# Tone, computation, and phonological theory

Adam Jardine


February 6, 2020
Haverford College

- 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 both within and across words. …
>
> **[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."

**This talk is about...**

- how, **computationally, tone is different** than segmental[1] phonology
- what the **limits** are of cross-linguistic variation in tone
- how the computational study of tone leads to novel insights about **representations** and **learning** in phonology *as a whole*

[1] ..and metrical?

## Computation and typology

- 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 typology

- **Attested**: all sibilants agree in [±anterior]:

| | |
|---|---|
| [ʃ-api-tʃʰol-it] | ‘I have a stroke of good luck’ |
| [s-api-tsʰol-us] | ‘he has a stroke of good luck’ |
| [ʃ-api-tʃʰol-uʃ-waʃ] | ‘he had a stroke of good luck’ |
| [ha-ʃ-xintila-waʃ] | ‘his former Indian name’ |
| *[s-api-tʃʰol-us] | |
| *[ha-s-xintila-waʃ] | |

Inseño Chumash (Applegate, 1972)

## Computation and typology

- **Unattested**: even and odd sibilants agree in [±anterior]:

[ha-ʃ-xintila-waʃ]
[ʃ-api-tʃʰol-us-was]
*[ha-s-xintila-waʃ]
*[s-api-tʃʰol-us-waʃ]

"Agreeing pairs" (not attested)

- Predicted by ABC in OT (McMullin and Hansson, 2019)

## Computation and typology

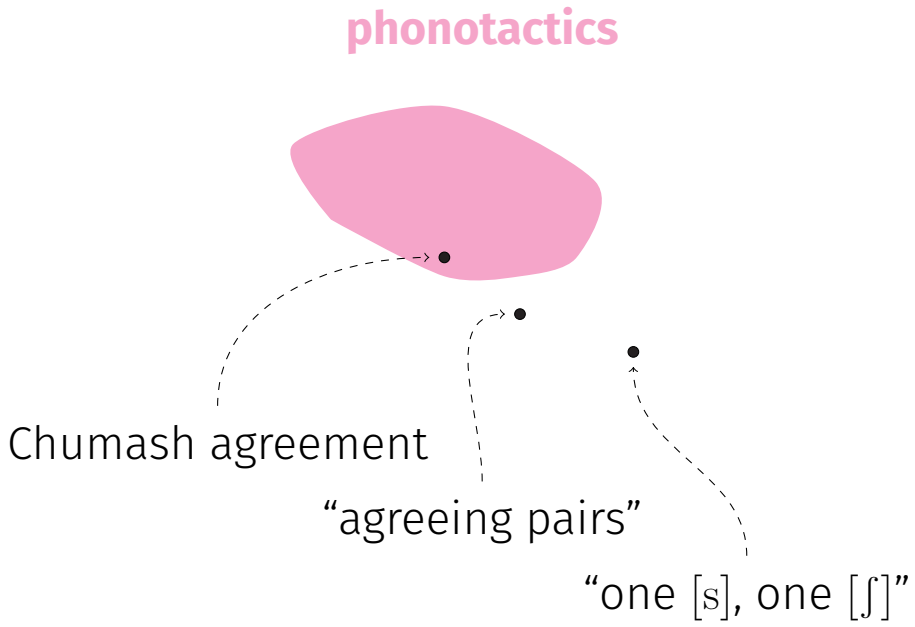
- **Unattested**: for each [−ant] sibilant there is exactly one following [+ant] sibilant:

| | |
|---|---|
| [ha-s-xintila-waʃ] | *[ha-ʃ-xintila-waʃ] |
| [s-api-ts$^{h}$ol-uʃ-waʃ] | *[ʃ-api-tʃ$^{h}$ol-uʃ-waʃ] |
| [sasasaʃaʃaʃa] | *[sasaʃaʃaʃaʃa] |

"One [s], one [ʃ]" (not attested)

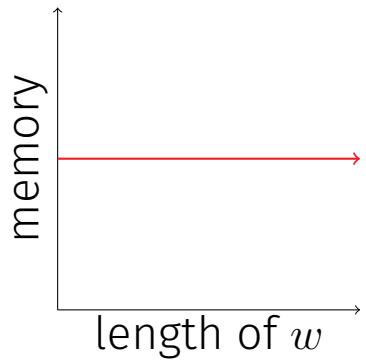
- Analogue of center embedding in syntax (Chomsky, 1956)

# Computation and typology

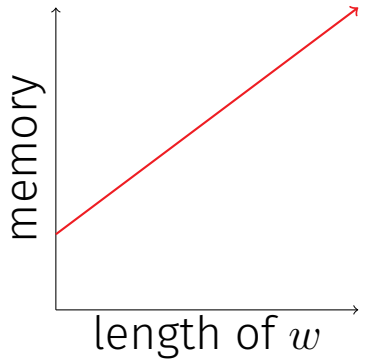


## Computation and typology

- Johnson (1972); Kaplan and Kay (1994): phonology is **regular**

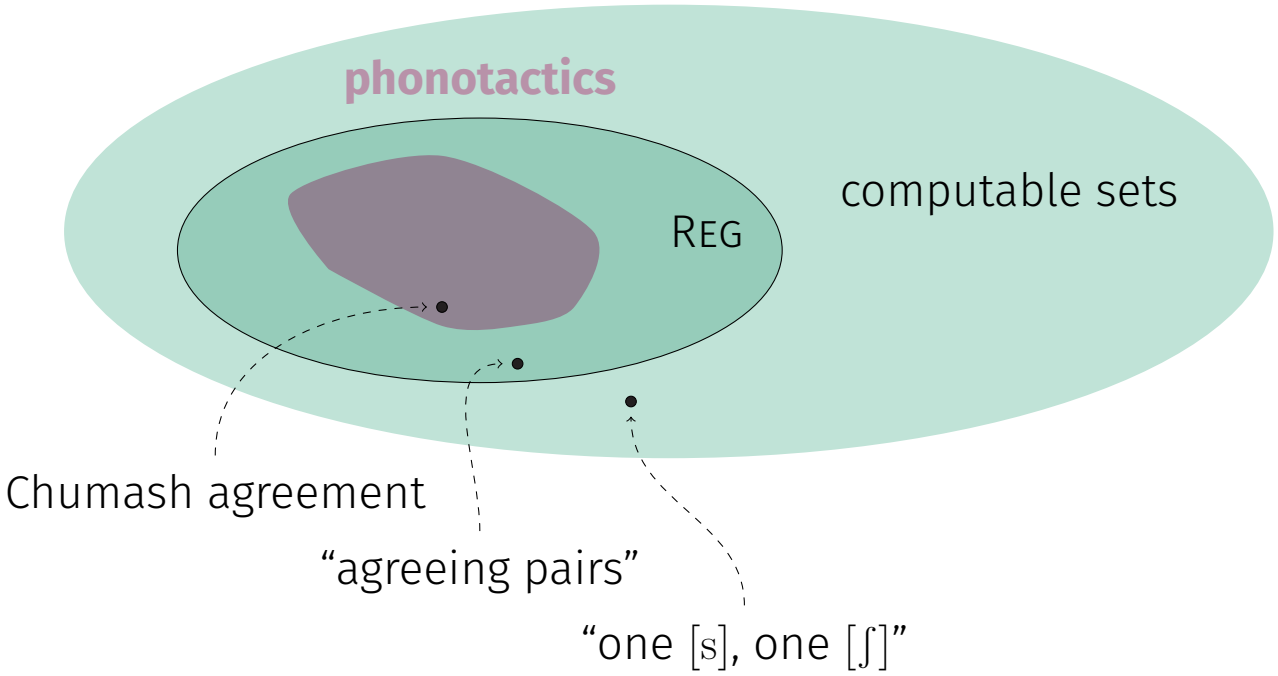



**regular**

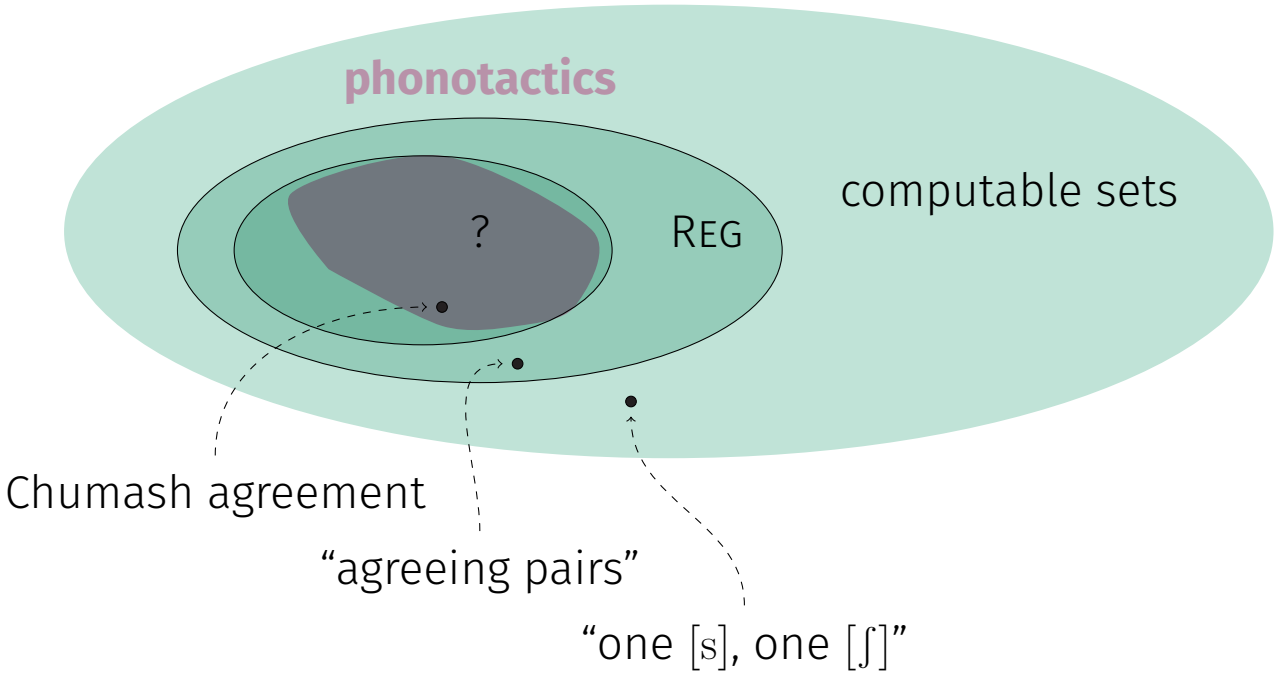



**non-regular**

# Computation and typology



# Computation and typology



## Computation and typology

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

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

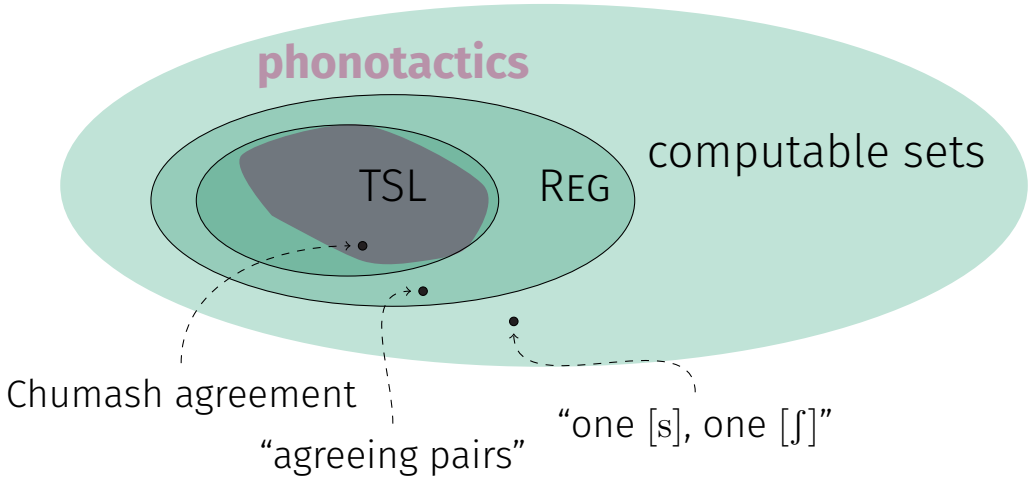
  - maps from underlying representations to surface representations (**processes**)?

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

# Computation and typology

- Phonotactics are **sub-regular sets** (Heinz, 2009, 2010)
  - Hypothesis: phonotactics are **tier-based strictly local**

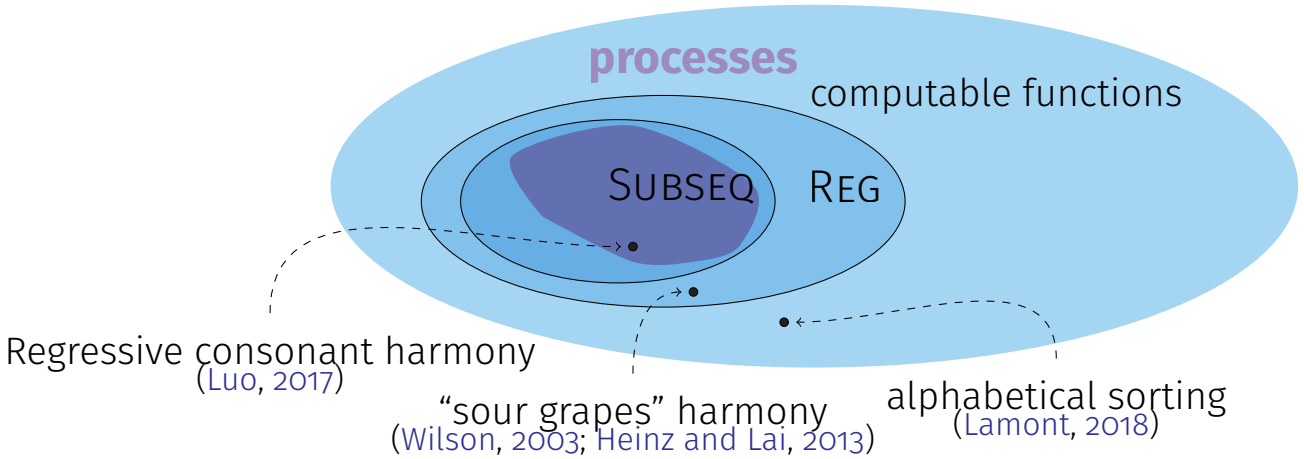
(Heinz et al., 2011; McMullin and Hansson, 2019)



# Computation and typology

- Processes are sub-regular **functions** (Heinz and Lai, 2013, et seq.)
  - Hypothesis: processes are **subsequential**

(Heinz and Lai, 2013; Payne, 2017; Luo, 2017)



## Computation and tone

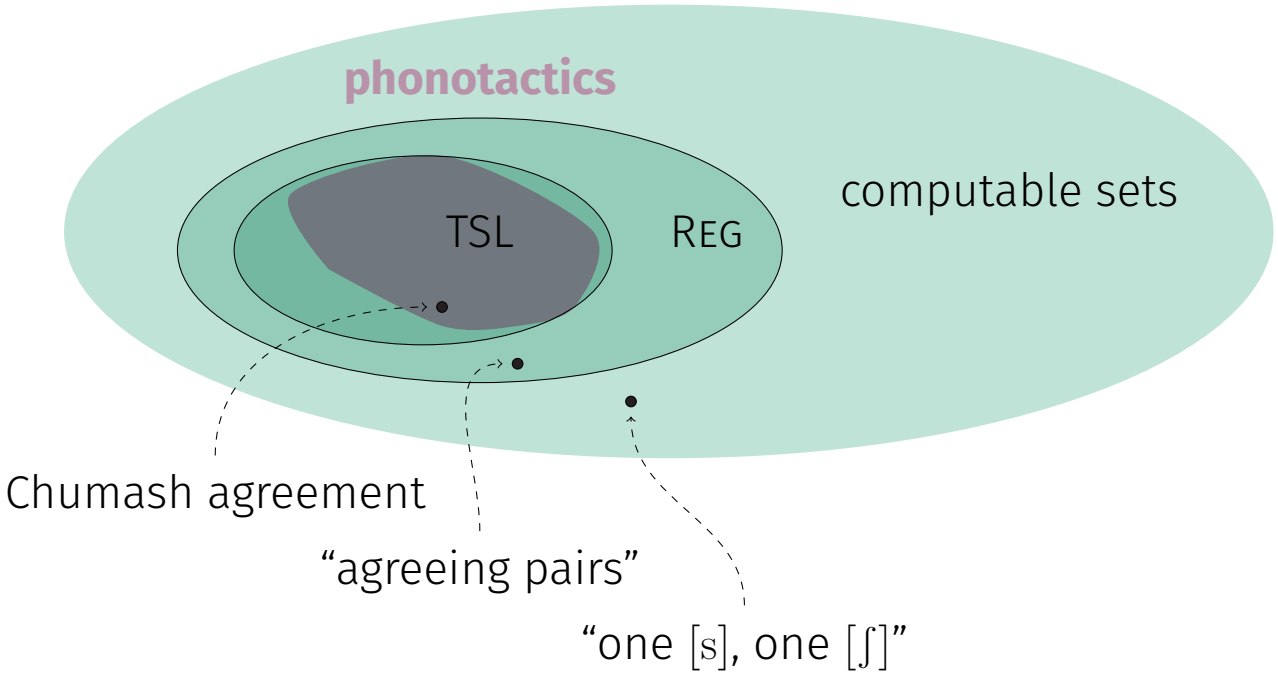
- Both hypotheses fail with tone:
  - Tonal phonotactics are *not* tier-based strictly local

    (Graf, 2017; Jardine, 2019, to appear)
  - Tonal processes are *not* subsequential (Jardine, 2016)
- However, many tonal...
  - phonotactics are **melody-local** (Jardine, to appear)
  - processes are **input melody-local**

    (Mamadou and Jardine, in progress)

# Tonal phonotactics and melody-local grammars

# Tier-based strictly local sets



## Tier-based strictly local sets

- Computationally **local**: computable by scanning string with a fixed window (Rogers and Pullum, 2011; Rogers et al., 2013)

*CCC (Kisseberth, 1970)

## Tier-based strictly local sets

- Long-distance phonotactics are not local in this way (Heinz, 2010)

Chumash $^{*}\text{s}\ldots\int$

| | |
|---|---|
| # h a ∫ x i n t i l a w a ∫ # | 'his former Indian name' |
| # h a s x i n t i l a w a ∫ # | (ill-formed) |

# Tier-based strictly local sets

- A strategy is to adopt a **tier-projection**

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

Chumash sibilant tier

| | |
|---|---|
| # h a ʃ x i n t i l a w a ʃ # | ‘his former Indian name’ |
| # h a s x i n t i l a w a ʃ # | (ill-formed) |

# Tier-based strictly local sets

- A strategy is to adopt a **tier-projection**

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

Chumash *sʃ with sibilant tier


'his former Indian name'


✗ (ill-formed)

# Tier-based strictly local sets

- **Tier-based strictly local**: local on a tier-projection

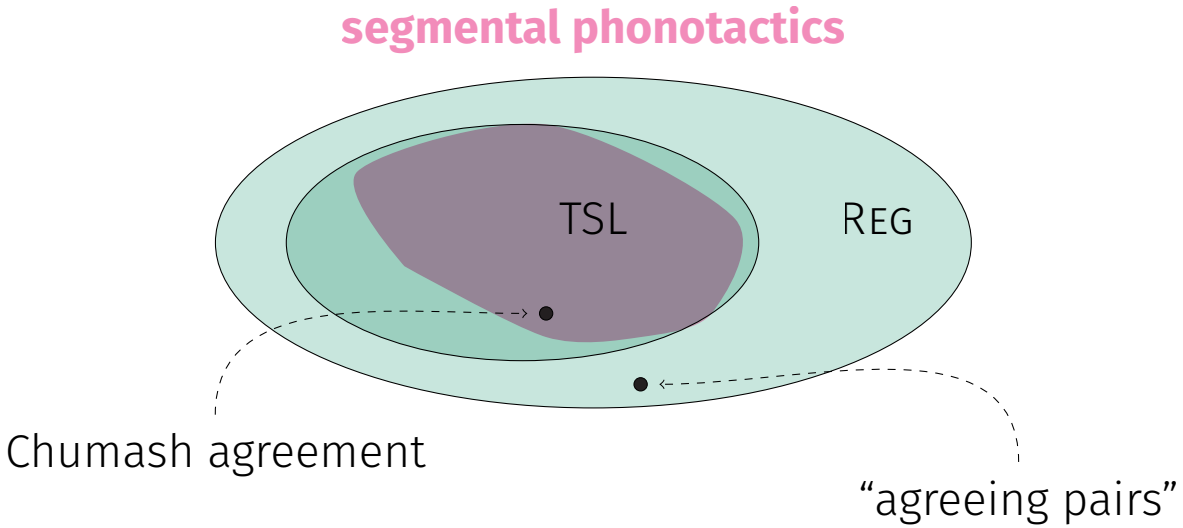
(Heinz et al., 2011)

Chumash *sʃ with sibilant tier


'his former Indian name'


✗ (ill-formed)

# Tier-based strictly local sets




- Tier-projection is the standard for learning long-distance 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)

## Challenges for TSL in tone

- Tone has local and non-local patterns that are not TSL

- Two examples:
  - Prinmi (Ding, 2006; Hyman, 2009)
  - Unbounded tone plateauing (Hyman, 2011; Jardine, 2016)

- For more see Jardine (2019, to appear)

# Challenges for TSL in tone

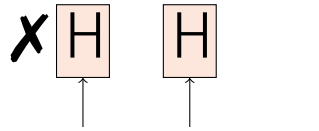
- Prinmi (Ding, 2006):
  - Exactly one H span per word
  - H span can be one or two moras

| | | |
|---|---|---|
| bɨ́bᴵobᴵoge | ‘as for roasted flour with honey’ | HLLL |
| bɨ́ɬípɜtsɨ | ‘sunflower’ | HHLL |
| tʃ’ɨn̥ĩ́dʒjɛ̃ɹə | ‘dog-nose groups’ | LHLL |
| tõpúmɜ́ɬe | ‘donkey tail’ | LHHL |
| dʒjõdʒɨmɜ́ɬe | ‘buffalo tail’ | LLHL |
| ɹətʃɨʃṍgé | ‘as for clean liquor’ | LLHH |
| | | *LLLL |
| | | *HLLH |
| | | *LHHH |

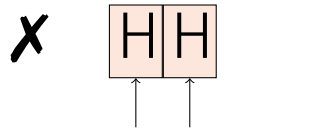
## Challenges for TSL in tone

- Tier projections cannot distinguish spans of H

*HH




(ill-formed)




tõpúmɜ́ɬe ‘donkey tail’

- Prinmi is not TSL

## Challenges for TSL in tone

- Unbounded tone plateauing (UTP) in Luganda

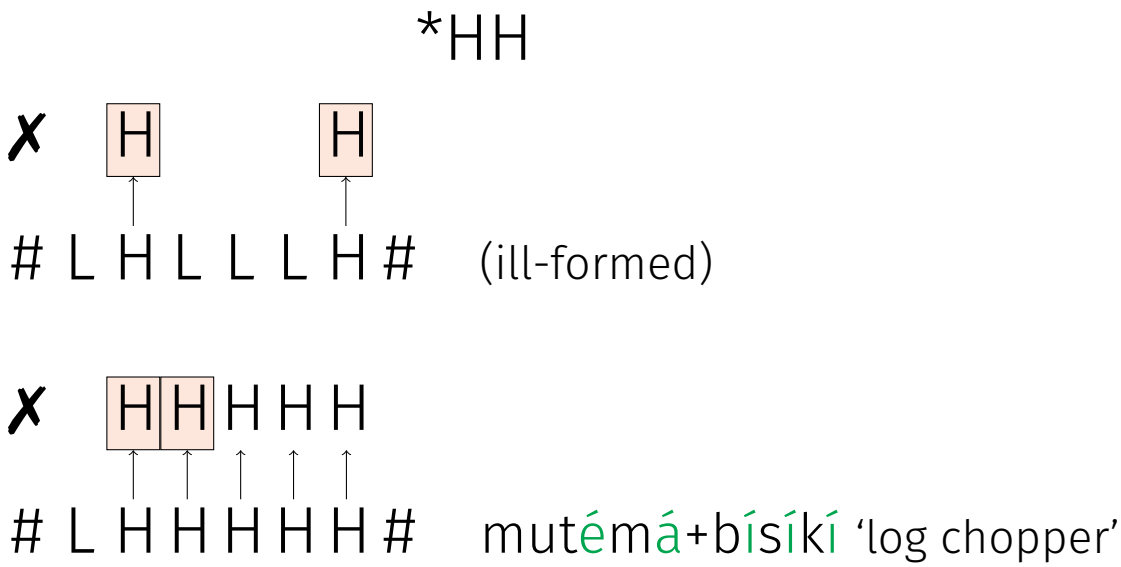
  (Hyman and Katamba, 2010; Hyman, 2011)

  - At most one H span per word
  - H span can be of any length

| | | |
|---|---|---|
| ‘book’ | kitabo | LLL |
| ‘chopper’ | mutéma | LHL |
| ‘log’ | kisikí | LLH |
| ‘log chopper’ | mutémá+bísíkí | LHHHHH |
| | *mutéma+bisikí | *LHLLLH |

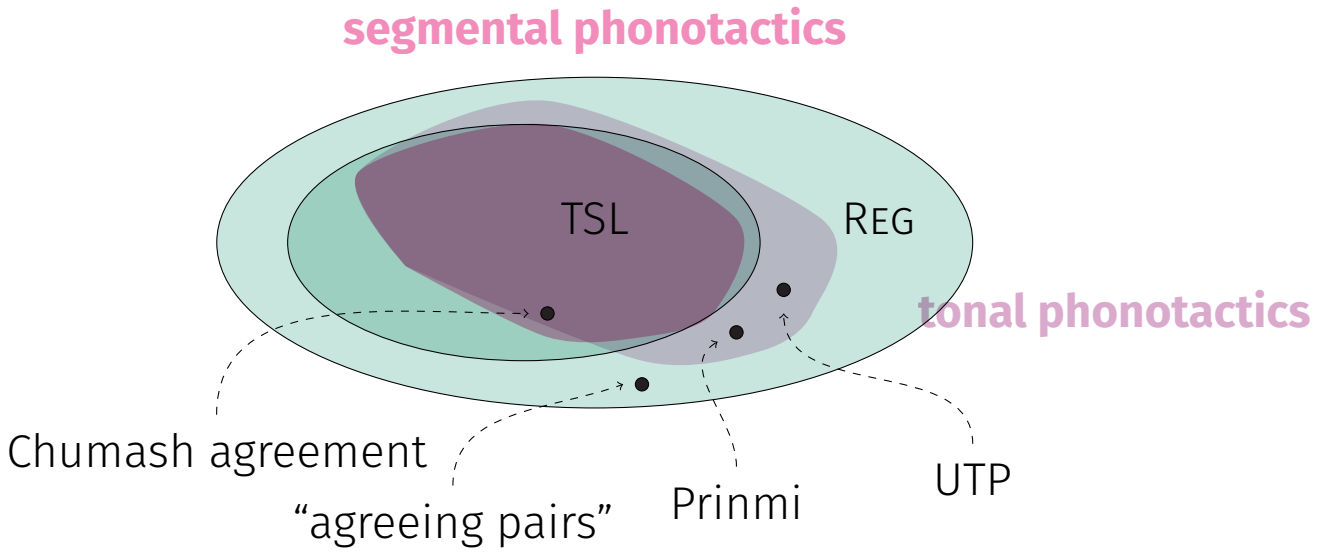
## Challenges for TSL in tone

- Tier projections cannot distinguish spans of H




- UTP is also not TSL

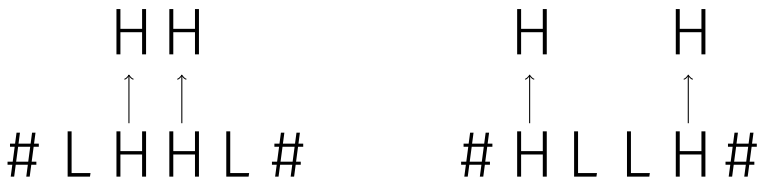
# Challenges for TSL in tone



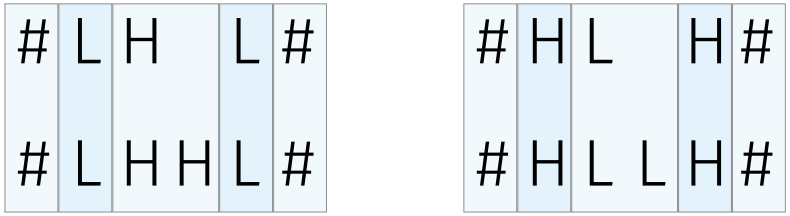

- Other non-TSL patterns: Copperbelt Bemba (Bickmore and Kula, 2015), several accent patterns in Japanese dialects (Haraguchi, 1977), Karanga Shona (Hewitt and Prince, 1989)

## Melody-local sets

- Tier-projection cannot distinguish *spans* of associated TBUs




- Autosegmental **melodies** can (Leben, 1973; Williams, 1976; Goldsmith, 1976)



## Melody-local sets

- **Melody-local (ML)** sets are local over
  - the melody; **and**
  - the string of surface TBUs

(Jardine, to appear)

## Melody-local sets

- UTP:
  - melody: *HLH
  - string: (none)

✗ # L H L H #

# L H L L L H # *mutéma+bisikí

✓ # L H #

# L H H H H H # mutémá+bísíkí ‘log chopper’

## Melody-local sets

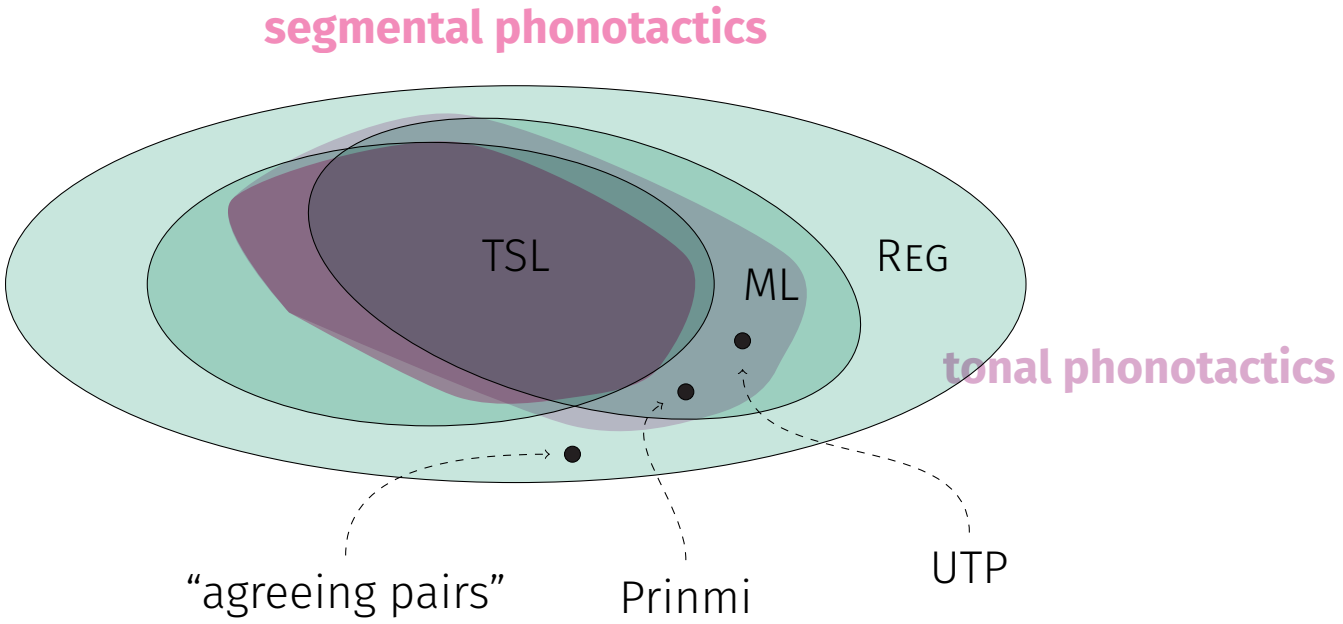
- Prinmi:
  - melody: *HLH
  - string: *HHH

✓ # L H L #
# L H H L # tõpúmɜ́łe ‘donkey tail’

✗ # H L H #
# H L L H # *HLLH

# L H #
✗ # L H H H # *LHHH

# Melody-local sets




- ML sets capture interactions in local and non-local phonotactics in tone, and they are learnable (Jardine, to appear)

# Tonal processes and input-melody local functions

## Subsequentiality and phonology

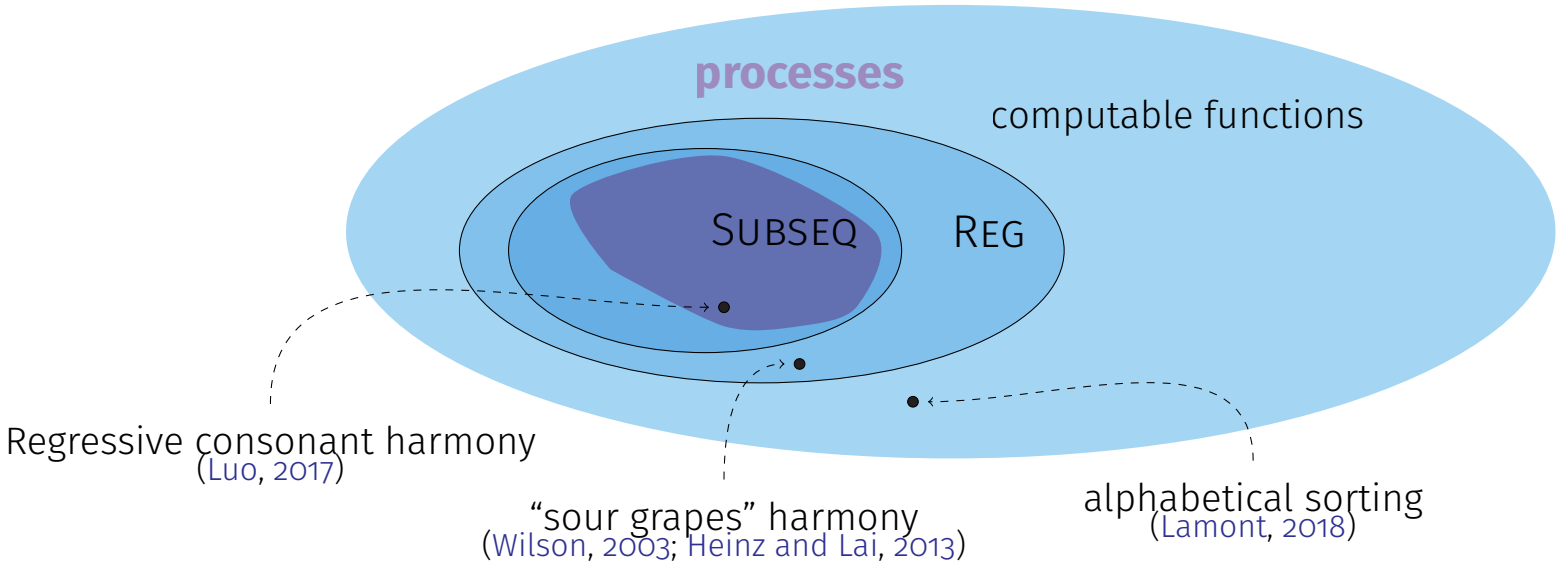
- Phonological patterns are also often considered as **processes**
- A process is a **function** from underlying representation and surface representations

| UR | | SR | |
|---|---|---|---|
| /s-api-tʃʰol-it/ | → | [ʃ-api-tʃʰol-it] | ‘I have a stroke of good luck’ |
| /s-api-tʃʰol-us/ | → | [s-api-tsʰol-us] | ‘he has a stroke of good luck’ |

Inseño Chumash (Applegate, 1972)

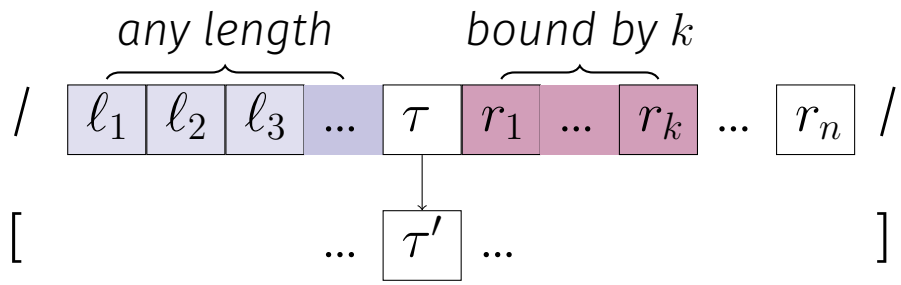
# Subsequentiality and phonology

- Hypothesis: phonological processes are **subsequential functions** (Heinz and Lai, 2013; Payne, 2017; Luo, 2017)



## Subsequentiality and phonology

- Subsequential: output can be determined deterministically in one direction




- (Determinisic $\neq$ no optionality; Heinz in progress)
- This aligns with Wilson's law that harmony is **myopic**

(Wilson, 2003, 2006; Kimper, 2012)

## Subsequentiality and phonology

- **'Sour grapes' (SG)** harmony: spread only when conditions are right on both sides of a target (Wilson, 2003, 2006)

| | UR | SR |
|---|---|---|
| / s … s̲ … s̲ … ʃ / → | [ s … s̲ … s̲ … ʃ] |
| / ʃ … s̲ … s̲ … ʃ / → | [ ʃ … ʃ̲ … ʃ̲ … ʃ] |

- SG is not subsequential (Heinz and Lai, 2013)
- Subsequentiality of segmental phonology is well-supported (Heinz and Lai, 2013; Luo, 2017; Payne, 2017, though c.f. McCollum et al. 2017)
- Subsequential functions are learnable (Oncina et al., 1993; Jardine et al., 2014; Chandlee et al., 2015)

## Subsequentiality and tone

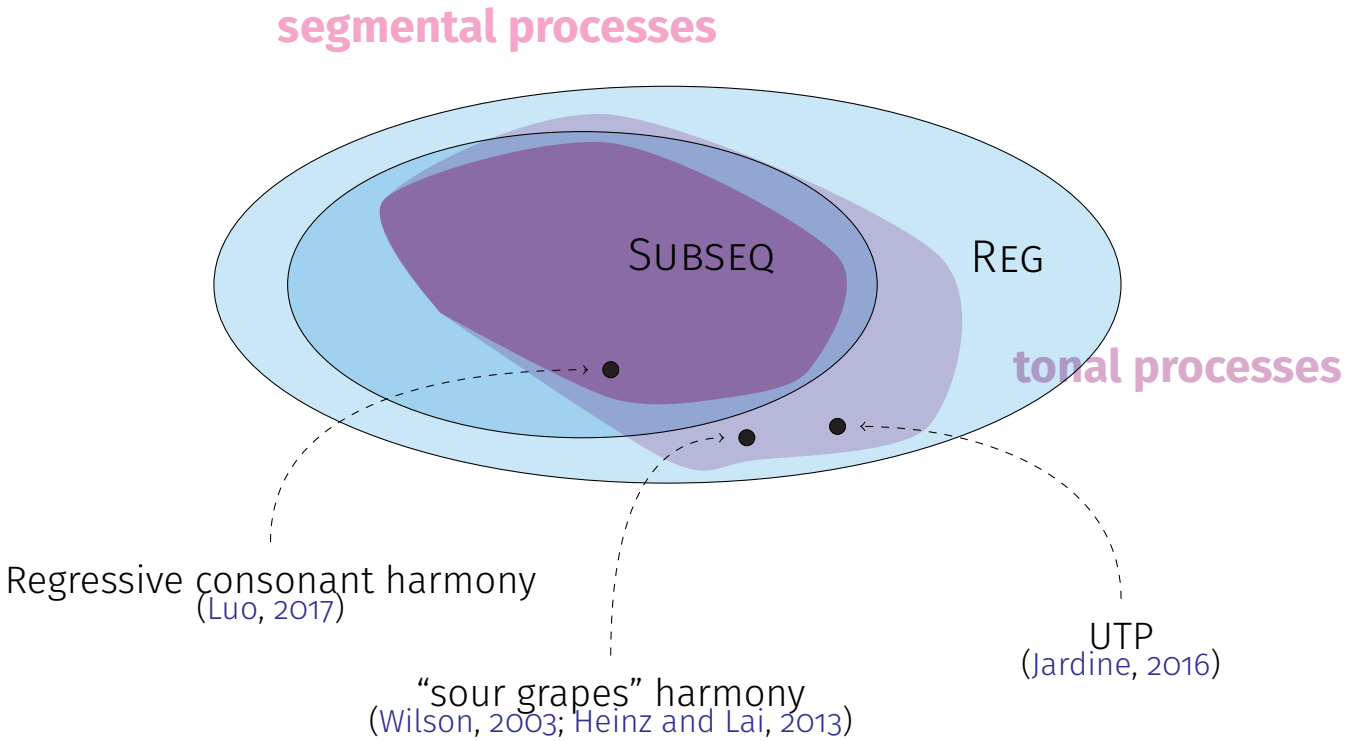
- However, UTP is like SG

| | | | |
|---|---|---|---|
| mutéma | /LHL/ | → [LHL] | ‘chopper’ |
| kisiki | /LLH/ | → [LLH] | ‘log’ |
| mutémá+bísíki | /LHLLLH/ | → [LHHHHH] | ‘log chopper’ |

(Hyman and Katamba, 2010)

- Jardine (2016): SG-like processes are common in tone

# Subsequentiality and tone

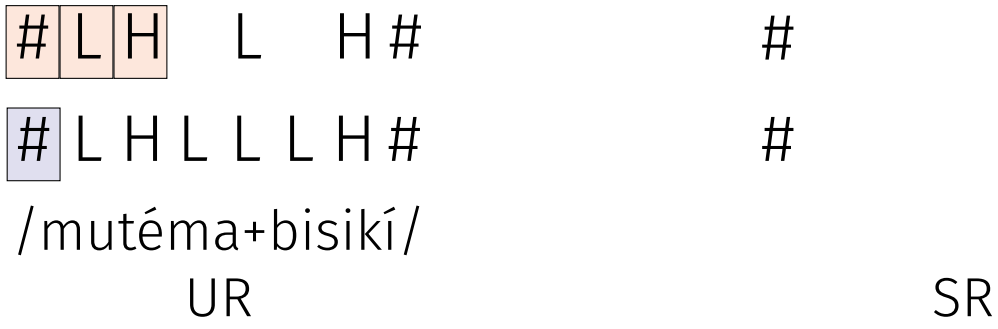


## Input melody-local functions

- ML sets were local over
  - the melody; **and**
  - the string of surface TBUs

- Mamadou (in progress) proposes ML **functions** that are local in the same way[2]

## Input melody-local functions



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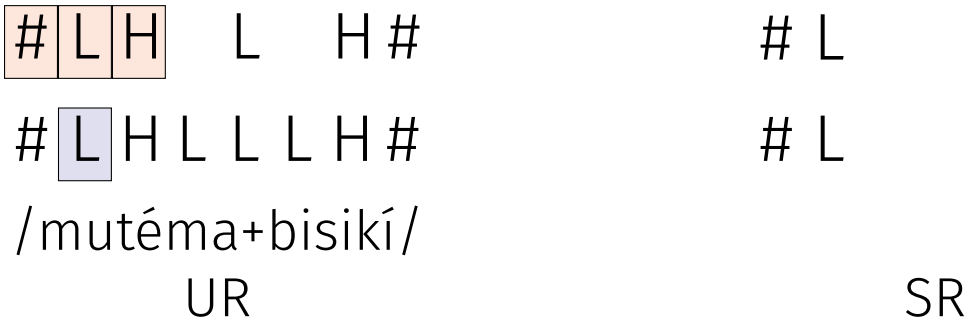

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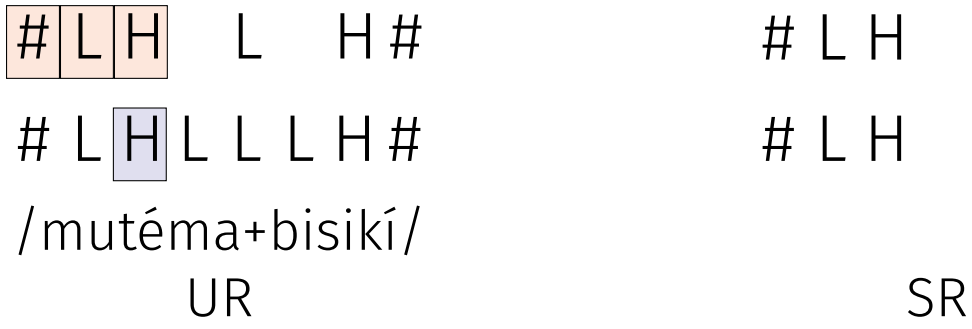

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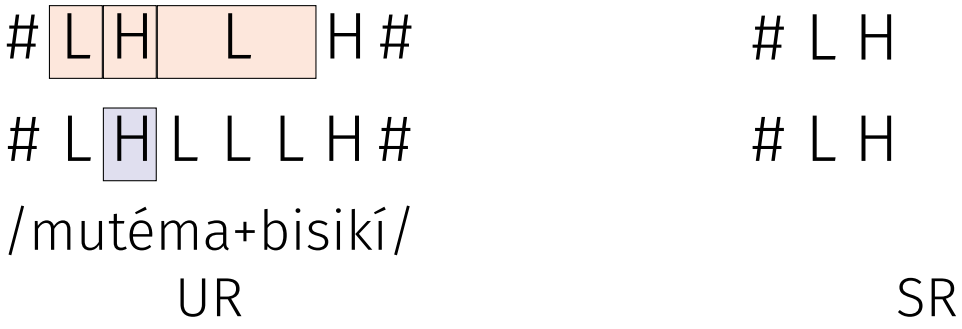


## Input melody-local functions



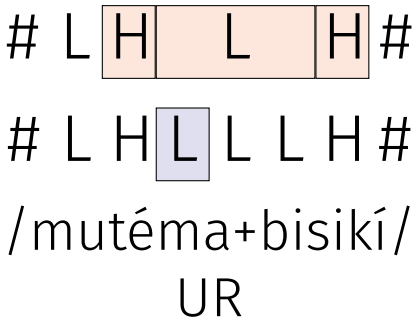
/mutéma+bisikí/

UR



SR

## Input melody-local functions

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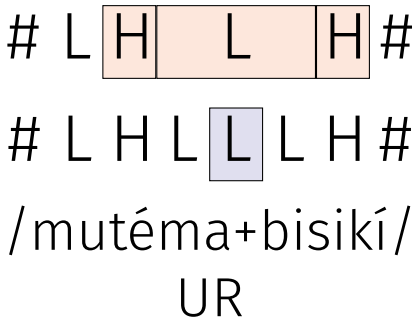


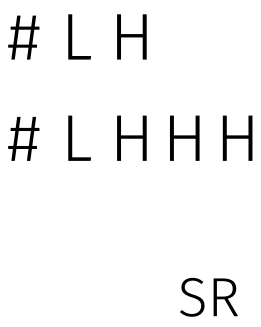

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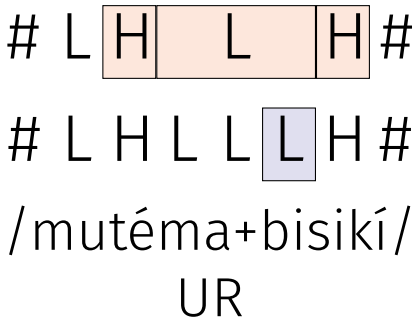


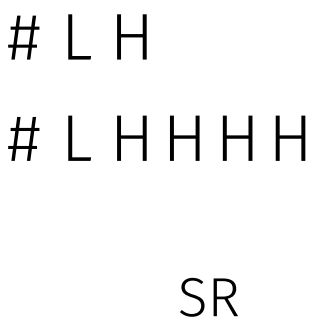

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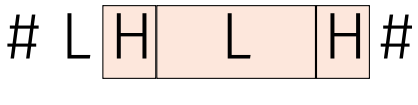
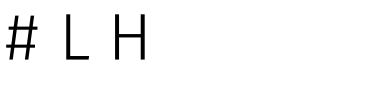


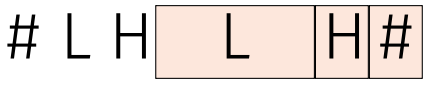

/mutéma+bisikí/

UR




SR

## Input melody-local functions




/mutéma+bisikí/

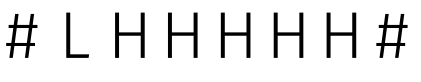
UR


SR

## Input melody-local functions



/mutéma+bisikí/
UR

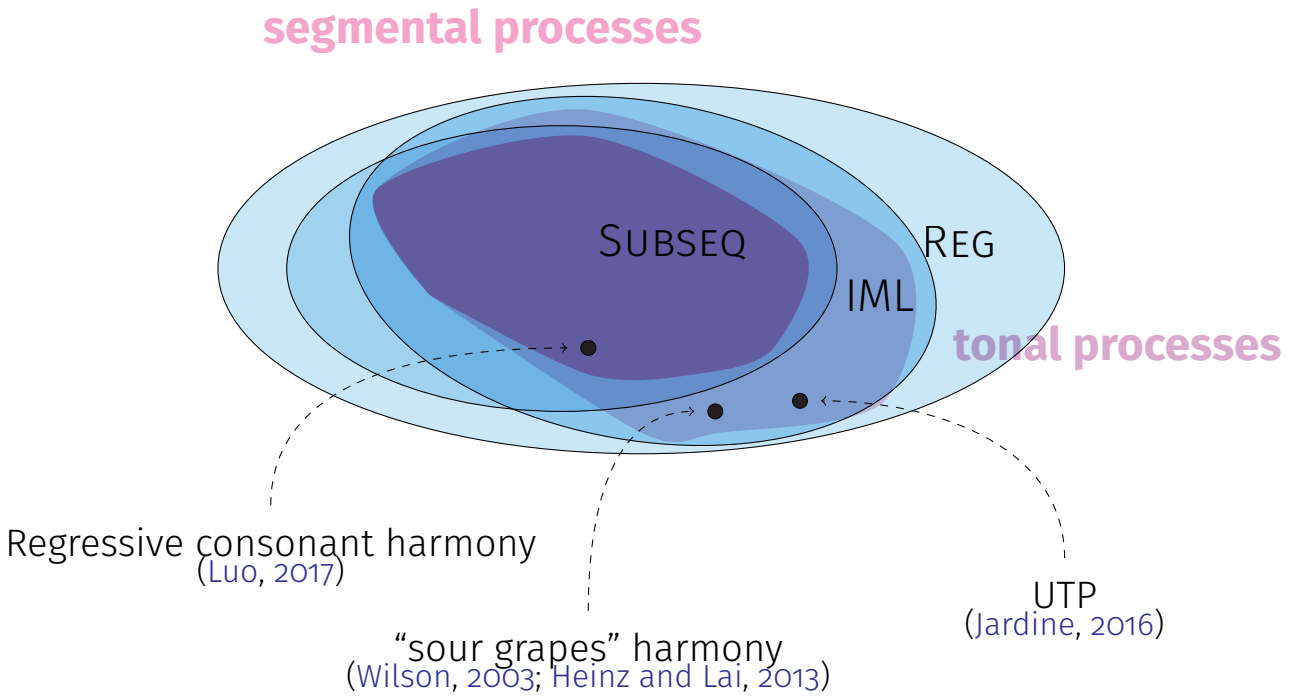




[mutémá+bísíkí]
SR

## Input melody-local functions

- UTP is deterministic **when considering the melody**
- In fact, it is local

# Input melody-local functions




- Mamadou (in progress): IML is a good fit for tonal processes

# Discussion

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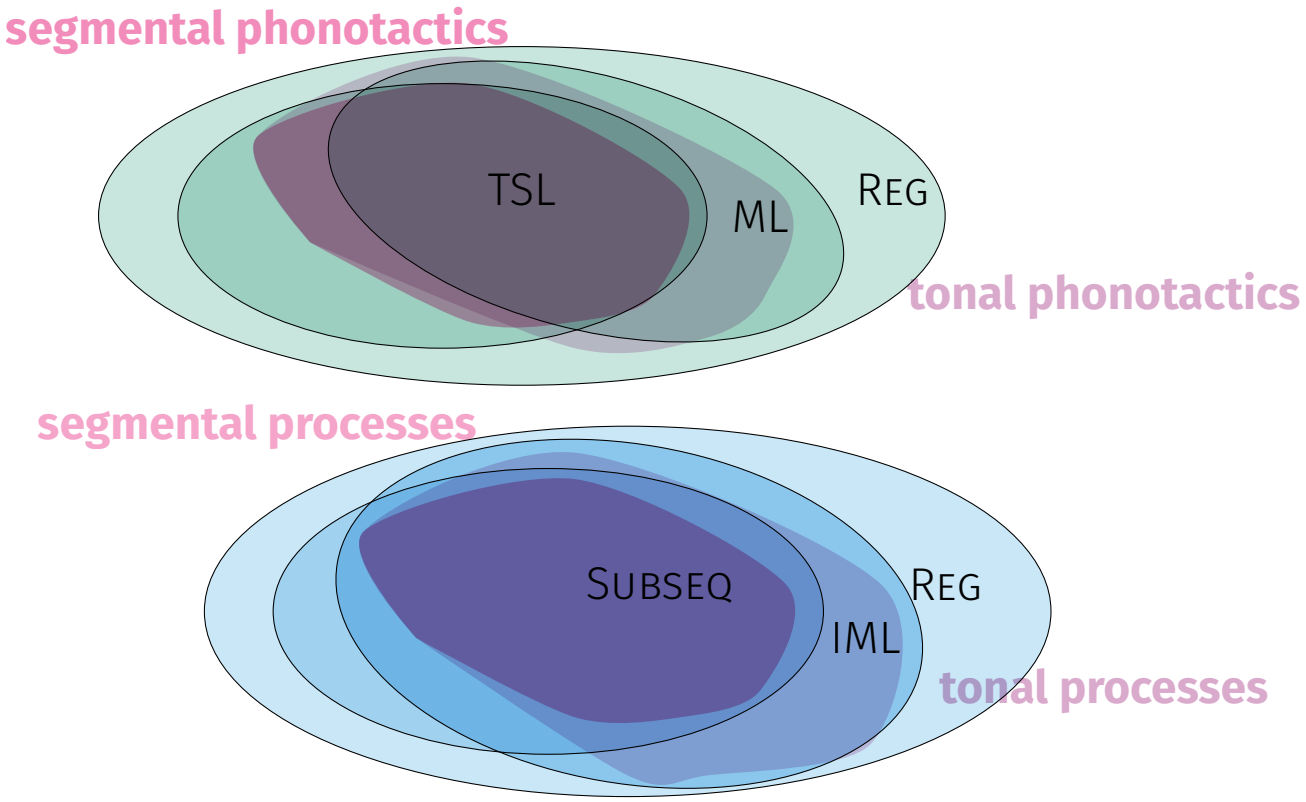
segmental phonotactics
TSL
ML
Reg
tonal phonotactics
segmental processes
Subseq
Reg
IML
tonal processes

## Discussion

> Hyman (2011): "[T]one can do everything that segmental and metrical phonology can do, but the reverse is not true."

- The computational perspective helps explain difference between segmental phonology and tone
- **Melody** representation is key to difference
- Computational **locality** is preserved
- For ML sets, this also guarantees learnability

## Future work

- Learnability of IML functions can be studied using subsequential learning techniques
- Hypothesis: ML/IML are the “outer limits” of what are possible in phonology
- How do IML functions compare to local autosegmental functions? (Chandlee and Jardine, 2019)

# Thank you!

**Acknowledgements**

Thanks to Jeff Heinz, Jane Chandlee, Jim Rogers, Thomas Graf, Larry Hyman, Joe Pater, Dine Mamadou, Chris Oakden, Jon Rawski, Hossep Dolatian, and countless others for their advice and comments on this work.

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