Computationally, Tone is Different

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Introduction

- Hyman (2011) asks: Is tone different?
- Automata-theoretic measure of complexity also says yes
- Typological studies provide evidence segmental phonology is *regular* and *subsequential* (Gainor et al. (2012), Chandlee and Heinz (2012), Heinz and Lai (2013), Chandlee, (in prep.))
- A common tonal process, *Unbounded Tonal Plateauing* (Hyman, 2011, henceforth UTP), is *regular*, but not *subsequential*, and thus more complex
- Gives us intuition that *unbounded, bidirectional* processes are not expected for segmental phonology

Why tone?

- Hyman (2011) argues that tone "can do everything that segmental or metrical phonology can do, but the reverse is not true" (p.236)
- Yip (2002) lists characteristics uniquely common in tone: ex. 'mobility' and 'one-to-many'
- An example from Digo (Bantu; Kisseberth, 1984)

(1) a. ni-na+tsukur-a 'I am taking'
    b. ni-na+a-tsukŭr-â 'I am taking them'

Why tone?

- Is tone more *complex* than segmental phonology?
- Segmental phonology also has long-distance and 'one-to-many' processes
- Can computational measures of complexity give us a hard distinction?

Processes and automata

- Much of phonology deals with change from underlying representation (UR) to surface representation (SR)

(2) $\mathrm{n} \rightarrow \mathrm{m}$ / ___ p

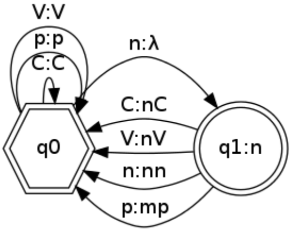
- The change (2) can be modeled as a string-to-string mapping

(3) ...nV... $\mapsto$ ...nV...
...nC... $\mapsto$ ...nC...
...np... $\mapsto$ ...mp...

An example

- *Regular* string-to-string mappings can be modeled with finite-state *transducers* (FSTs)

(4) A FST for n $\rightarrow$ m /__ p

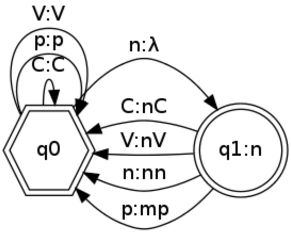


CVnp↦CVmp

Input	0	Output
C	0	C
V	0	V
n	1	
p	0	mp

Why automata?

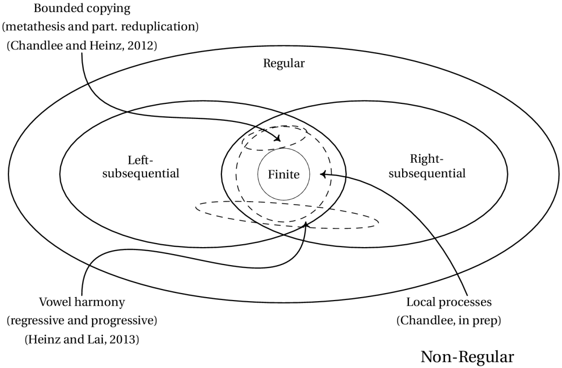
(4) n → m /__ p



- Can look at binary UR/SR relation independent of phonological theory
- (4) is a *subsequential* FST (SFST)
- At each state, one transition per input

Complexity of mappings

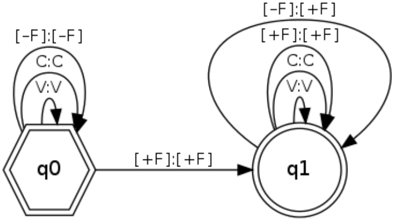
- SFSTs are *strictly less expressive* than FSTs Mohri (1997)
- Mappings describable with SFSTs fall into two subsequential subregions of the *regular* region
- Typological studies of segmental processes show they fall into one of these regions



Complexity of mappings

- Even long-distance regressive harmony is subsequential

(5) ...[-F]...[+F]... ↦ ...**[+F]**...[+F]...



[-F]VCV[+F]↦[+F]VCV[+F]

Input	0	Output
[+F]	1	[+F]
V	1	V
C	1	C
V	1	V
[-F]	1	[+F]

Complexity of mappings

- Subsequentiality is shared by local and long-distance segmental processes
- UTP, a tonal process, is not

Unbounded Tone Plateauing

- UTP (Hyman, 2011) is a tonal process in which all TBUs inbetween two H tones become H (assuming underlying H/∅)

(6) Luganda (Bantu; Hyman et al., 1987; Hyman and Katamba, 2010)

a. /bikopo/ → bikópo
∅ H ∅ → L H L
'cups'

b. /byaa-walusiimbi/ → byaa-walúsiimbi
∅ ∅ H∅ ∅ → L L H L L
'of Walusimbi'

c. /bikopo byaa-walusiimbi/ → bikópó byáá-wálúsiimbi
∅ H ∅ ∅ ∅H∅ ∅ → L H H H H H L L
'the cups of Walusimbi'

Unbounded Tone Plateauing

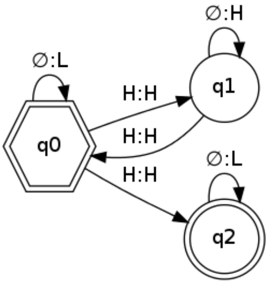
- Can be formalized as the following:

(7) $\varnothing^n \rightarrow \text{H}^n$ / H ___ H

- Attested in Luganda (Hyman and Katamba, 2010; Hyman et al., 1987), Zulu (Cassimjee and Kisseberth, 2001), Kihunde (Goldsmith, 1990), Amahuaca (Russel and Russel, 1959), and others

UTP as a mapping

(7) $\varnothing^n \rightarrow H^n$ / H __ H



ØØØ↦ LLL

ØHØ↦ LHL

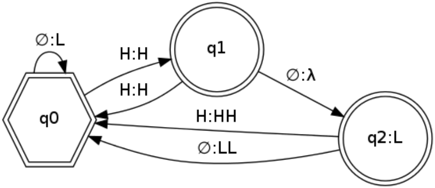
ØHØHØ↦ LHHHL

HØØØH ↦ HHHHH

- This machine is *not* a SFST
- I have a formal proof, based on properties of subsequentiality given in Oncina et al. (1993), showing we *cannot* build an SFST for (7)

UTP as a non-subsequential mapping

- Recall that SFSTs can ‘wait’ some set time before writing an output



∅∅∅↦ LLL

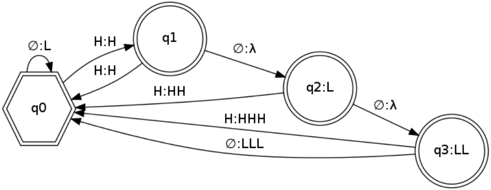
∅H∅H∅↦ LHHHL

H∅∅∅H ↦ *HLLLH

(8) SFST with one wait state

UTP as a non-subsequential mapping

- Recall that SFSTs can 'wait' some set time before writing an output



∅∅∅ ↦ LLL

∅H∅H∅ ↦ LHHHL

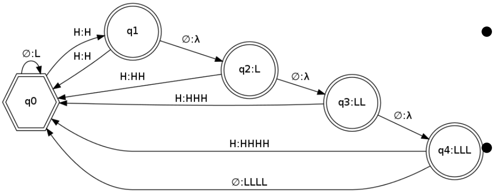
H∅∅H ↦ HHHH

H∅∅∅H ↦ *HLLLH

(9) SFST with two wait states

UTP as a non-subsequential mapping

- Recall that SFSTs can 'wait' some set time before writing an output



(10) SFST with three wait states

H∅∅∅H ↦ HHHHH

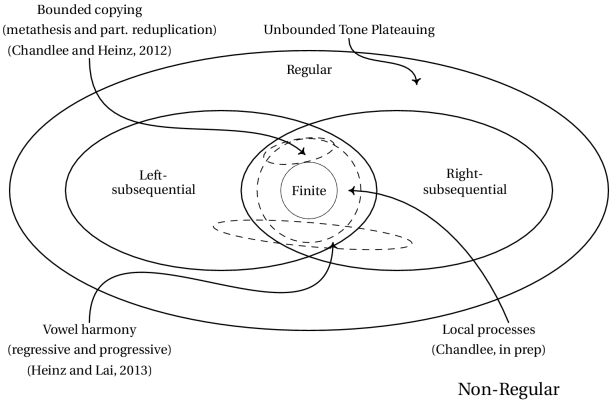
H∅∅∅∅H ↦ *HLLLLH

- A SFST with n number of wait states will fail when Hs are $n+1$ TBUs apart
- To capture UTP, an SFST needs an infinite number of wait states

The complexity of UTP

- UTP cannot be modeled with a SFST
- It is not a subsequential mapping
- This comes from the *unbounded, bidirectional* nature of the mapping
- Unlike harmony, there are *two* triggers on either side of the target, arbitrarily far away
- It *can* be modeled with a non-subsequential FST, so it is regular

Conclusions



Conclusions

- UTP, a common tonal process, is not subsequential
- Tone *is* different; it appears to be more computationally complex
- New generalization: tone can have *unbounded, bidirectional* processes; segmental processes cannot
- There are two potential exceptions to this: Sanskrit *ṇati* (Whitney, 1889; Macdonell, 1910), and Yaka vowel 'plateauing' harmony (Hyman, 1998), a VH version of UTP
- Subsequentiality of segmental processes remains robust, but we can be on the look out for unbounded, bidirectional processes

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