hypothesis: phonology only needs **subregular** power

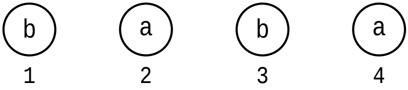
Input Strictly Local Functions



ISL Functions (Chandlee 2014, Chandlee & Heinz 2018)

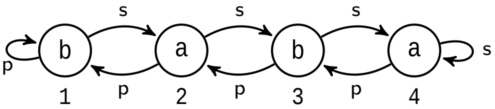
- output u tracks contiguous input substrings x of length k
  - (CAD, CBD), A ! B / C__D, *CAD >> FAITH(A ! B)
  - Intervocalic Voicing is 3-ISL: VTV ! VDV
- About 95% of processes in P-Base (Mielke 2008)
  - Substitution, deletion, epenthesis, general affixation, metathesis (local & bounded nonlocal), partial reduplication, ...

What information is present in a string?



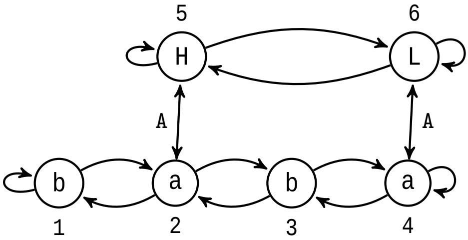
- Domain of sequence elements *f*1,2,3,4*g*
- Labeling relations *f*a,b*g*(IPA, features, orthography, etc)
- Ordering functions (successor and predecessor)

What information is present in a string?



- Domain of sequence elements $\{1,2,3,4\}$
- Labeling relations $\{a,b\}$(IPA, features, orthography, etc)
- Ordering functions (successor and predecessor)

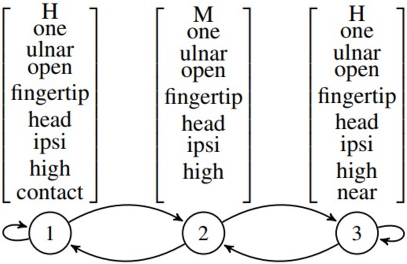
What information is present in a string?



- Domain of sequence elements {1,2,3,4,5,6}
- Labeling relations {a,b,H,L} (now including tone)
- Association relations
- Ordering functions (successor and predecessor)

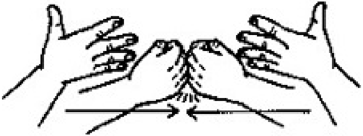
Signs as Strings

IDEA (ASL)

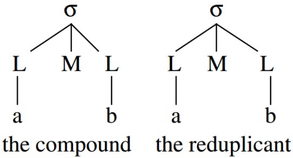


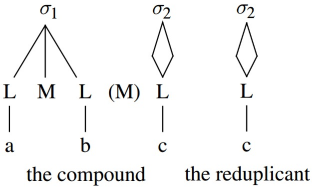
- Models signs as sequential hold & movement segments with features (Liddell 1984)
- Explicit claim: Only difference between sign and speech is size & content of feature system
- Rawski 2017: metathesis, compound reduction, partial reduplication are ISL in speech/sign

ASL Final Syllable Reduplication



pics from Sandler & Lillo-Martin 2006





ASL Final Syllable Reduplication

4-ISL function: $\emptyset$! LML / LML__n

Input String: LMLML

o L M L M L n

ASL Final Syllable Reduplication

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Input String: LMLML

o L M L M L n

ASL Final Syllable Reduplication

4-ISL function: $\emptyset$! LML / LML__n

Input String: LMLML

o L M L M L n

L

ASL Final Syllable Reduplication

4-ISL function: ∅ ! LML / LML__n

Input String: LMLML

o L M L M L n

L

ASL Final Syllable Reduplication

4-ISL function: ∅ ! LML / LML__n
Input String: LMLML

o L M L M L n
L M

ASL Final Syllable Reduplication

4-ISL function: $\emptyset \rightarrow$ LML / LML__n

Input String: LMLML

o L M L M L n

L M

ASL Final Syllable Reduplication

4-ISL function: $\emptyset$! LML / LML__n
Input String: LMLML

o	L	M	L	M	L	n
	L	M	L	M		

ASL Final Syllable Reduplication

4-ISL function: ∅ ! LML / LML__n

Input String: LMLML

o	L	M	L	M	L	n
	L	M	L	M		

ASL Final Syllable Reduplication

4-ISL function: $\emptyset$! LML / LML__n

Input String: LMLML

o	L	M	L	M	L	n
	L	M	L	M		

ASL Final Syllable Reduplication

4-ISL function: ∅ ! LML / LML __n

Input String: LMLML

o	L	M	L	M	L	n
	L	M	L	M	L	LML

Signs as Graphs

- encodes autosegmental relations (Sandler 1989, van der Hulst 1993, Brentari 1998)

picture from (Sandler & Lillo-Martin 2006)

Metathesis

Metathesis

$$P_1^O(x) \stackrel{\text{def}}{=} P_2(x) \quad (1)$$

$$P_2^O(x) \stackrel{\text{def}}{=} P_1(x) \quad (2)$$

Metathesis

$$\text{loc}^{O}(x) \overset{\text{def}}{=} \begin{cases} \text{loc}\,(s(s(x)) & \text{loc}\,(p(p(x)) = \text{loc}\,(s(s(x))) \\ \text{loc}\,(p(p(x)) & \text{loc}\,(x) = \text{loc}\,(p(p(p(p(x))))) \\ \text{loc}\,(x) & \text{else} \end{cases} \qquad (3)$$

Compound Reduction

$\overset{def}{}$

Compound Reduction

$$\begin{aligned} A^{O}(x;y) \stackrel{def}{=} & [\,A(x;y) \text{\textasciicircum}\ H_2(y)]\_ \\ & [A(s(x);y) \text{\textasciicircum}\ H_2(y)]\_ \\ & [A(s(s(x));y) \text{\textasciicircum}\ H_2(y)]\_ \\ & [A(s(s(s(x)));y) \text{\textasciicircum}\ H_2(y)] \end{aligned} \tag{4}$$

Compound Reduction

$$\mathrm{lic}_H(x) \overset{\mathrm{def}}{=} \bigvee_i H_i(x) \wedge A(x; \mathrm{last}\ \ ) \tag{5}$$

$$\mathrm{lic}_{LM}(x) \overset{\mathrm{def}}{=} (L(x) \vee M(x)) \wedge [x = \mathrm{last}\ \ \vee x = p(\mathrm{last}\ \ ) \vee x = s(s(\mathrm{first}\ \ ))] \tag{6}$$

$$\mathrm{lic}_P(x) \overset{\mathrm{def}}{=} \bigvee_j P_j(x) \wedge [x = \mathrm{loc}\ (\mathrm{last}\ \ ) \vee x = \mathrm{loc}\ (s(s(\mathrm{first}\ \ )))] \tag{7}$$

$$\mathrm{lic}(x) \overset{\mathrm{def}}{=} \mathrm{lic}_H(x) \vee \mathrm{lic}_{LM}(x) \vee \mathrm{lic}_P(x) \tag{8}$$

ASL Reduplication Again

ASL Reduplication Again

$$lic^{O}_{1}(x) \stackrel{def}{=} TRUE \tag{9}$$

$$lic^{O}_{2}(x) \stackrel{def}{=} [(L(x) \vee M(x)) \wedge x = [last \vee p(last) \vee p(p(last))]] \tag{10}$$

$$\vee [\bigvee_{i} H^{O}_{i}(x) \wedge A(x; last)]$$

$$\vee [\bigvee_{i} P^{O}_{i}(x) \wedge x = [loc(last) \vee loc(p(p(last)))]]$$

$$s((x; i)) \stackrel{def}{=} \begin{cases} (s(x); 1); & x \neq last; \quad i = 1 \\ (p(p(last)); 2); & x = last; \quad i = 1 \\ (s(x); 2); & i = 2 \end{cases} \tag{11}$$

$$p((x; i)) \stackrel{def}{=} \begin{cases} (p(x); 1); & i = 1 \\ (last; 1); & x = p(p(last)); i = 2 \\ (p(x); 2); & x \neq p(p(last)); i = 2 \end{cases} \tag{12}$$

ISL Across Speech and Sign

Process	Strings	Graphs
Metathesis	ISL	A-ISL
Partial Reduplication	ISL	A-ISL
Compound Reduction	ISL	A-ISL

Interpretation

- Strict Locality is salient across spoken and signed phonology
- Locality ranges over the representation
- "Adapted systems" view
  - signers exploit nonlinear structure
  - restrict sequential structure to preserve ISL requirements
- Locality as unified inductive learning bias

Cognitive Implications

Phonology is amodally sensitive to

- particular locality representations (e.g. substrings/subgraphs)
- ISL memory restrictions (e.g. bounded substrings).
  - reflected experimentally (Finley 2011; Lai 2015, Avcu 2017)

Any cognitive mechanism with ISL complexity is sensitive to length k blocks of consecutive events occuring in the underlying structure. (Rogers et al 2013)

If structures occur in time, this means sensitivity, at each point, to immediately prior sequence of k 1 events.

Computation teases apart amodality and modality effects

All learning systems necessarily structured by representational and computational nature of their domains (Rawski & Heinz 2019).

Answering Poeppel's "Mapping Problem"

Maps problem: Find brain areas correlating with cognitive tasks
Mapping problem: Decompose cognition into neuronal operations

Poeppel 2012

"focus on the operations and algorithms that underpin language processing"

"commitment to an algorithm or computation in this domain commits one to representations of one form or another with increasing specificity and also provides clear constraints for what the neural circuitry must accomplish."

Where to go from here?

- Further linguistic work on computational comparisons of phonology across speech and sign
- Learning algorithms/theorems, integrating learnability with linguistic theory
- Representational tradeoffs (strings, trees, graphs, etc)
    - Phonology, morphology, syntax, may be local over the right representations (Graf et al 2018).
- Computationally motivated experimental work on modality