Tone: Computation, Representation, and Learning

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- The computational perspective on phonology teaches us much about the nature of tone

- Phonological tone teaches us much about the computational nature of phonology

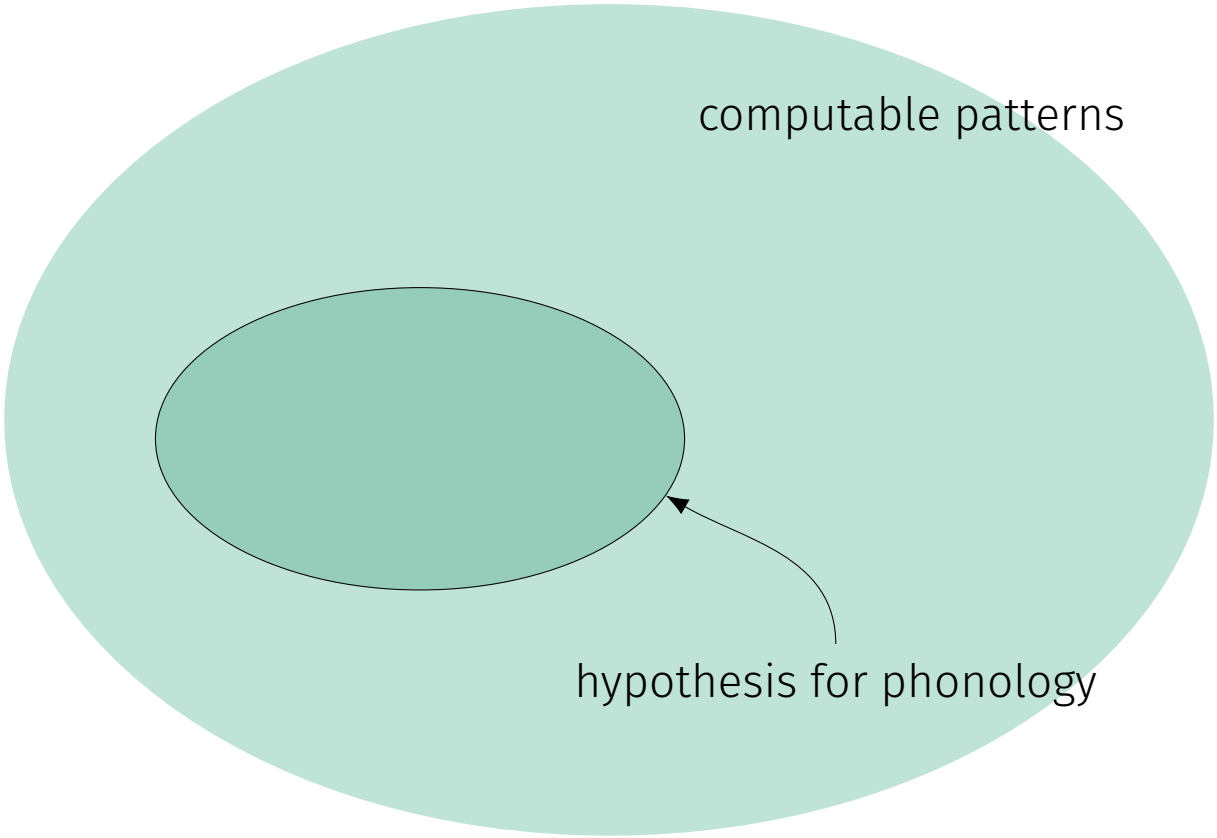
Hyman (2011):

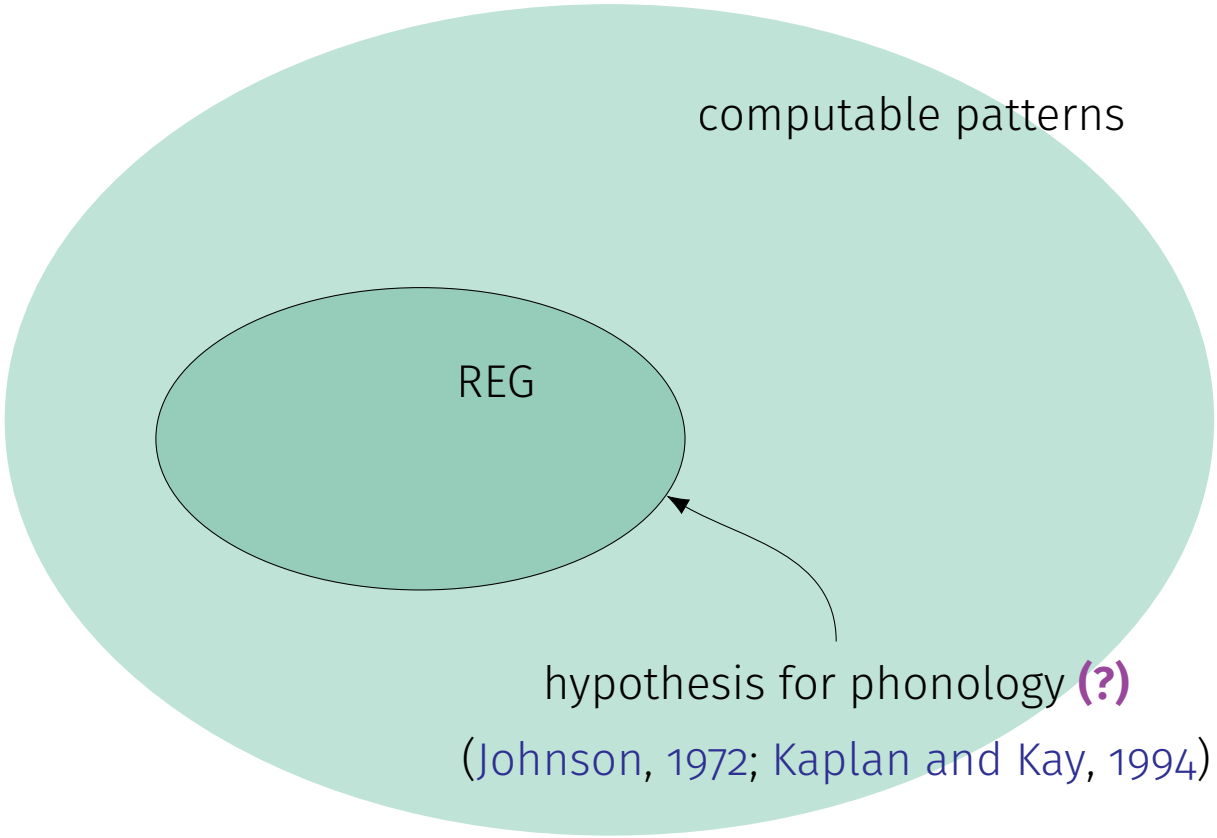
> "[T]one can do everything that segmental and metrical phonology can do, but the reverse is not true. This is especially true of the long-distance effects that tone exhibits...
>
> **[A]nyone who is interested in the outer limits of what is possible in phonology would thus be well-served to understand how tone systems work.**"

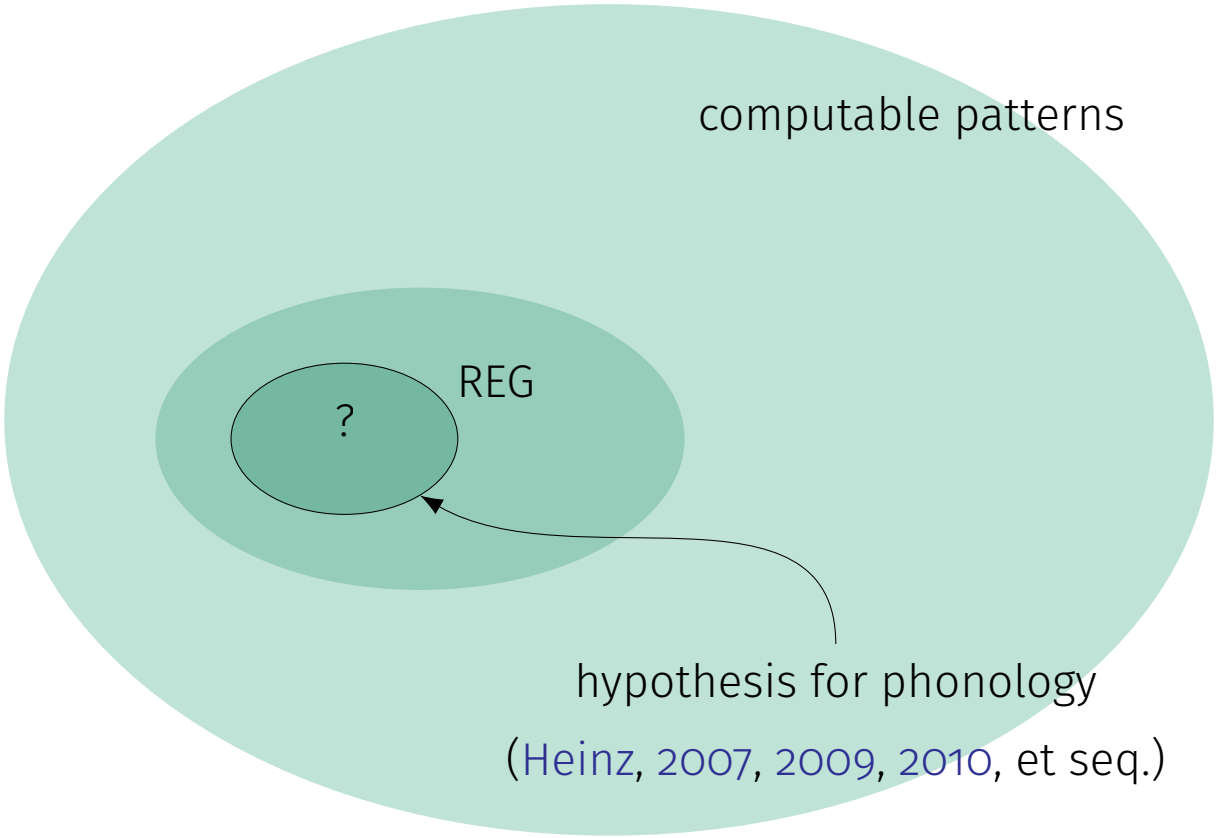
- **Theoretical computational phonology:**
  What computational principles define the outer limits of what is possible in phonology?

Heinz (2018):

> There are computational laws that make "strong predictions ... about which logically possible phonological generalizations are not humanly possible ones."


computable patterns
hypothesis for phonology


computable patterns
REG
hypothesis for phonology (?)
(Johnson, 1972; Kaplan and Kay, 1994)


computable patterns
REG
?
hypothesis for phonology
(Heinz, 2007, 2009, 2010, et seq.)

- **Computationally,** tone appears different (Jardine, 2016, 2017, 2020)
- In this talk:
  - **melody locality** as a hypothesis for how tonal phonotactics are computed
  - this hypothesis comes with its own **learning model**
  - computational evidence that **tone is represented differently**

Computation and well-formedness

Computation and well-formedness

- What are possible...
  - well-formedness constraints (**phonotactics**)?

    (Chomsky and Halle, 1965; Kisseberth, 1970; Prince and Smolensky, 1993)

  - maps from underlying representations to surface representations (**processes**)?

    (Chomsky and Halle, 1968; Prince and Smolensky, 1993)

Computation and well-formedness

- What are possible...
  - well-formedness constraints (**phonotactics**)?

    (Chomsky and Halle, 1965; Kisseberth, 1970; Prince and Smolensky, 1993)

  - maps from underlying representations to surface representations (**processes**)?

    (Chomsky and Halle, 1968; Prince and Smolensky, 1993)

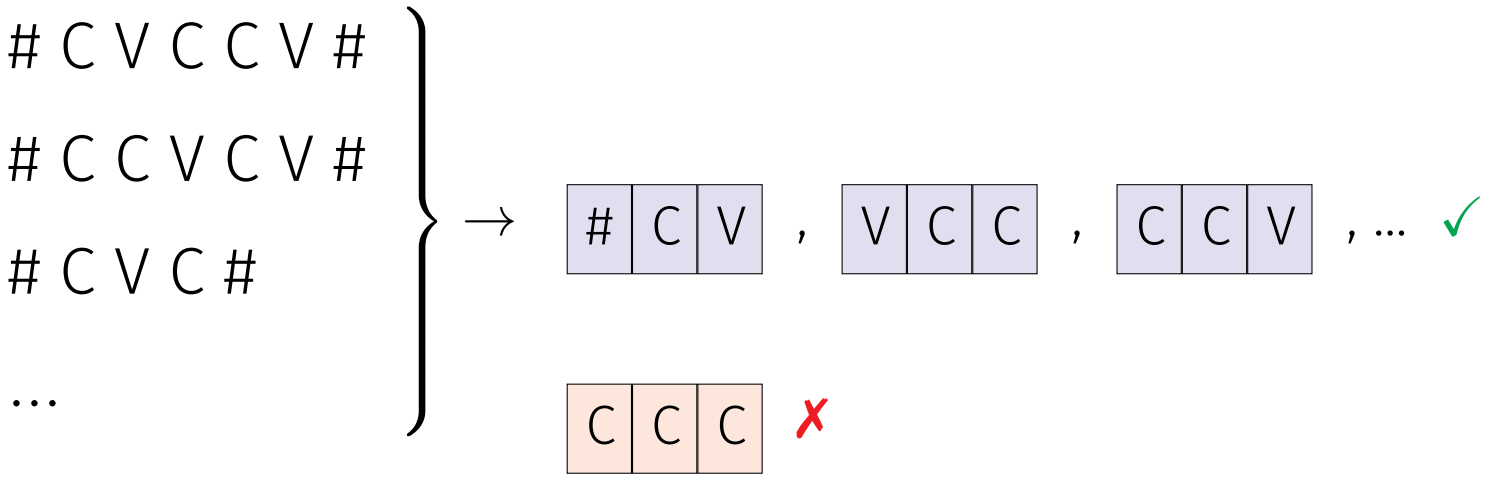
Computation and well-formedness

- Computationally **local**: computable by scanning string with a fixed window (McNaughton and Papert, 1971; Rogers and Pullum, 2011)

*CCC (Kisseberth, 1970)

Computation and well-formedness

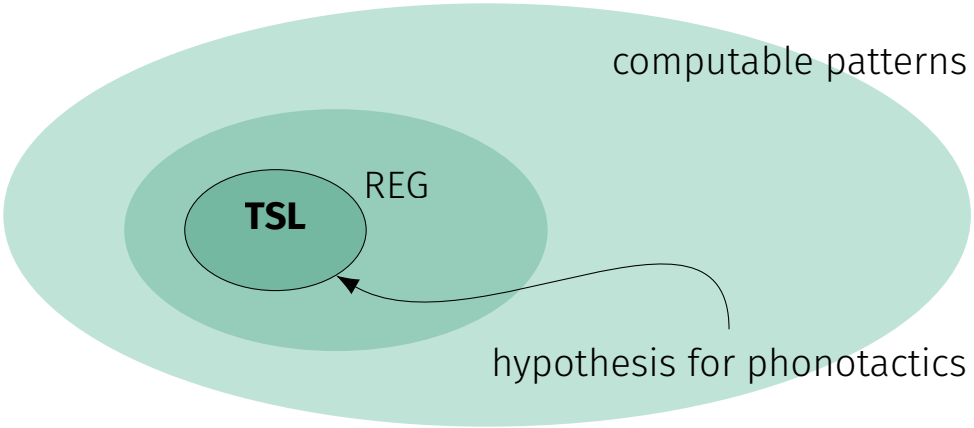
- Computationally **local**: **learnable** by scanning example strings with a fixed window (García et al., 1990; Heinz, 2010)



Computation and well-formedness

- Hypothesis: phonotactics are **(tier-based) strictly local**

(Heinz et al., 2011; McMullin and Hansson, 2019)



- This is the standard for learning phonotactics (Hayes and Wilson, 2008; Jardine and Heinz, 2016; Jardine and McMullin, 2017; Gallagher and Wilson, 2018; McMullin and Hansson, 2019; Gouskova and Gallagher, 2020)

Computation and well-formedness

- Tone has unique **combinations of local and long-distance** phonotactics
- **Tier projection doesn’t work for tone**
- Tone requires a distinct **melody projection**

Well-formedness in tone: Two examples

Well-formedness in tone

- **Prinmi** (Tibeto-Burman; Ding, 2006; Hyman, 2009):[1]
  - Exactly one H span per word
  - H span only one or two moras

bɨ́brobroge	‘as for roasted flour with honey’	HLLL	*LLLL
bɨ́ɬípɜtsɨ	‘sunflower’	HHLL	*HLLH
dʒjodʒɨmɜ́ɬe	‘buffalo tail’	LLHL	*LHHH
ɹətʃɨʃógé	‘as for clean liquor’	LLHH	

[1] For clarity, not all diacritics transcribed

Well-formedness in tone

- **(Northern) Bemba** (Bantu; Bickmore and Kula, 2013)
  - Last H extends to end of word

tu-ka-pat-a	'we will hate'	LLLL	*LHHLL
tu-léé-pát-á	'we are hating'	LHHHH	
bá-ká-fík-á	'they will arrive'	HHHH	

  - All other Hs spread exactly two moras (obeying OCP)

béléeng-á	'read!'	HHLH	*HHHLH
tú-lúb-ul-ul-é	'we should explain '	HHLLH	*HLLLH
bá-a-pít-ílé	'they passed'	HLHHH	
twáá-ku-láá-pá	'we will be drawing (water)'	HHLHHH	

Well-formedness in tone

- These patterns are **not local**
  - Prinmi:

LHLL	*LHLH
LHLLL	*LHLLH
LHLLLL	*LHLLLH
⋮	⋮

  - Bemba:

LHHLH	*LHHLL
LHHLLH	*LHHLLL
LHHLLLLH	*LHHLLLL
⋮	⋮

Well-formedness in tone

- These patterns have **local aspects**
  - Prinmi: LHLL, LHHL, *LHHH
  - Bemba: LHHLH, *LHLLH, *LHHHLH
- And we need to distinguish between the two
  - Prinmi: LHHL, *HLLH
- This kind of interaction is common in tone (Jardine, 2019, 2020)

Melody locality

Melody locality

- **With the right representation**, these patterns can be computed & learned locally

- We use a combination of **melody and local** constraints

- This approximates the information in autosegmental representations (Leben, 1973; Williams, 1976; Goldsmith, 1976)

Melody locality

- For **long-distance** aspects, project a **melody string** from the surface string

L H H L L

Melody locality

- For **long-distance** aspects, project a **melody string** from the surface string

Melody locality

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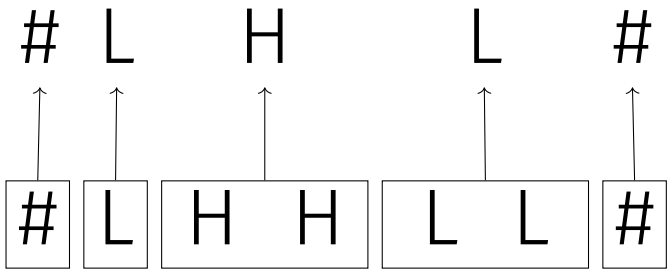


Melody locality

- Well-formedness evaluated with **two strictly local grammars**:

	Prinmi
– One for the **surface string**	*HHH
– One for its **melody string**	*HLH, *#L#

Melody locality

- Prinmi:
  - Grammar for **surface string:** *HHH
  - Grammar **melody string:** *HLH, *#L#

	string	melody	well-formed?
a.	#LHHLL#	#LHL#	✓

Melody locality

- Prinmi:
  - Grammar for **surface string:** *HHH
  - Grammar **melody string:** *HLH, *#L#

	string	melody	well-formed?
a.	#LHHLL#	#LHL#	✓
b.	#LHHHL#	#LHL#	✗

Melody locality

- Prinmi:
  - Grammar for **surface string:** *HHH
  - Grammar **melody string:** *HLH, *#L#

	string	melody	well-formed?
a.	#LHHLL#	#LHL#	✓
b.	#LHHHL#	#LHL#	✗
c.	#LHHLLH#	#LHLH#	✗

Melody locality

- Prinmi:
  - Grammar for **surface string:** *HHH
  - Grammar **melody string:** *HLH, *#L#

	string	melody	well-formed?
a.	#LHHLL#	#LHL#	✓
b.	#LHHHL#	#LHL#	✗
c.	#LHHLLH#	#LHLH#	✗
d.	#LLL#	#L#	✗

Melody locality

- The Prinmi pattern is **all and only** the strings that obey
  - *HHH in the **surface string**
  - *HLH, *#L# in its **melody string**

HLLL	*LLLL
HHLL	*HLLH
LHLL	*LHHH
LHHL	*LHHLH
⋮	⋮

- Prinmi tone is **melody local**

Melody locality

- The Bemba pattern is that for which ...
  - Last H extends to end of word
    LLLL *LHHLL
    LHHHH
    HHHH
  - All other Hs spread exactly two moras (obeying OCP)
    HHLH *HHHLH
    HHLLH *HLLLH
    HLHHH
    HHLHHH
- Bemba is also melody local

Melody locality

- Bemba
  - Grammar for **surface string:** *#HLL, *LHLL, *HHHL
  - Grammar **melody string:** *HL#

	string	melody	well-formed?
a.	#HHLLH#	#HLH#	✓
b.	#LHHHH#	#LH#	✓

Melody locality

- Bemba
  - Grammar for **surface string:** *#HLL, *LHLL, *HHHL
  - Grammar **melody string:** *HL#

	string	melody	well-formed?
a.	#HHLLH#	#HLH#	✓
b.	#LHHHH#	#LH#	✓
c.	#LHLLH#	#LHLH#	✗
d.	#HLLHH#	#HLH#	✗

Melody locality

- Bemba
  - Grammar for **surface string:** *#HLL, *LHLL, *HHHL
  - Grammar **melody string:** *HL#

	string	melody	well-formed?
a.	#HHLLH#	#HLH#	✓
b.	#LHHHH#	#LH#	✓
c.	#LHLLH#	#LHLH#	✗
d.	#HLLHH#	#HLH#	✗
e.	#HHLLL#	#HL#	✗

Melody locality

- Melody local grammars capture Prinmi and Bemba
- Two kinds of constraints working in tandem:
  - Local constraints restricting melody
  - Local constraints restricting how tones are realized on surface string

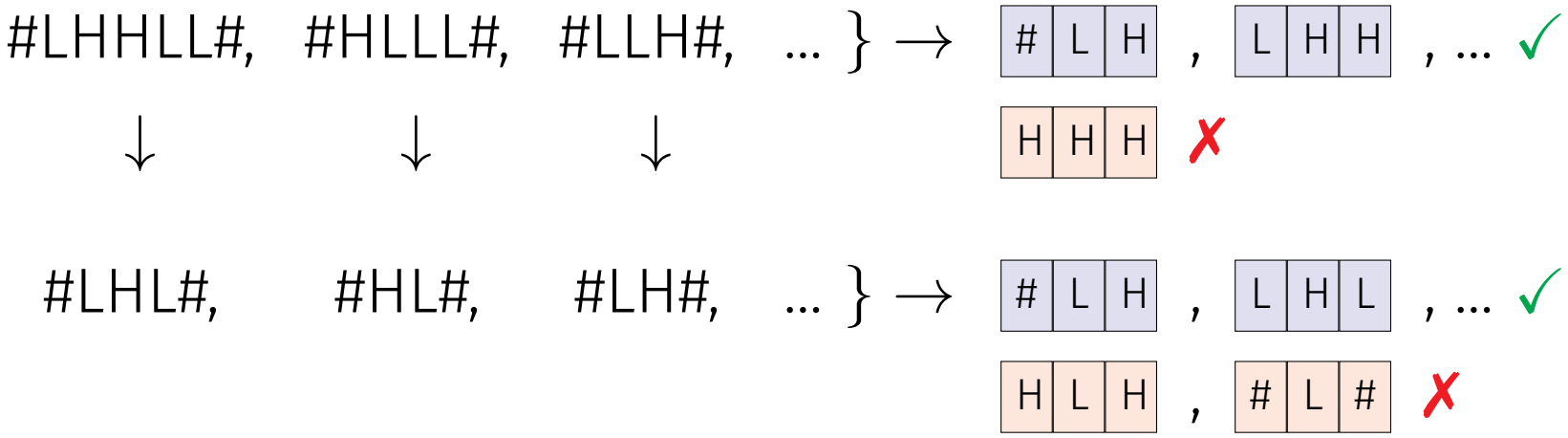
Melody locality

- **Hypothesis**: tonal phonotactics are **melody local**
- Jardine (2020) shows a number of tone patterns[2] are melody local

[2]With a close exception in Karanga Shona (Odden, 1981; Hewitt and Prince, 1989).

Melody locality

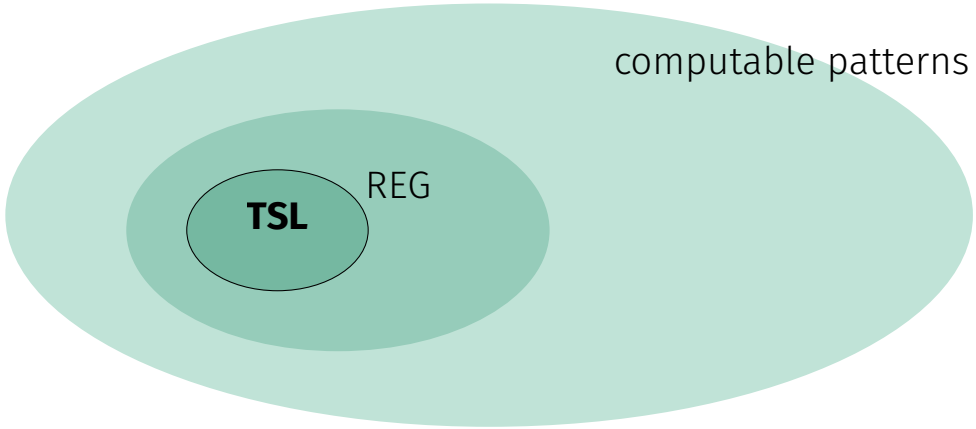
- Learning model: local learning on both example strings and their melodies



Discussion

Discussion: Comparison with TSL

- **Tier-based strictly local** models are the current standard for learning phonotactics (Hayes and Wilson, 2008; Jardine and Heinz, 2016; Jardine and McMullin, 2017; Gallagher and Wilson, 2018; McMullin and Hansson, 2019; Gouskova and Gallagher, 2020)



Discussion: Comparison with TSL

- Idea: **project** relevant segments on a **tier**

(Hayes and Wilson, 2008; Heinz et al., 2011; McMullin and Hansson, 2019)

Chumash *s...ʃ (Applegate, 1972)

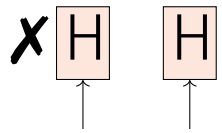
'his former Indian name'

✗ (ill-formed)

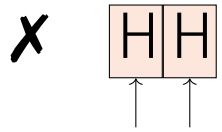
Discussion: Comparison with TSL

- Prinmi is not TSL
- Tier projections conflate adjacent and non-adjacent H TBUs

*HH



(ill-formed)



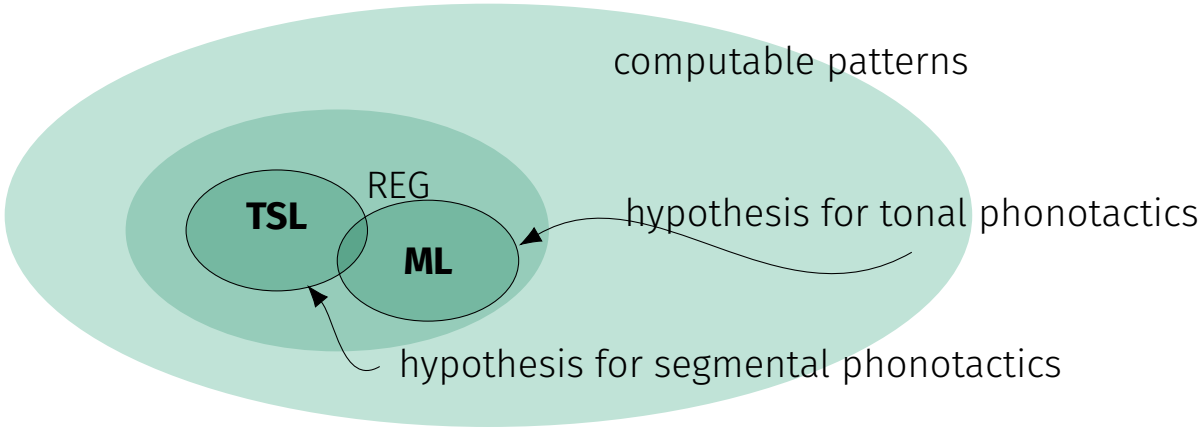
tõpúmɜ́łe ‘donkey tail’

Discussion: Comparison with TSL

- Bemba is not TSL for a similar reason
- Other non-TSL patterns: Unbounded tone plateauing (Kisseberth and Odden, 2003; Hyman, 2011), several accent patterns in Japanese dialects (Haraguchi, 1977), Karanga Shona (Hewitt and Prince, 1989)
- TSL models cannot learn tone **no matter what**

Discussion: Comparison with TSL

- Hypothesis: tone uses **melody local** computation; segmental phonology uses TSL computation



- Both are local; the difference is representation

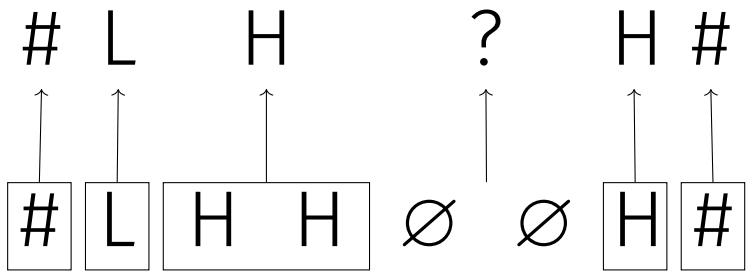
Discussion: Remaining issues

- Computing tone **processes**:
  - Mamadou (in progress) proposes melody local **functions** that work in the same way

  - (See also Rawski and Dolatian 2020 and Chandlee and Jardine (forthcoming))

Discussion: Remaining issues

- Incorporating other aspects of representation, such as **underspecification**



(for, e.g., Luganda (Hyman and Katamba, 2010), Saramaccan (Good, 2004))

Conclusion

- Melody locality is a **necessary** condition for learning tonal phonotactics

- This is both distinct from, and similar to, learning segmental phonology

- It is **not sufficient**, and much remains to be done!

Thank you!

Thanks to Nik & Florian for inviting me, and to Deen Mamadou, Chris Oakden, Jon Rawski, Hossep Dolatian, Arto Anttila, some anonymous reviewers at *NLLT*, Jeff Heinz, Bill Idsardi, Jane Chandlee, and probably others I have forgotten to mention (sorry!) for their advice and comments on this work.

Appendix

Karanga non-assertive verb stems (Odden, 1994)

H-toned	L-toned
H	
HL	LH
HLH	LHL
HHLH	LHHL
HHHLH	LHHLL
HHHLLH	LHHLLL
HHHLLLH	LHHLLLL
…	…

Surface : *#LL, *#HLL, *#HHLL, *HHHH, *LHLL, *LHHH, *HH#
Melody **(almost)**: *#HL#, *HLHL, *LHLH