Learning local constraints over autosegmental representations

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Introduction

- How do we learn over non-linear phonological structures?

Introduction

- Autosegmental phonological representations (APRs) still offer important insights in phonology (McCarthy, 2010; de Lacy, 2011; Walker, 2014, etc.), especially in tone (Hyman, 2011, 2014)
- APRs capture long-distance patterns locally (Odden 1994; Jardine, forthcoming)
- There is cross-linguistic variation in what constitutes a valid APR

Introduction

- Grammatical inference (de la Higuera, 2010) gives us ways to learn grammars organized around **local substructures** (García et al. 1990; Heinz 2010a; Jardine and Heinz accepted)
- "Learning" = exact convergence in the limit in polynomial time from positive data (de la Higuera, 1997)

Introduction

- This talk extends this idea of learning local substructures to APRs
- By invoking grammars organized around **subgraphs**, we can learn
  - language-specific well-formedness constraints on APRs
  - long-distance generalizations for which no proven learner exists

Computational locality (strings)

- *blick* vs. **bnick*
- Constraint: **#bn*
- This is a **forbidden substructure constraint**

*

#	b	n

#	b	l	ɪ	k	#

#	**b**	**n**	ɪ	k	#

- *#bn* is a **3-factor** of **#bnɪk#* (but not *#blɪk#*)
- Formal languages described with forbidden *k*-factors are the **Strictly *k*-Local (SL) languages** (McNaughton and Papert, 1971)

Computational locality (strings)

Learning forbidden substructure constraints (strings)

- Fix k

$$\texttt{fac}_k(w) = \{u |\ u \text{ is a } k\text{-factor of } w\}$$

$$\texttt{fac}_k(D) = \bigcup_{w \in S} \texttt{fac}_k(w)$$

- Let F_k be the set of all possible k-factors

Computational locality (strings)

Learning forbidden substructure constraints (strings)

- Learner based on $\texttt{fac}_k$:

Time	Datum	Grammar
(start)		F_k
0	w_0	$F_k - \texttt{fac}_k(\{w_0\})$
1	w_1	$F_k - \texttt{fac}_k(\{w_0, w_1\})$
2	w_2	$F_k - \texttt{fac}_k(\{w_0, w_1, w_2\})$
	...	
n	w_n	$F_k - \texttt{fac}_k(\{w_0, w_1, w_2, ..., w_n\})$

- **Fact**: For any target grammar G of forbidden k-factors, there is some data point w_i for which the learner converges to G (García et al., 1990; Heinz, 2010b)
- $\texttt{fac}_k(D)$ calculated in time linear in size of D

Computational locality (strings)

- SL languages are are learnable in the limit in polynomial time from positive data
- **Tier-based Strictly *k*-Local (TSL) languages** are also so learnable, even without prior knowledge of the tier (Jardine and Heinz, accepted)

Tone and non-linear phonology

- Tone seems to need some representation beyond strings (Hyman, 2014)
- Some tone patterns (e.g., Hirosaki Japanese) are beyond power of even TSL grammars (Jardine, forthcoming)
- How do we learn over non-linear representations?
- First step: **local** theory of constraints for non-linear representations

Tone and non-linear phonology

Mende word tone (Leben, 1973; Goldsmith, 1976; Leben, 1978)

H	a. kɔ́	H	‘war’	b. pɛ́lɛ́	HH	‘house’	c. háwámá	HHH	‘waist’
L	d. kpà	L	‘debt’	e. bɛ̀lɛ̀	LL	‘pants’	f. kpàkàlì	LLL	‘stool’
HL	g. mbû	F	‘owl’	h. ngílà	HL	‘dog’	i. félàmà	HLL	‘junction’
LH	j. mbǎ	R	‘rice’	k. nìká	LH	‘cow’	l. ndàvúlá	LHH	‘sling’
LHL	m. mbǎ̂	R-F	‘comp.’	n. nyàhâ	LF	‘woman’	o. nìkílì	LHL	‘nut’

*LLH, *HHL, *RH, *RHH, etc.

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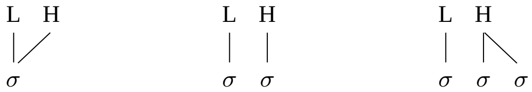
*LLH, *HHL, *RH, *RHH, etc.



Tone and non-linear phonology

Hausa tone-integrating suffixes (Newman, 1986, 2000)

a. jáa	H	'pull'	b. jíráa	HH	'wait for'	c. béebíyáa	HHH	'deaf mute'
c. wàa	L	'who?'	d. màcè	LL	'woman'	e. zàmfàrà	LLL	'Zamfara'
f. jàakíi	LH	'donkey'	g. jìmìnúu	HHL	'ostriches'	h. bàbbàbbàkú	LLLH	'roasted'
i. fáadì	HL	'fall'	j. hántúnàa	LLH	'noses'	k. búhúnhúnàa	HHHL	'sacks'
l. mântá	FH	'forget'	m. káràntá	HLH	'read'	n. kákkáràntá	HHLH	'reread'

Tone and non-linear phonology

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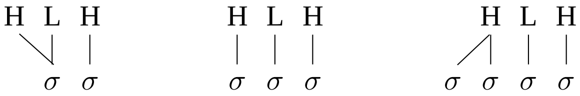
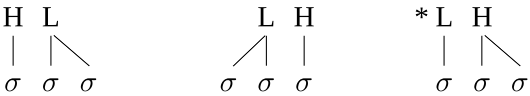
l. mântá	FH	‘forget’	m. káràntá	HLH	‘read’	n. kákkáràntá	HHLH	‘reread’



Tone and non-linear phonology

Kukuya word tone (Hyman, 1987; Zoll, 2003)

a. kâ ‘to pick’	F	b. sámà ‘conversation’	HL	c. káràgà ‘entangled’	HLL
d. sǎ ‘knot’	R	e. kàrá ‘paralytic’	LH	f. m^{w}àrə̀gí ‘brother’	LLH
g. bá ‘palms’	H	h. bágá ‘show knives’	HH	i. bálágá ‘fence’	HHH
j. bvǐ̀ falls’	R-F	k. pàlî ‘goes out’	LF	l. kàlə́gì ‘turns’	LHL



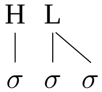
Tone and non-linear phonology

Previous approaches:

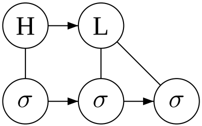
- Rule-based frameworks parameterized directionality (e.g., Archangeli and Pulleyblank, 1994) and employed language specific rules for quality-dependent spreading (Hyman, 1987)
- Zoll (2003) captures these with violable constraints in OT; *CLASH for Kukuya, ALIGN for directionality
- Unclear how rules are learned
- ALIGN overgenerates (Eisner, 1997) and cannot capture 'edge-in' patterns like in N. Karanga Shona (Hewitt and Prince, 1989; Zoll, 2003)

Computational locality (APRs)

- All of these patterns are **local**
- What is a substructure in an APR?

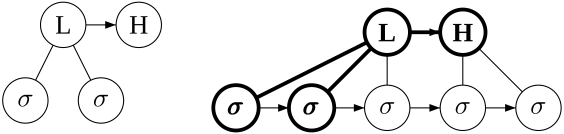


- APRs are **graphs** (Goldsmith, 1976; Coleman and Local, 1991)



Computational locality (APRs)

- Let a **subgraph** be some finite, connected piece of a graph



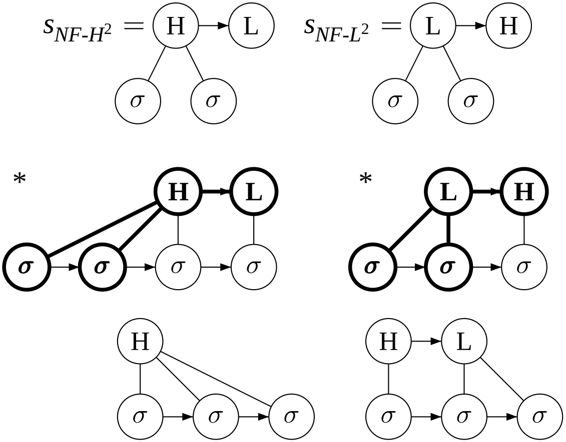
- Let *k* be number of nodes

Computational locality (APRs)

- A local grammar specifies sets of **forbidden subgraphs** $\{s_1, s_2, ..., s_n\}$, where each s_i is a subgraph
- This is a set of **inviolable** and **language-specific** constraints

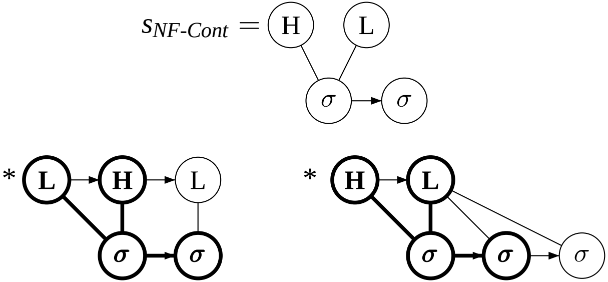
Case study: Mende

Spreading in Mende



Case study: Mende

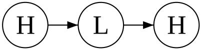
Contours in Mende

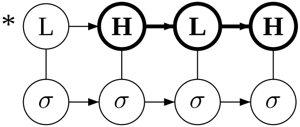


- c.f. Zhang (2000)

Case study: Mende

Melody constraint in Mende

$s_{HLH} =$ 



Local language-specific well-formedness

- Mende grammar: $\{s_{HLH},\ s_{NF\text{-}Cont},\ s_{NF\text{-}H^2},\ s_{NF\text{-}L^2}\}$
- $k = 4$
- Language-specific constraints in Hausa, Kukuya, N. Karanga all local in this way (Jardine and Heinz, AMP)
- Long-distance patterns, like Hirosaki Japanese, are local over APRs (Jardine, forthcoming)
- Because they are local, do not overgenerate like ALIGN
- These constraints are *language-specific*

Learning local APR constraints

- Fix k

$$\mathtt{subg}_k(g) = \{s \mid s \text{ is a } k\text{-subgraph of } g\}$$

$$\mathtt{subg}_k(D) = \bigcup_{g \in S} \mathtt{subg}_k(g)$$

- Let S_k be the set of all possible k-subgraphs

Learning local APR constraints

- Learner based on $\texttt{subg}_k$:

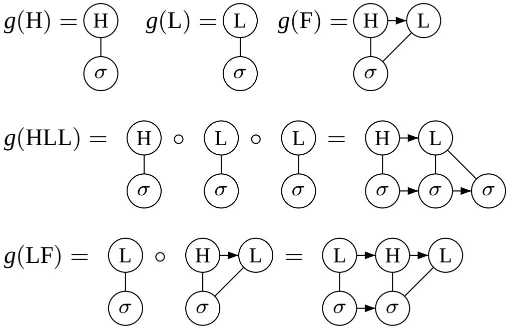
Time	Datum	Grammar
(start)		S_k
0	g_0	$S_k - \texttt{subg}_k(\{g_0\})$
1	g_1	$S_k - \texttt{subg}_k(\{g_0, g_1\})$
2	g_2	$S_k - \texttt{subg}_k(\{g_0, g_1, g_2\})$
	$\ldots$	
n	g_n	$S_k - \texttt{subg}_k(\{g_0, g_1, g_2, ..., g_n\})$

- **Fact**: For any target grammar G of forbidden k-subgraphs, there is some data point g_i for which the learner converges to G
- **Conjecture**: $\texttt{subg}_k(D)$ runs in polynomial time (Ferrera, 2013)

Learning local APR constraints

A note on the input data

- Given correspondence of string symbols to graph primitives, input can be strings (Jardine and Heinz, 2015)



Discussion/conclusions

- This method learns autosegmental constraints
- This is thanks to a **theory** of constraints which captures the typology of tone patterns *locally*
- This theory is sufficient, yet does not overgenerate
- It is able to capture long-distance patterns

Discussion/conclusions

- We can extend ideas to other non-string based representational theories, such as Optimal Domains Theory (Cassimjee and Kisseberth, 2001), correspondence theory (Rose and Walker, 2004; Shih and Inkelas, 2014), and others.
- We can extend idea of locality to learning APR transformations (a la Chandlee, 2014, et seq.)

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Hirosaki Japanese (Haraguchi, 1977)

- Exactly one H or F-toned mora in every word

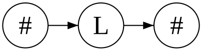
In L_{HJ}	Not in L_{HJ}
H, F, LH, LF, HL,	L, LL, HH, HF,
LLH, LLF, LHL, HLL,	LLL, FLL, LFL, HLF,
LLLH, LLLF, LLHL, LHLL,	LLLL, LLFL, LFLL,
HLLL, ...	FLLL, HLLF, ...

- F can only be word final
- No k can exclude a word L^{k+1}
- One-H generalization is TSL, but final F is SL

Hirosaki Japanese

- Over APRs, HJ describable with

$$\{ s_{HLH},\ s_{NF\text{-}Cont}, s_{\#\mathrm{L}\#},\ s_{H^2} \}$$

- $s_{\#\mathrm{L}\#} =$ 

$s_{H^2} =$