Investigating phonological typology: a computational approach

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February 17, 2016

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Objectives

What factors delimit the set of possible phonological mappings?

The approach:

- Characterize phonological UR$\mapsto$SR maps using methodology from theoretical computer science.
- Establish the computational complexity class these maps belong to (i.e., what is the upper bound?).

Objectives

- More specifically, many phonological maps are shown to belong to a **subregular** class of functions called the Input Strictly Local functions.
- These functions are computationally restrictive, which in part accounts for why certain logically possible maps that do not belong to the class are also unattested.
- Belonging to this class also has an advantage when it comes to learnability.

Phonological functions

underlying form $\mapsto$ surface form

(1) German final devoicing
/bɑd/ $\mapsto$ [bɑt], 'bath'

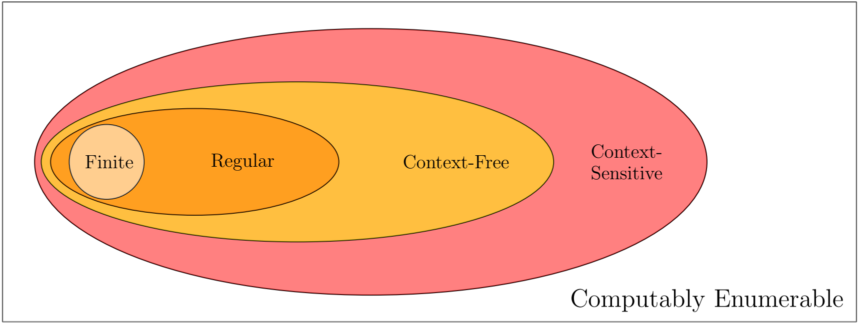
Why functions?

(2) $[-\textit{son}] \rightarrow [-\textit{voice}]\ /\ \_\_\ \#$

(3) $\text{*D}\# \gg \textsc{Ident}(\textsc{Voice})$

(Baković 2013)

Chomsky hierarchy



Restricting phonology

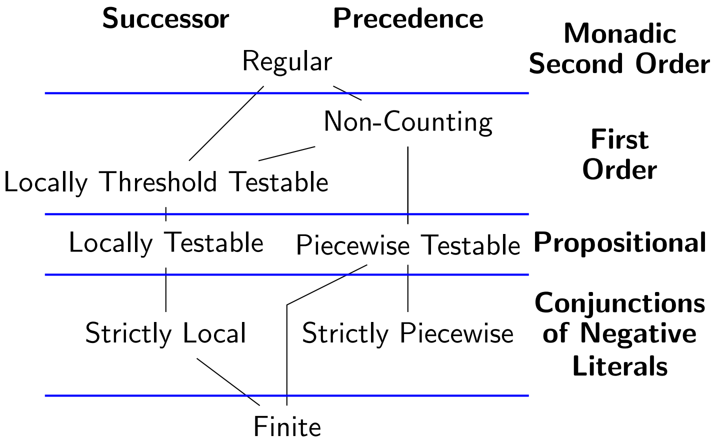
- Phonological rules of the form $A \rightarrow B/C \_\_ D$ are **regular relations** provided the rule doesn't re-apply to its own structural change. (Johnson 1972, Kaplan & Kay 1994)

Restricting phonology further

- Phonological maps $CAD \mapsto CBD$ are **subregular** provided CAD is a finite set. (Chandlee 2014, Chandlee et al. 2014)

(4) Final devoicing
$D\# \mapsto T\#$

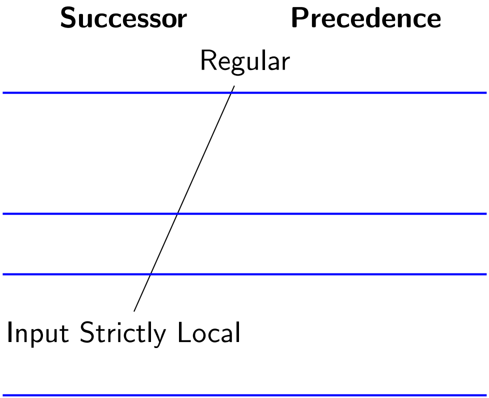
Subregular hierarchy of languages



Subregular hierarchy of languages

- As a hierarchy of formal languages (i.e., stringsets), the subregular hierarchy has been used to study phonotactics (Heinz 2009, 2010, Heinz et al. 2011, Rogers et al. 2013).
- Phonotactic constraints appear to be restricted to the SL and SP regions.
- What about phonological maps?

Subregular hierarchy of functions



ISL function: Example 1

(5) Quechua post-nasal obstruent voicing

a. /kampa/ $\mapsto$ [kamba] 'yours'

(Pater 2004)

ISL function: Example 1

k a m p a

ISL function: Example 1

#	k	a	m	p	a	#
	k					

ISL function: Example 1

#	k	a	m	p	a	#
	k	a				

ISL function: Example 1

#	k	a	m	p	a	#
	k	a	m			

ISL function: Example 1

#	k	a	m	p	a	#
	k	a	m	b		

ISL function: Example 1

#	k	a	m	p	a	#
	k	a	m	b	a	

Input Strictly Local Functions

- The ‘window’ size is the length of the targeted sequence: e.g., the length of NC̥.
- This length is the *k*-value of the function: Post-nasal obstruent voicing is 2-ISL.

ISL function: Example 2

(6) Rotuman (CV$\#$ $\mapsto$ VC$\#$)

a.	ho**sa** $\mapsto$ ho**as**	'flower'
b.	hu**la** $\mapsto$ hu**al**	'moon'
c.	ti**ko** $\mapsto$ ti**ok**	'flesh'

(Churchwood 1940)

ISL function: Example 2

#	h	u	l	a	#

ISL function: Example 2

#	h	u	l	a	#

ISL function: Example 2

#	h	u	l	a	#
			hu		

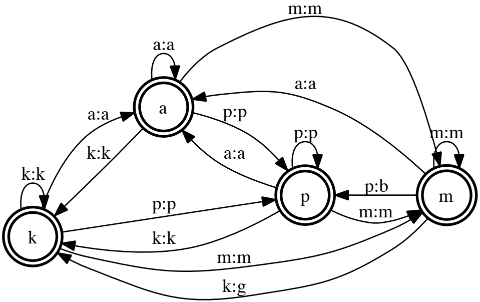
ISL function: Example 2

#	h	u	l	a	#
			hu		

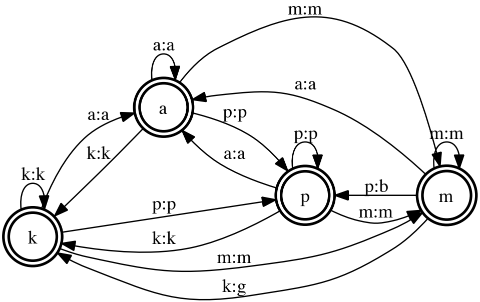
ISL function: Example 2

#	h	u	l	a	#
			hu		al

ISL functions: automata characterization

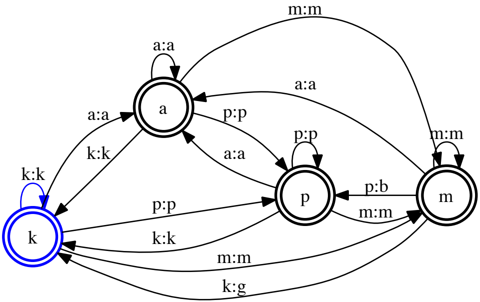


ISL functions: automata characterization



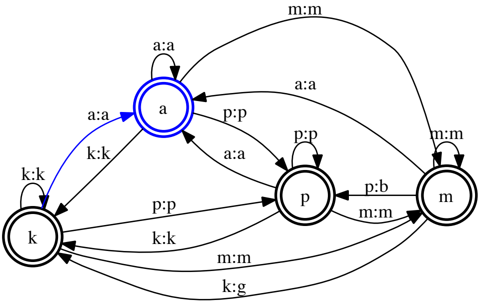
k ɑ m p a

ISL functions: automata characterization



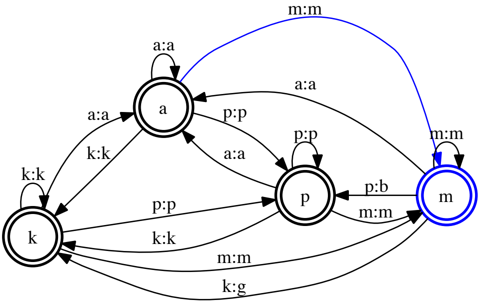
k a m p a
k

ISL functions: automata characterization



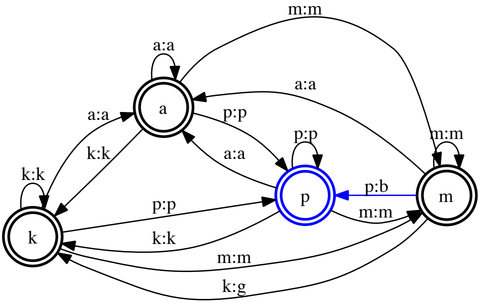
k a m p a
k a

ISL functions: automata characterization



k a m p a
k a m

ISL functions: automata characterization



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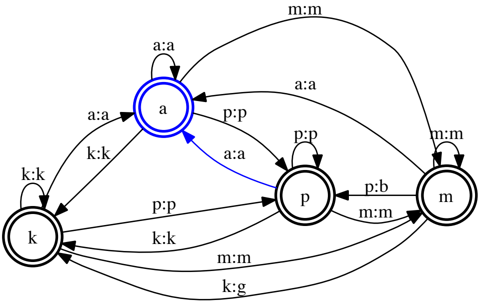
ISL functions: automata characterization



k a m p a
k a m b a

ISL functions: automata characterization

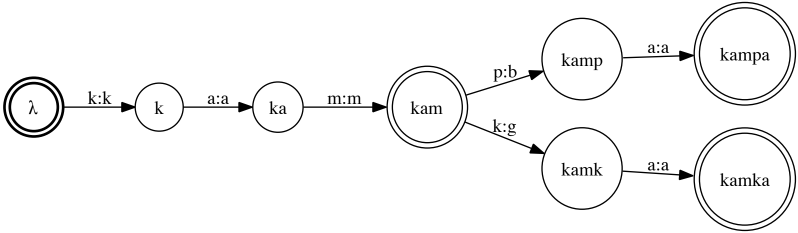
- FSTs are primarily for **classification**, but they are also useful for proving the class is learnable.
- Two provably correct algorithms for learning ISL functions:
  1. ISLFLA (Chandlee et al. 2014)
  2. SOSFIA (Jardine et al. 2014)

ISLFLA

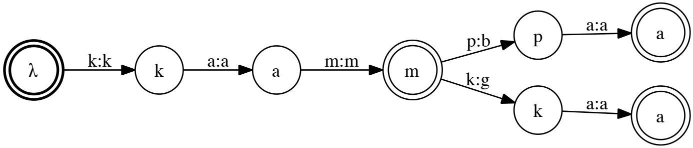
Given this data: {(kampa, kamba), (kamka, kamga), (kam, kam)...}

How can we learn the function (i.e., the FST)?

ISLFLA

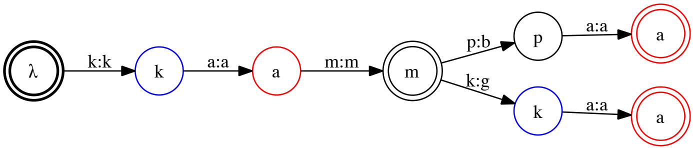


ISLFLA

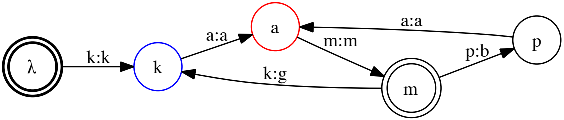


Inductive principle: if the target function is ISL-2, then all that matters is the previous input symbol.

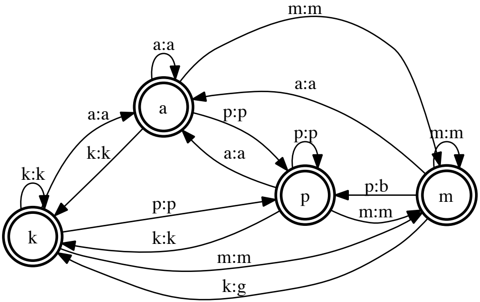
ISLFLA



ISLFLA



ISLFLA



How much of phonology is ISL?

- A review of P-Base (v1.95, Mielke 2008), which includes approximately 5500 patterns from 500 languages, revealed that 95% are ISL functions (Chandlee 2014, Chandlee & Heinz to appear).
- This includes local substitution, plus (all?) deletion, (all?) epenthesis, and all synchronic metathesis.

Non-ISL maps

(7) Sarcee
/na**s**ɣat**ʃ**/ ↦ [na**ʃ**ɣat**ʃ**] 'I killed them again'

(8) Kikongo
/tu-**n**ik-i**d**i/ ↦ [tu**n**iki**n**i] 'we ground'

(Cook 1984, Bennett 2013, Rose & Walker 2004)

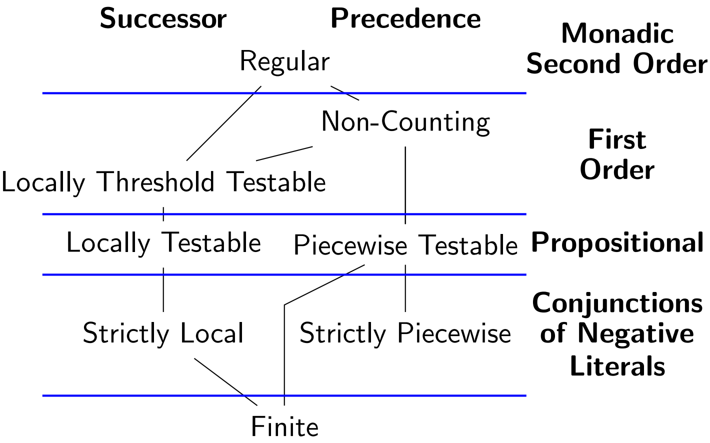
Non-ISL maps

- Long-distance substitution corresponds to markedness constraints against non-contiguous sequences:

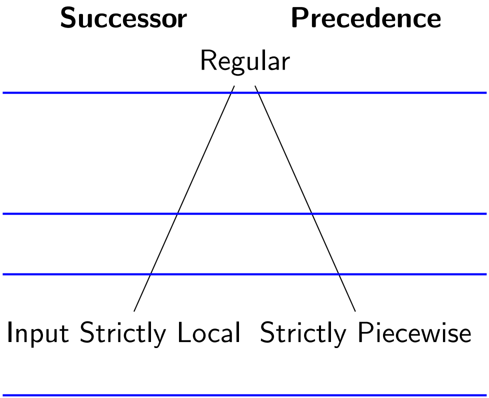
(9) a. *s...ʃ
b. *n...d

- Work on long-distance phonotactics indicates that these patterns are still computationally restricted when locality is interpreted as *precedence* (Heinz 2010).

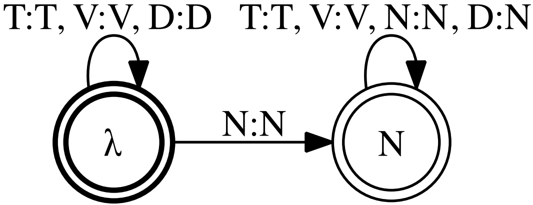
Subregular hierarchy of languages



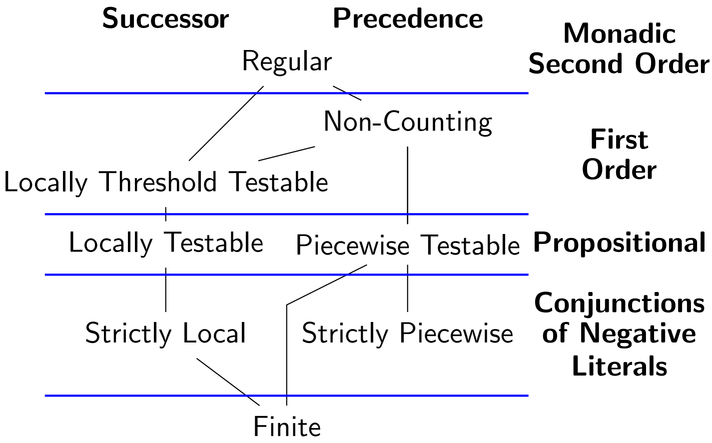
Subregular hierarchy of functions



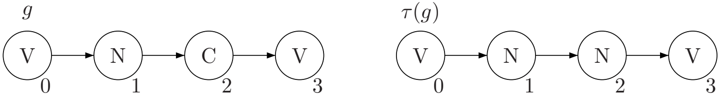
SP functions?



Subregular hierarchy of languages



Logical characterization of ISL



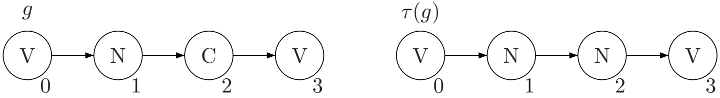
a. $NC(x) = (\exists y)[N(y) \wedge C(x) \wedge y \triangleleft x]$

b. $\varphi^0_N(x) = N(x) \vee NC(x)$

c. $\varphi^0_C(x) = C(x) \wedge \neg NC(x)$

d. $\varphi^0_V(x) = \mathit{true}$

Logical characterization of SP



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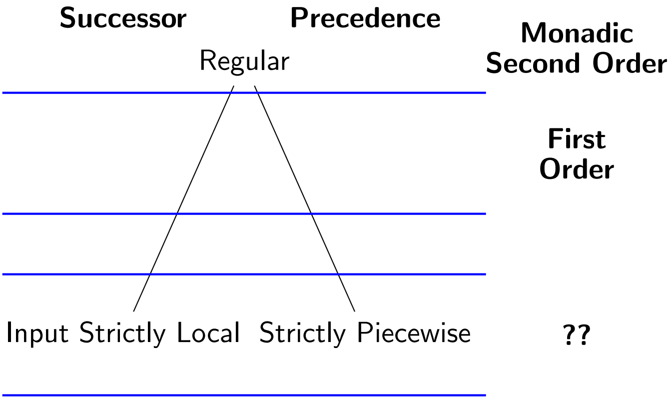
d. $\varphi^0_V(x) = true$

Logical characterization

Question: what logic is sufficiently expressive for ISL and SP functions?

Subregular hierarchy of functions



Logical characterizations

- The distinction between local and long-distance phonological maps is in the representation, not the computational complexity.
- Beyond strings, the same types of logical formulae can also be defined for other representations, such as autosegmental representations (Jardine 2016) and metrical trees.

Conclusions

- Locality has been an implicit guideline for phonological formalisms (rules and constraints), but it is also a defining property of the phonological mappings themselves.
- Identifying a restrictive computational complexity class for phonology has implications for both typology and learning.
- The use of logical characterizations in phonology provides a unified analytical framework for studying the computational nature of a range of phenomena.

Thank you!

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