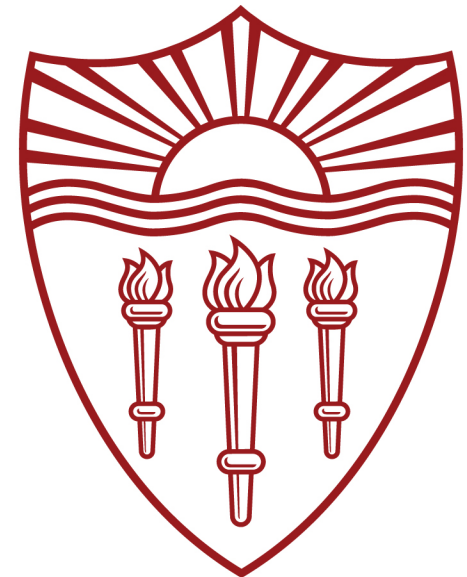# Weakly Deterministic Characterizations of Unbounded Tonal and Featural Spreading
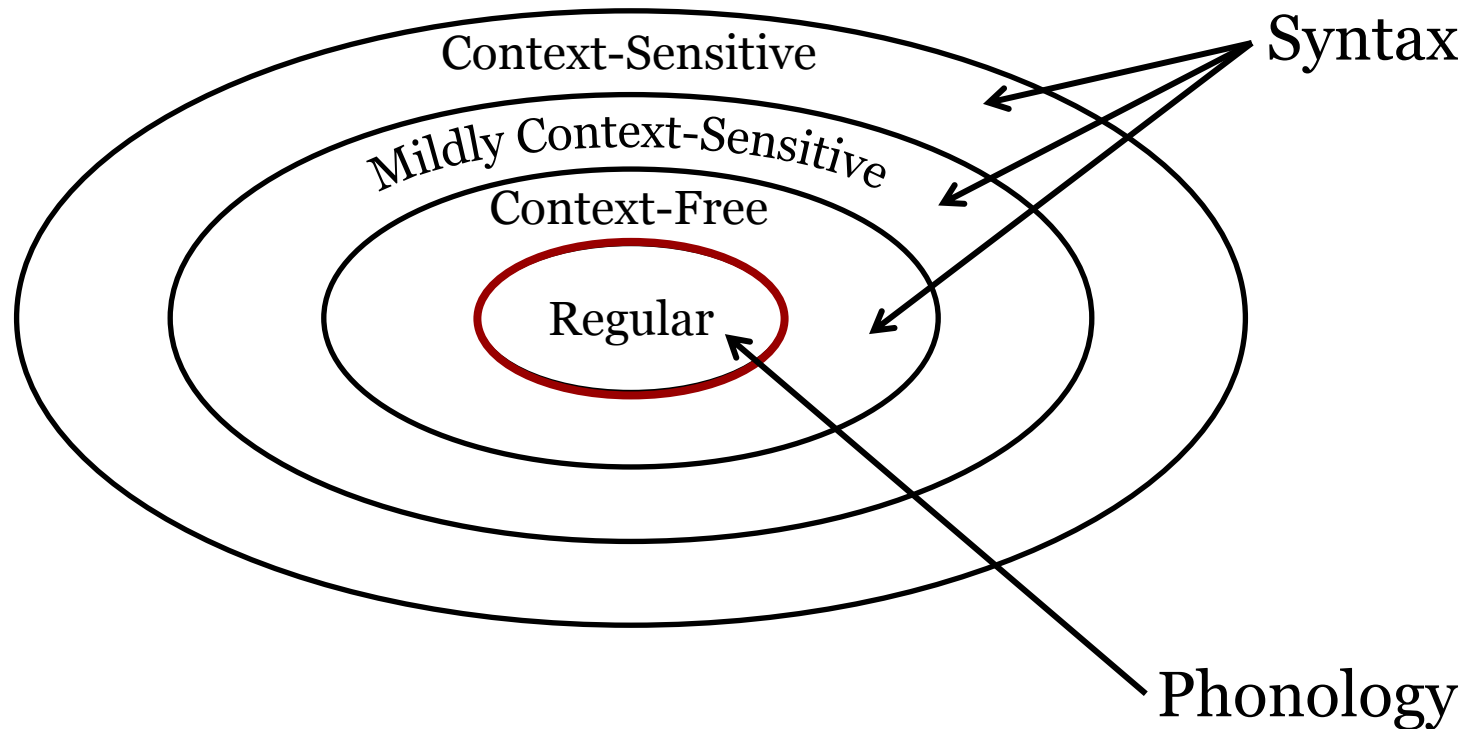
Charlie O'Hara
Caitlin Smith

University of Southern California

The Chomsky Hierarchy

Languages (sets of strings) can be classified by computational complexity (Chomsky 1956):
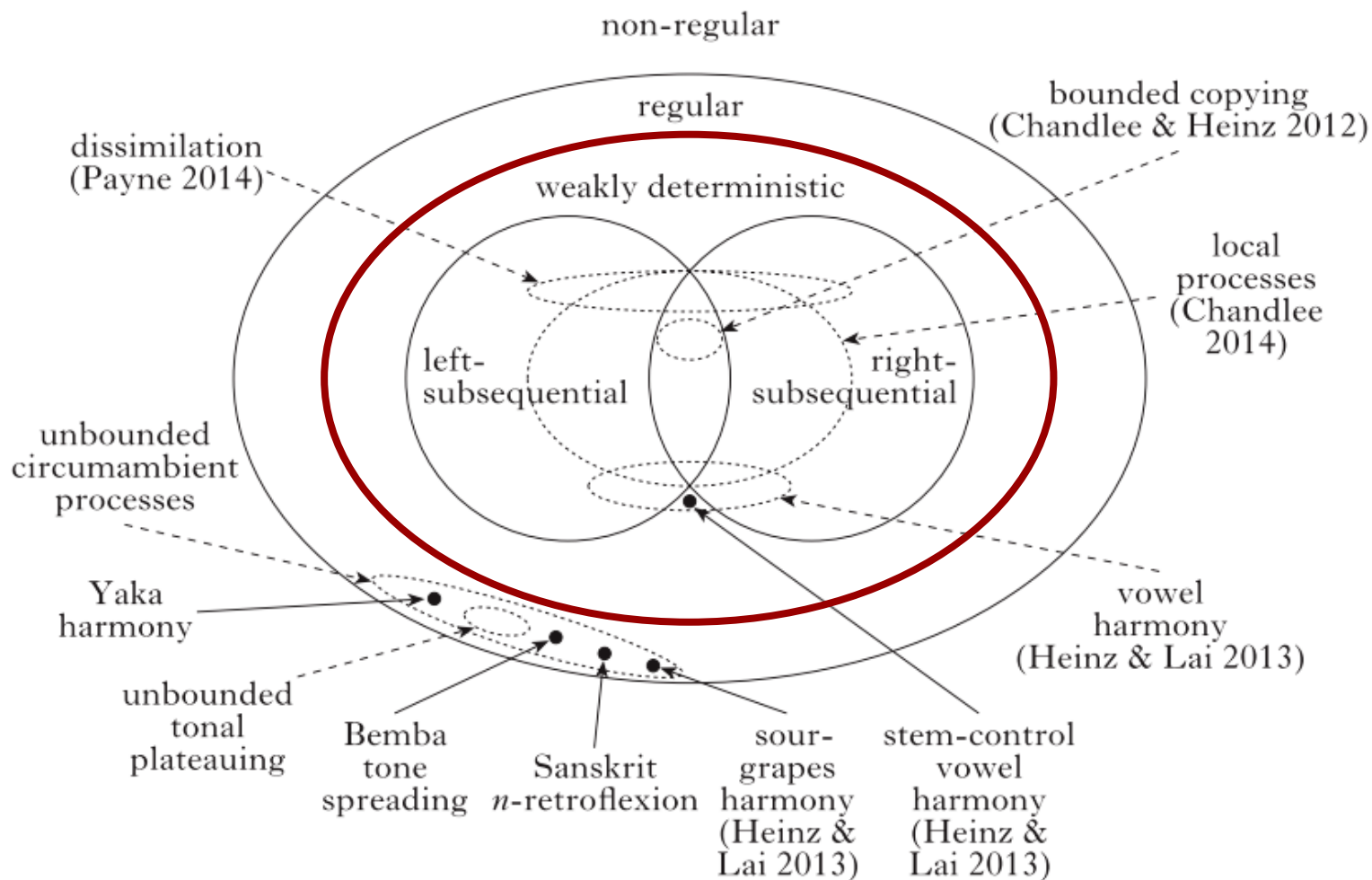
The Subregular Hierarchy

figure from Jardine (2016)

Lango Unbounded Tonal Plateauing
(Hyman & Katamba 2010)

- Single high tone does not spread:

$$\begin{array}{c} H \\ | \end{array}$$
/mu-tund-a-bi-kópo/

$$\begin{array}{c} H \\ | \end{array}$$
[mu-tund-a-bi-kópo] 'cup-seller'

- Multiple high tones spread to tone bearing units between them:

$$\begin{array}{cc} H & H \\ | & | \end{array}$$
/mu-tém-a-bi-sikí/

$$\begin{array}{cc} H & L \end{array}$$
[mu-tém-á-bí-síkî] 'log-chopper'

$$\begin{array}{ccc} H & H & H \\ | & | & | \end{array}$$
/tw-áá-láb-w-a walúsimbi/

$$\begin{array}{c} H \end{array}$$
[tw-áá-láb-w-á wálúsimbi] 'we were seen by Walusimbi'

Classifying Featural and Tonal Spreading

- Segmental phenomena are at most weakly deterministic (Heinz & Lai 2013)

- Some tonal phenomena (unbdounded plateauing) are regular, but not weakly deterministic (Jardine 2016)

> Proposals:
> 1) Attested featural and tonal spreading patterns **are** weakly deterministic
> 2) Unattested patterns (i.e. sour grapes) are **not** weakly deterministic
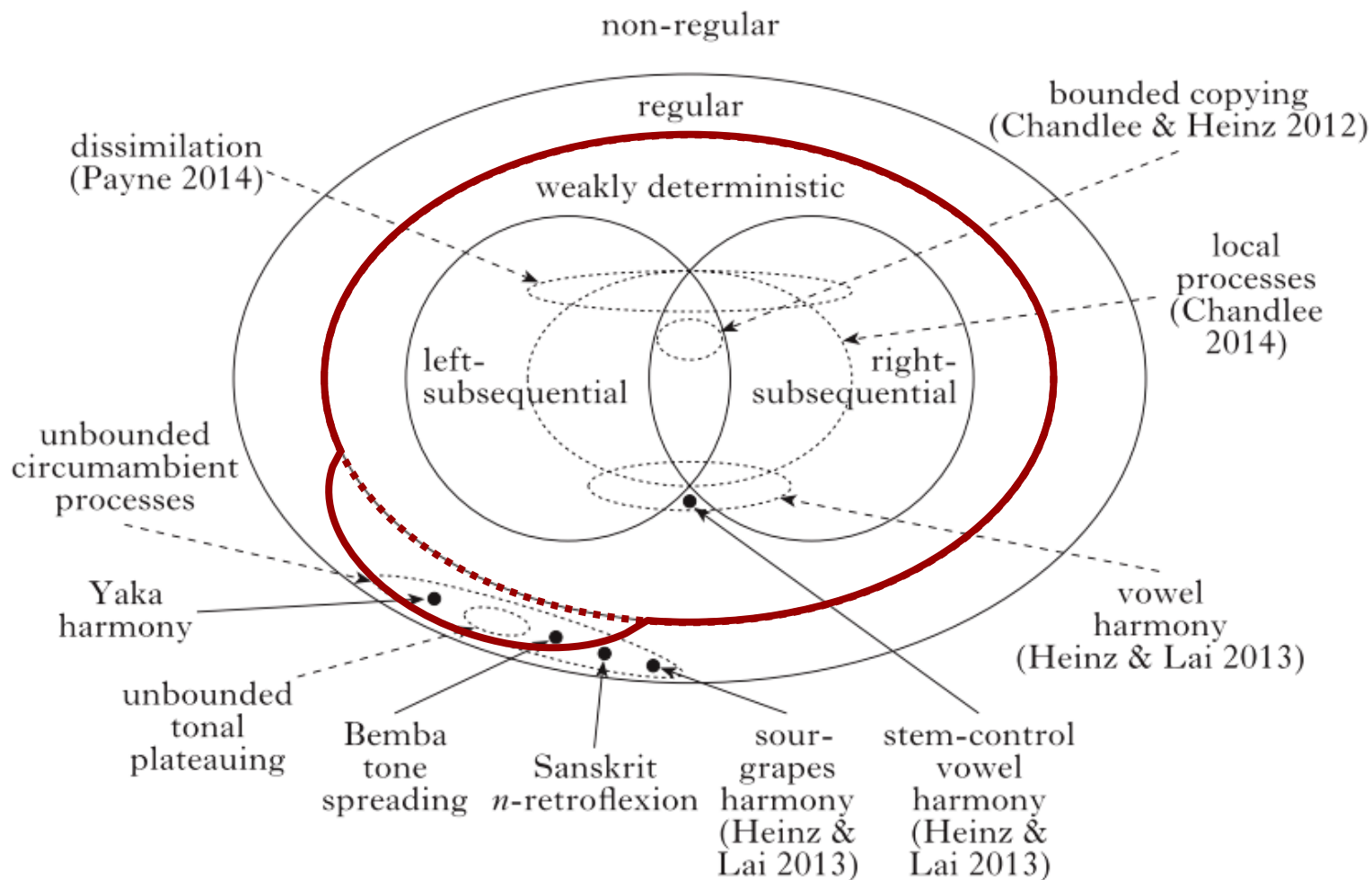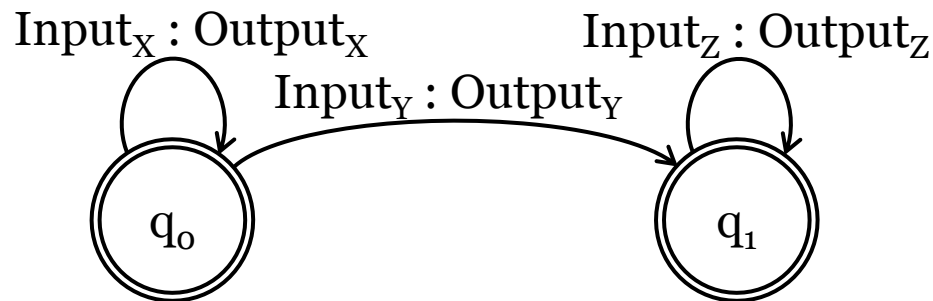
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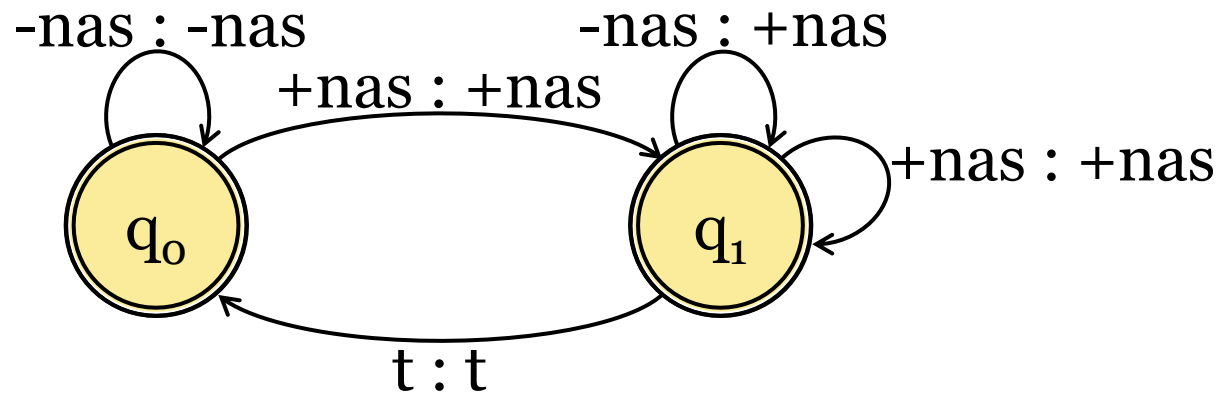

figure from Jardine (2016)

Finite State Transducers

- Input-output mapping of strings can be conceptualized as finite state transducers

- Maps inputs to outputs by following *transitions* between *states*

$$\text{Input}_X : \text{Output}_X \qquad \text{Input}_Z : \text{Output}_Z$$

$$\text{Input}_Y : \text{Output}_Y$$

q_0 $\qquad$ q_1

- Finite state transducer indicates which input-output mappings are licit in a language

Progressive Harmony

/ l   a   w   a /   / n   a   w   a /
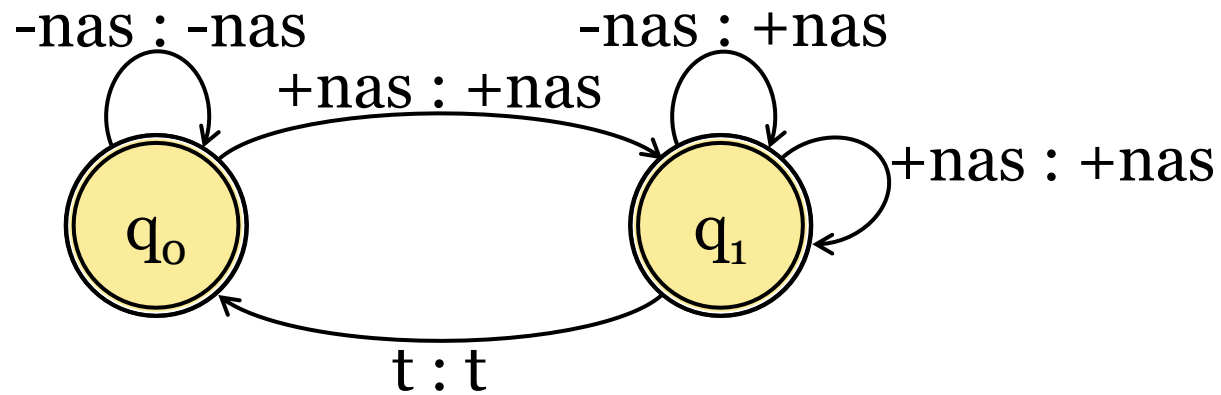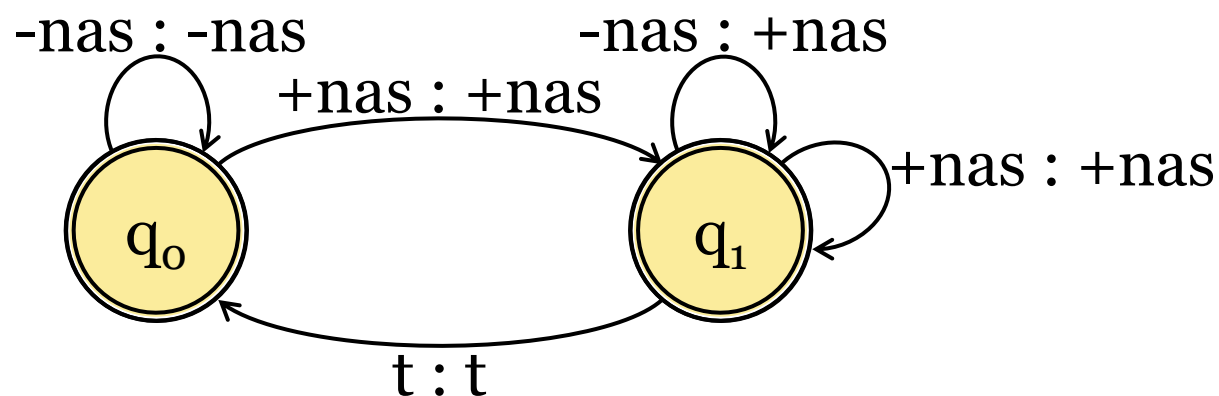
[l   a   w   a]   [n   ã   w̃   ã]

Progressive Harmony

-nas : -nas

-nas : +nas

+nas : +nas

+nas : +nas

q_0

q_1

t : t

/ n a w a t a /

[n ã w̃ ã t a]

Bidirectional Harmony

-nas : -nas

+nas : +nas

-nas : +nas

+nas : +nas

q_0 q_1

t : t

/	w	a	n	a	w	a	/
	w	a	n	ã	w̃	ã	
[	w̃	ã	n	ã	w̃	ã	]

Determinism

- Properties of finite state transducers indicate computational complexity of input-output maps

- Deterministic: for a given input symbol, there is only one possible transition
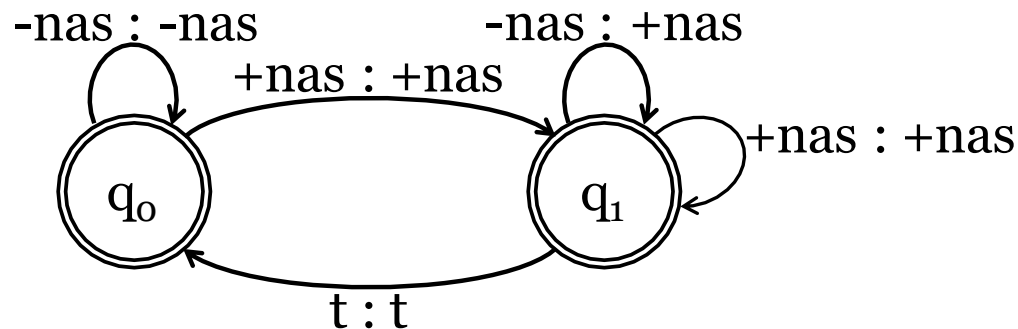
- Non-deterministic: for a given input symbol, there are multiple possible transitions

Weak Determinism

- Unidirectional harmony and bidirectional harmony are *weakly deterministic* (Heinz & Lai 2013)

- Weakly deterministic maps:

  - Can be decomposed into left- and right-subsequential functions

  - Are alphabet-preserving

  - Are length-preserving

Metaphony (Bounded Harmony)

- Metaphony: post-tonic high vowel targets stressed mid vowel for raising

- Central Veneto (Walker 2005, 2010, 2011)

[kant-é-se] 'sing (1sg impf subj)'   kant-í-si-mo] 'sing (1pl impf subj)'

[órden-o] 'order (1sg)'   [úrdin-i] 'order (2sg)'

[ángol-o] 'angle (sg)'   [ángol-i] 'angle (pl)'

Metaphony (Bounded Harmony)

- Metaphony is circumambient:

  /an . go . l-i/   /or . de . n-o/   /or . de . n-i/

  [an . g<u>o</u> . l-i]   [or . <u>de</u> . n-o]   [ur . <u>di</u> . n-i]

- Vowel's status as undergoer of metaphony determined by material on both sides

- BUT that material is not unboundedly far away
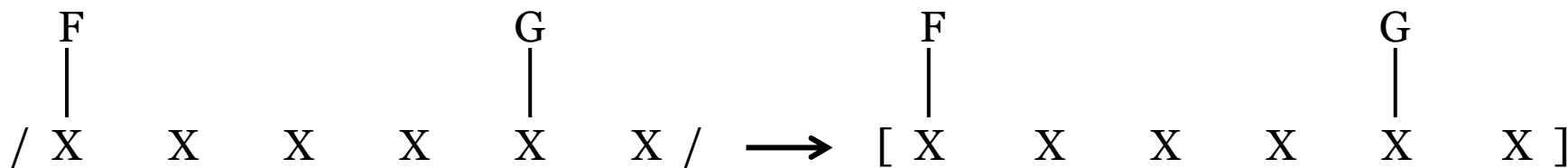
Metaphony (Bounded Harmony)
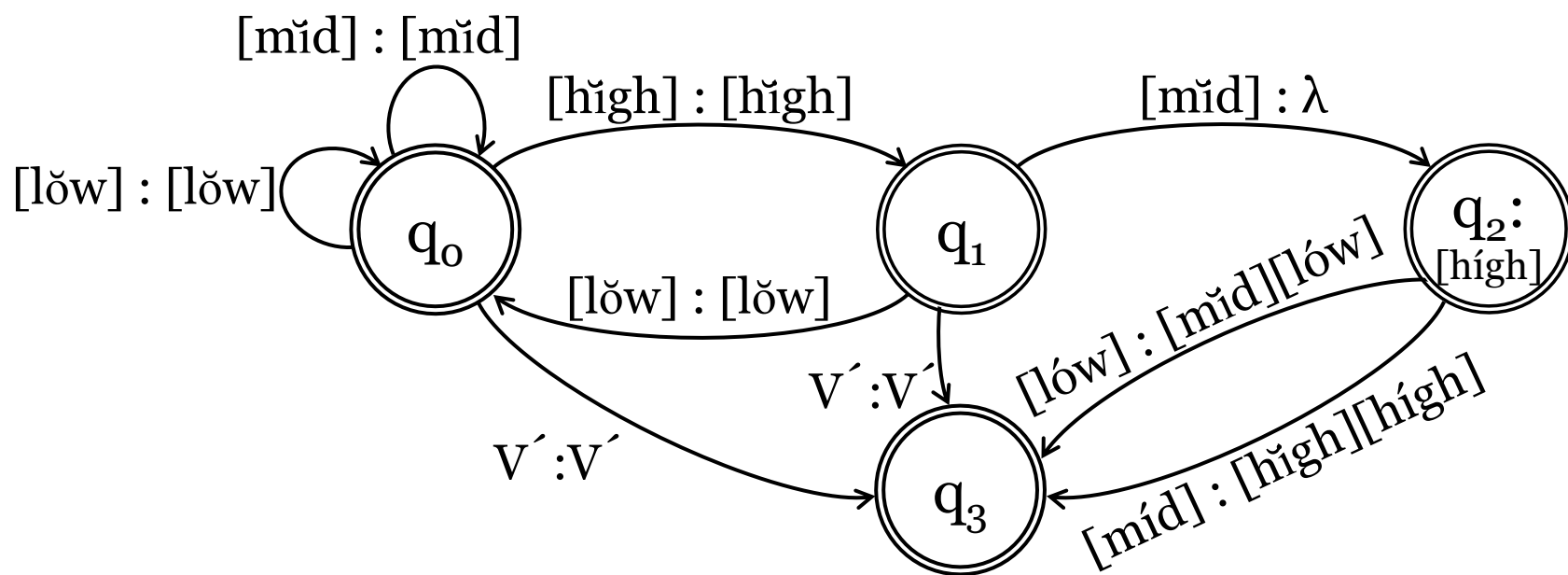
Sour Grapes in Unbounded Feature Spreading

- Full spreading with no blocker present:
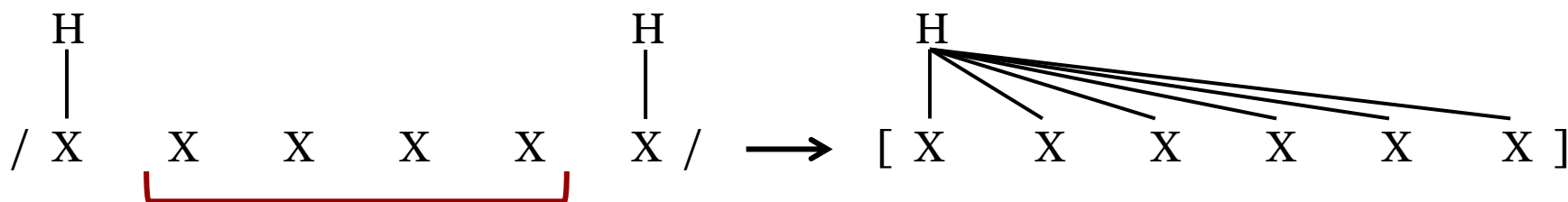
F   F

/ X   X   X   X   X   X / ⟶ [X   X   X   X   X   X]
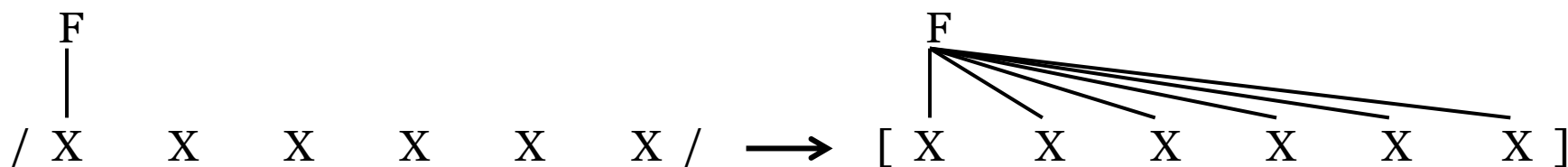
- No spreading with blocker present:

F   G   F   G

/ X   X   X   X   X   X / ⟶ [X   X   X   X   X   X]

status as undergoers of harmony determined by material on both sides

Unbounded Tonal Plateauing

- Tonal plateauing between high tones:

- No spreading with single high tone:
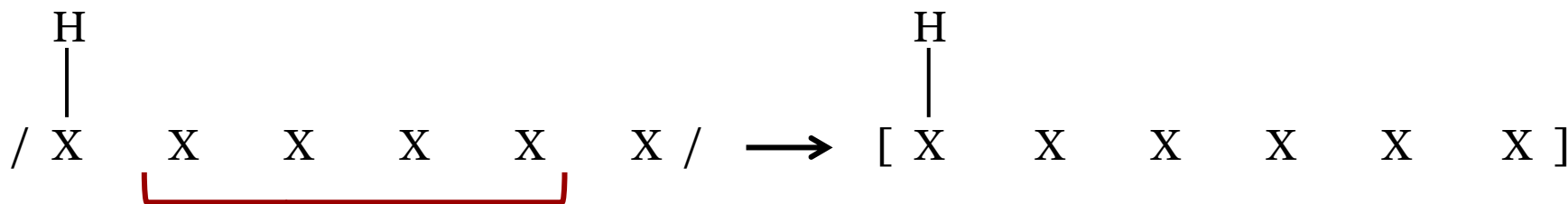
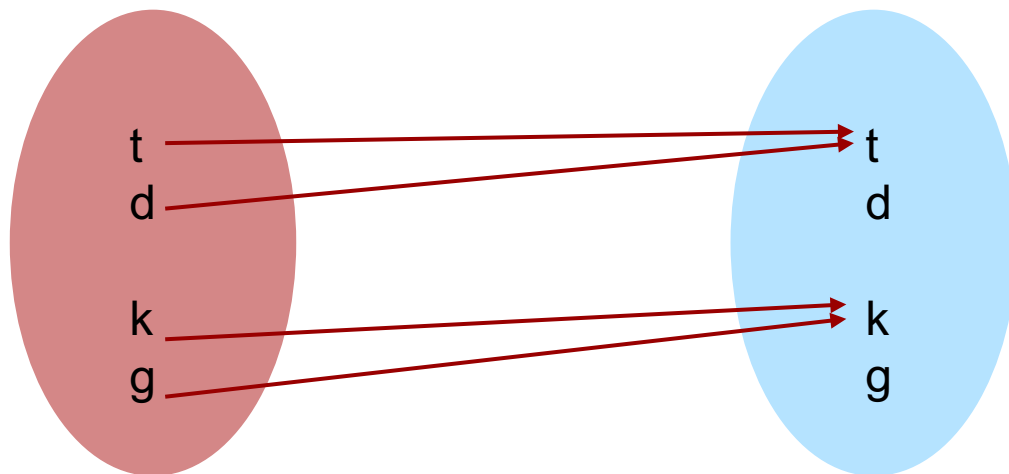status as undergoers of spreading determined by material on both sides

Unbounded Tonal Plateauing & Non-Determinism

Finite state transducer necessary for unbounded tonal plateauing is non-deterministic (Jardine 2016)
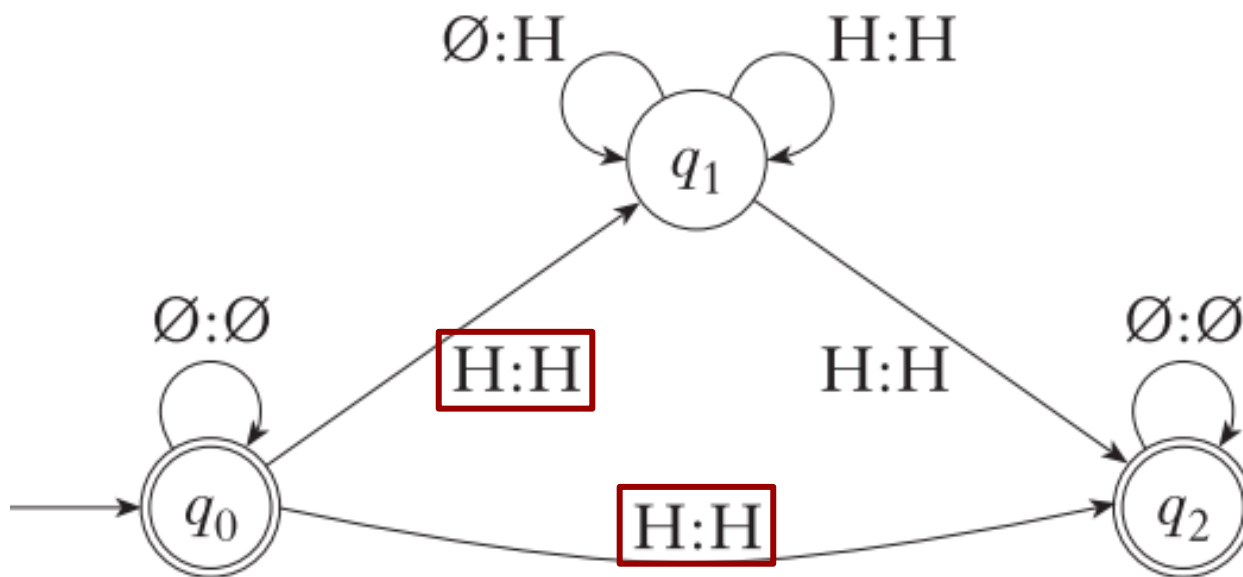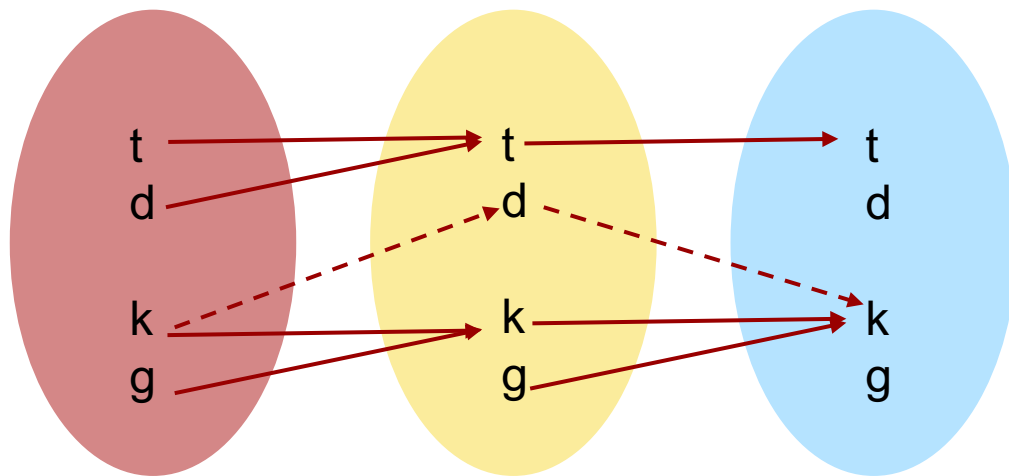
Weak Determinism Allows for Some Markup

- To be weakly deterministic, the first FST cannot add new characters to the alphabet, or increase the length of the word

- But there is still a lot of unused information!
    - Very few phonological patterns are *one-to-one* (injective)
    - We can mark up positional information on the intermediate representation
- For markup to work, there must be fewer possible surface representations than intermediate representations

Weak Determinism Allows for Some Markup

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Two Understandings of Unbounded Tonal Plateauing

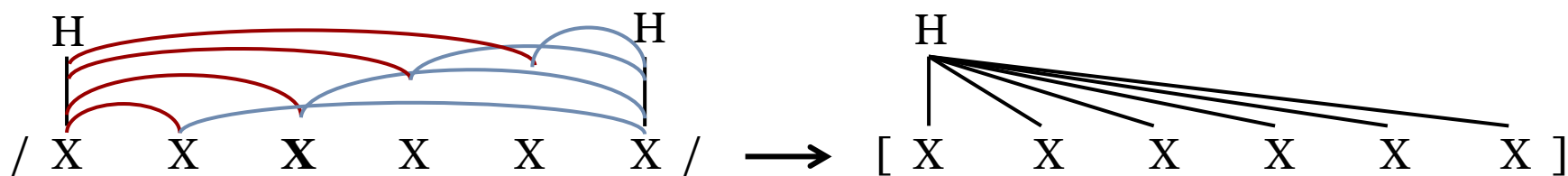- Undergoers must precede and follow triggers (from any distance)
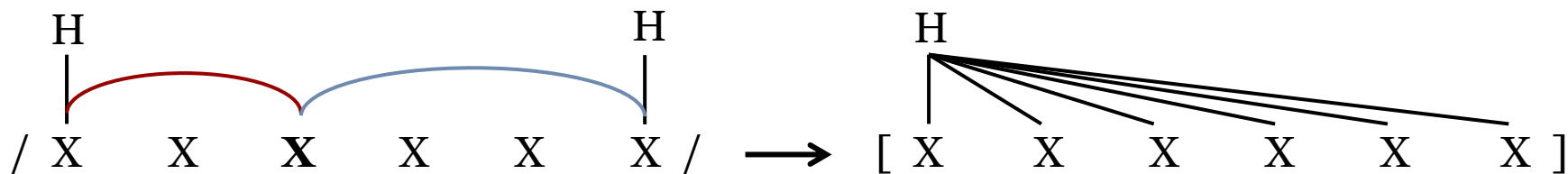
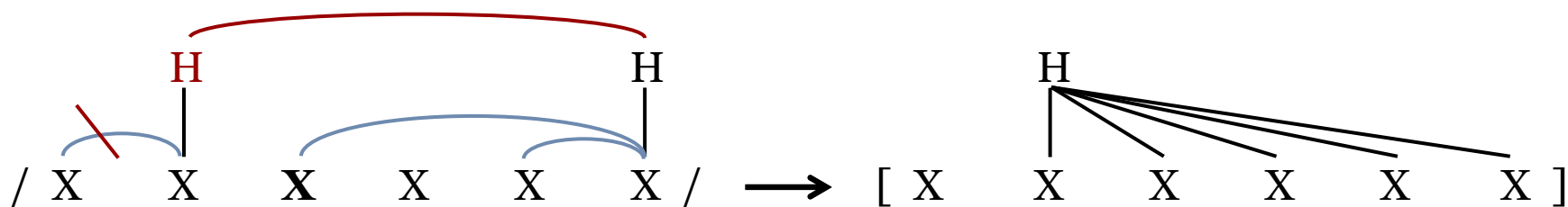- Undergoers precede a trigger, but not the first trigger
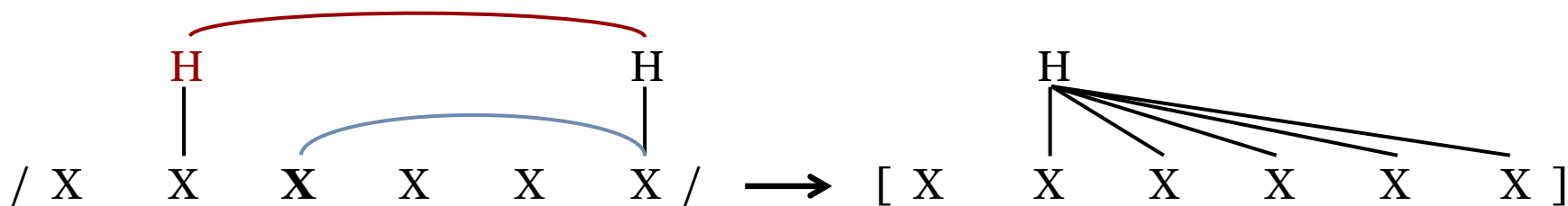
Two Understandings of Unbounded Tonal Plateauing

- Undergoers must precede and follow triggers (from any distance)

H   H

/ X   X   **X**   X   X   X /   ⟶   [X   X   X   X   X   X]

Each undergoer must be marked up

- Undergoers precede a trigger, but not the first trigger

H   H

/ X   X   **X**   X   X   X /   ⟶   [X   X   X   X   X   X]

Only the triggers need to be marked up

Local Markup Strategy

- All *x* in the alphabet are available on the surface
  - Markup cannot be segmental
- Not all substrings *xy* are available on the surface
- UTP is attempted with a LFST then a RFST
- Three properties of UTP:
  - Anything preceding the first H, surfaces as L
  - Anything following the final H surfaces as L
  - Anything between the first H and final H surfaces as H
- LFST can mark first H with adjacent TBUs, since they will surface predictably
  - If markup for H is unique, RFST can spread from last H to the first H, by stopping at the markup

Local Markup-LFST

- Marks up first H with LHH
  - #H→#H
  - #LH→#LH
  - LL<u>H</u>L→HL<u>H</u>H
  - LL<u>H</u>H→LL<u>H</u>H
- Makes sure no other LHH appear
  - H...LHH→H...LLH
- This overwrites underlying tone in three places
  - H...L<u>X</u>H→H...L<u>L</u>H, but <u>X</u> will surface as H regardless.
  - H<u>Y</u>→H<u>H</u>,   could be a problem, so encoded in <u>Z</u>
  - <u>Z</u>LH{H,L}→<u>{L,H}</u>LHH,   but <u>Z</u> must have been L.

Leftward FST

After First Trigger
LHH→LLH

Before First Trigger

Markup of First Trigger
LL_H_L→H**LHH**
LL_H_H→L**LHH**

25
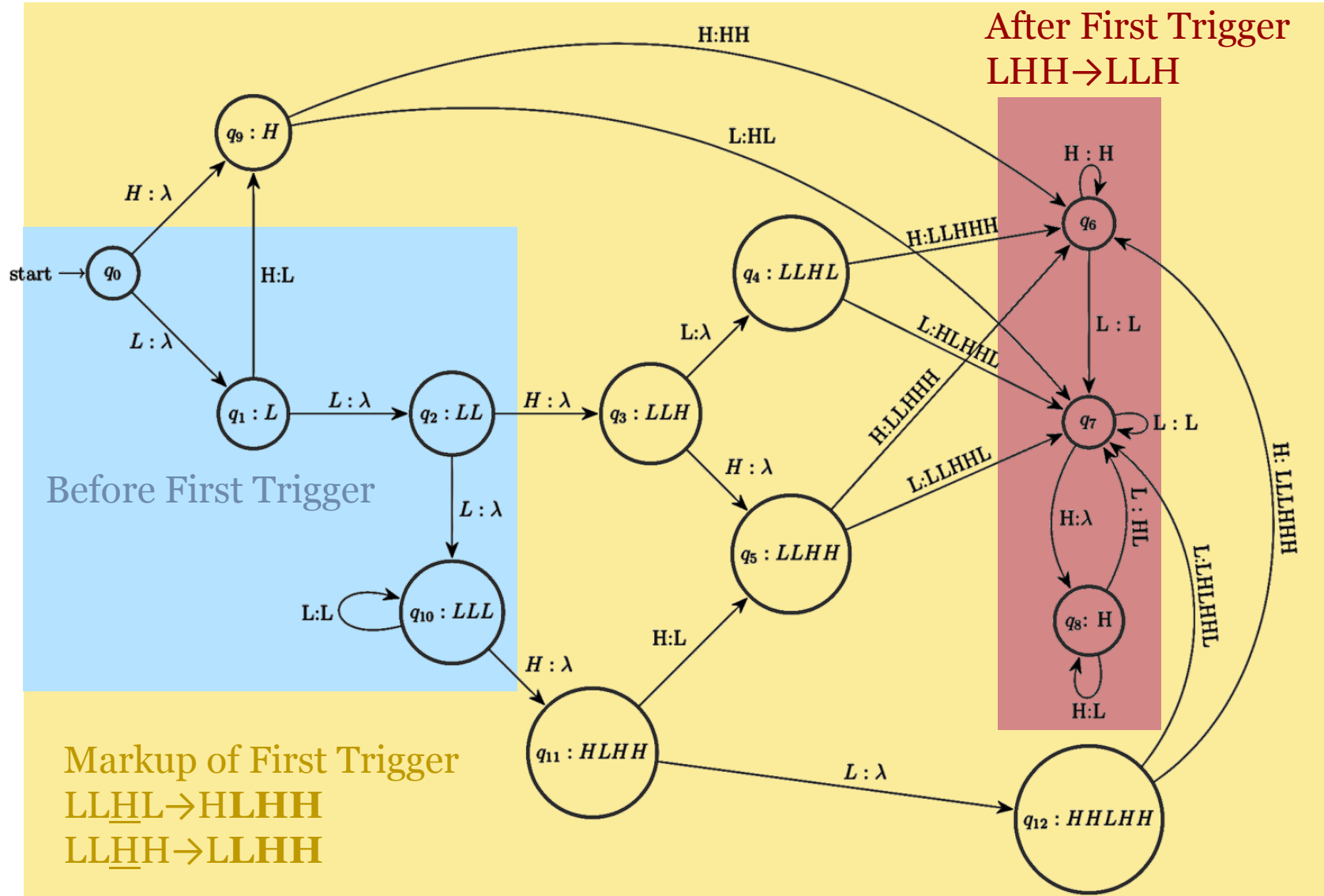
Right FST

- Right FST can identify the last H
- Spreads H from last H until it sees the LHH substring (reversed to HHL).
  – After which, spreads L.
- If the last H is in a LHH substring
  – HLHH→LLHL
  – LLHH→LLHH
- Also, if last H is in #LH, no spreading occurs.

Right-to-Left Spread

Last Trigger is in First Trigger String

HHLL→HHLL
HHLH→LHLL

Pre-Last Trigger
L→L
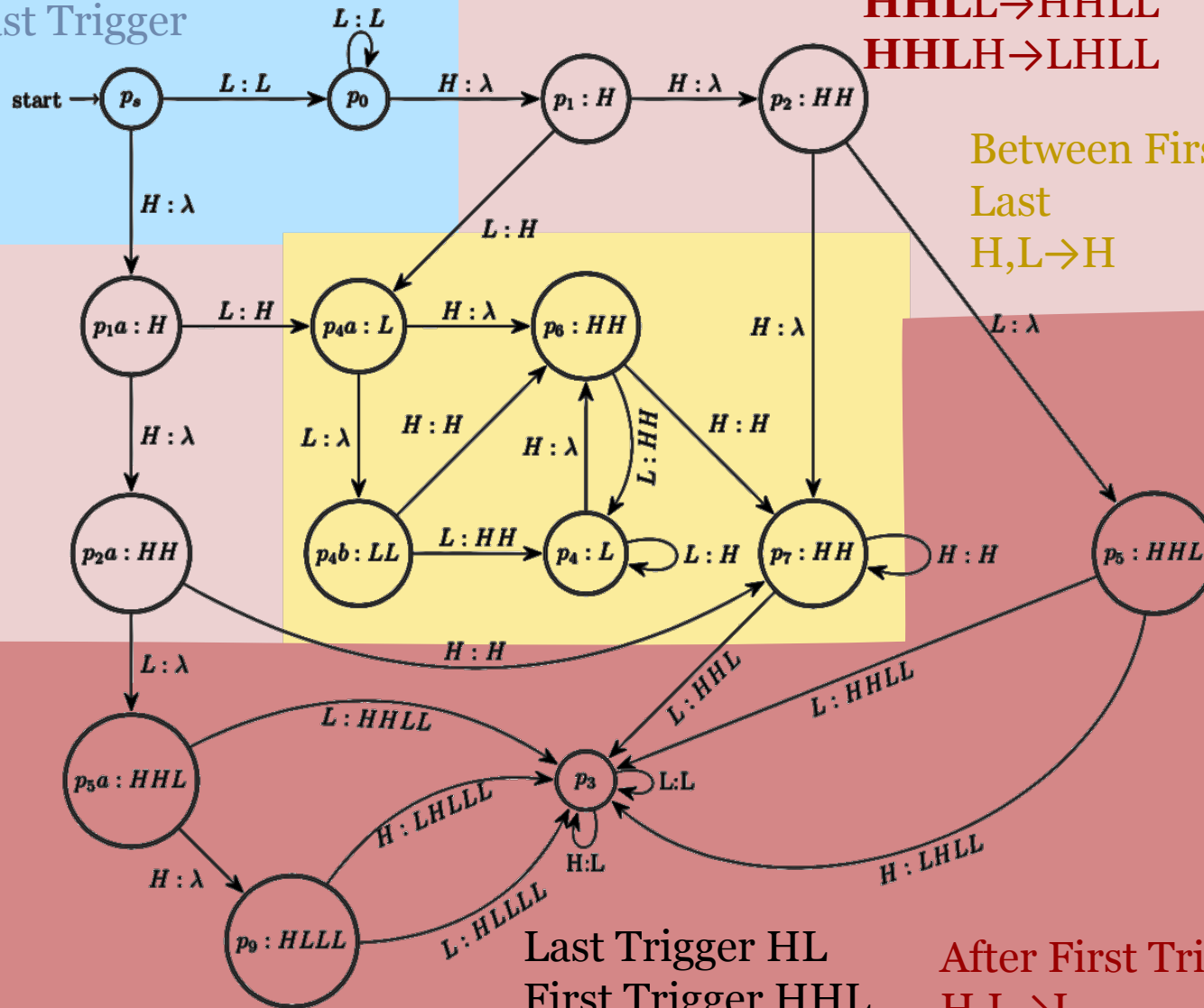
Between First and
Last
H,L→H
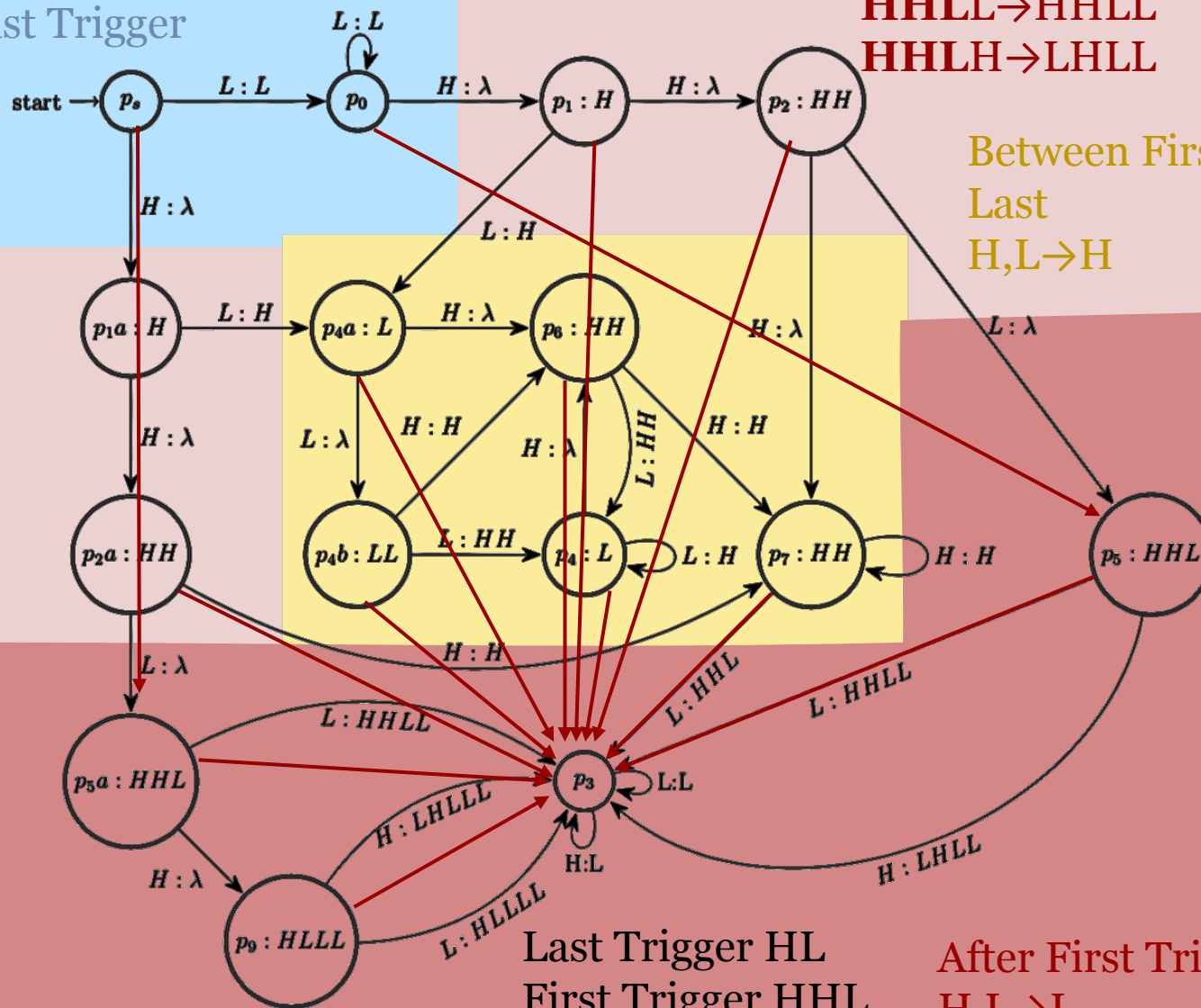
Last Trigger HL
First Trigger HHL

After First Trigger
H,L→L

Right-to-Left Spread

Last Trigger is in First Trigger String

Pre-Last Trigger
L→L

HHLL→HHLL
HHLH→LHLL

Between First and Last
H,L→H

Last Trigger HL
First Trigger HHL

After First Trigger
H,L→L

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Sour Grapes-ish: Copperbelt Bemba

- Full spreading to right edge with no intervening High tone

```
         H                                          H
         |                                          |\\\\
/ X   X   X   X   X   X /          [ X   X   X   X   X   X ]
```
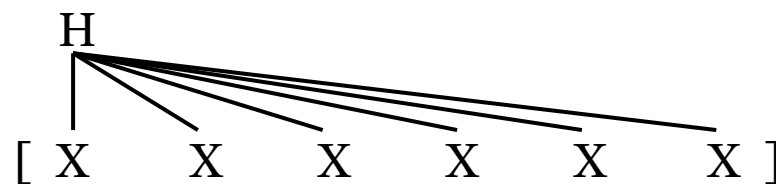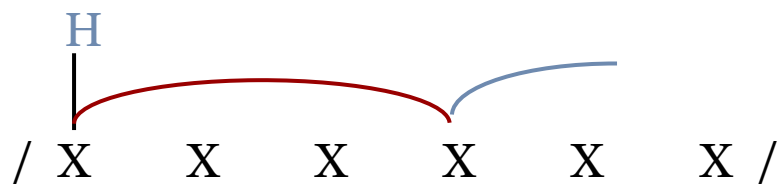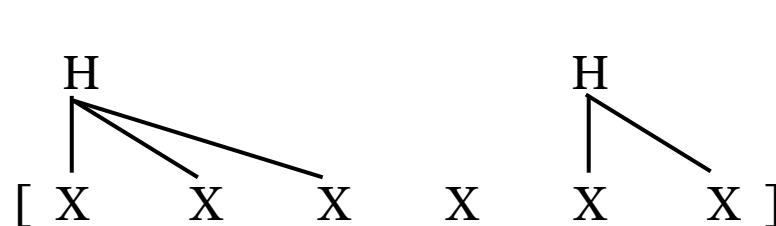
- Non-iterative spreading with an intervening High tone

```
    H               H                      H              H
    |               |                      |\             |\
/ X   X   X   X   X   X /          [ X   X   X   X   X   X ]
```
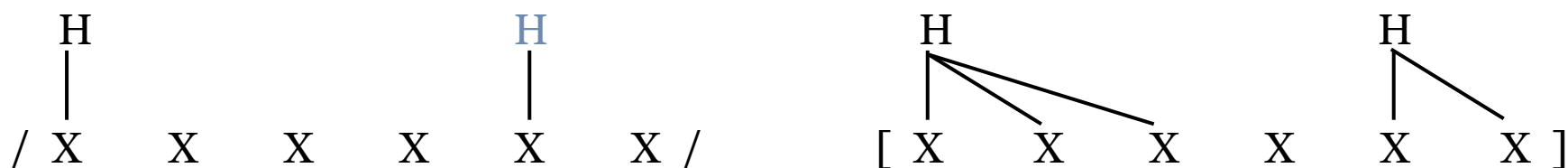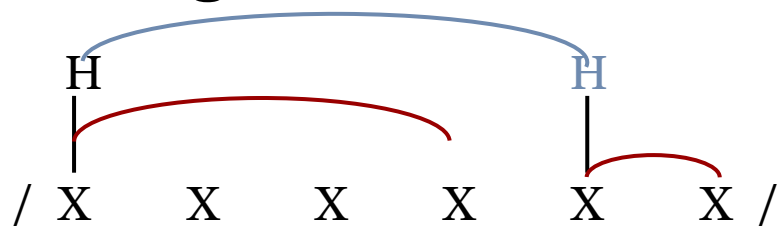
Output tone dependent on TBUs on both sides

Sour Grapes-ish: Copperbelt Bemba

- Full spreading to right edge with no intervening High tone

- Non-iterative spreading with an intervening High tone

Output tone dependent on TBUs on both sides
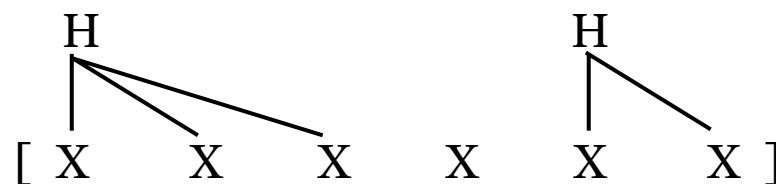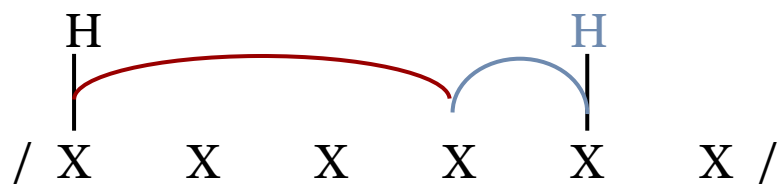
Sour Grapes-ish: Copperbelt Bemba

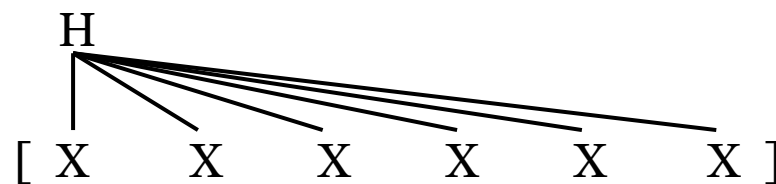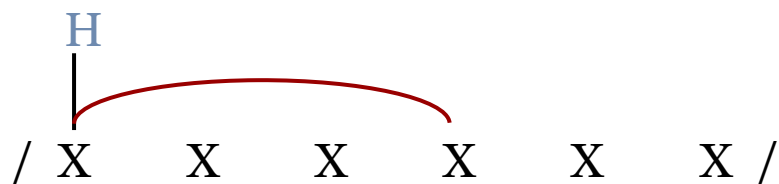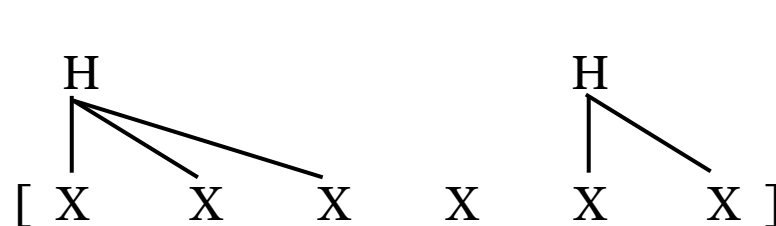- Full spreading to right edge with no intervening High tone

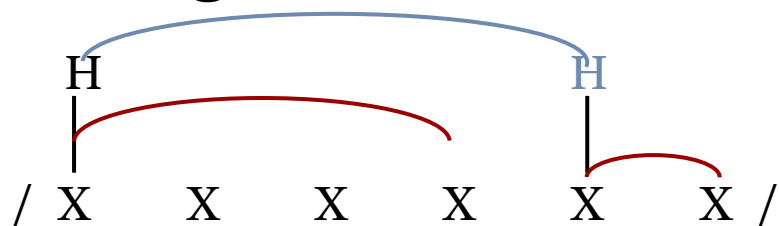- Non-iterative spreading with an intervening High tone

Undergoers follow the last trigger

Sour Grapes-ish: Copperbelt Bemba

- Full spreading to right edge with no intervening High tone

- Non-iterative spreading with an intervening High tone

Need to mark up non-last High tones

Copperbelt Bemba Markup

- Non-last H have two predictable TBUs following them
  - H??…H→HHH…H   (due to bounded spread)
  - Mark up H??…H   as HLH…H
- All TBUs following last H are predictable
  - H…?→H…H
  - So mark up last H locally   HL   as HH
- LFST then fills in HLH→HHH, and spreads from HHLL

Copperbelt Bemba

Rightward:

Leftward:
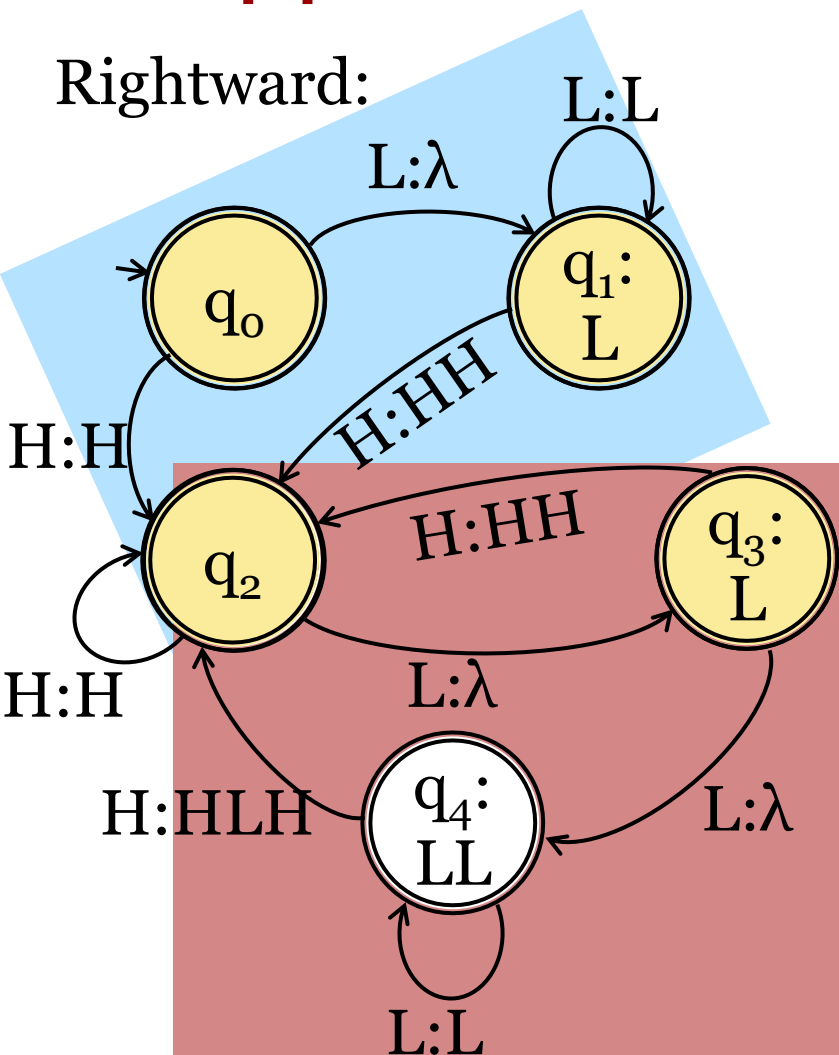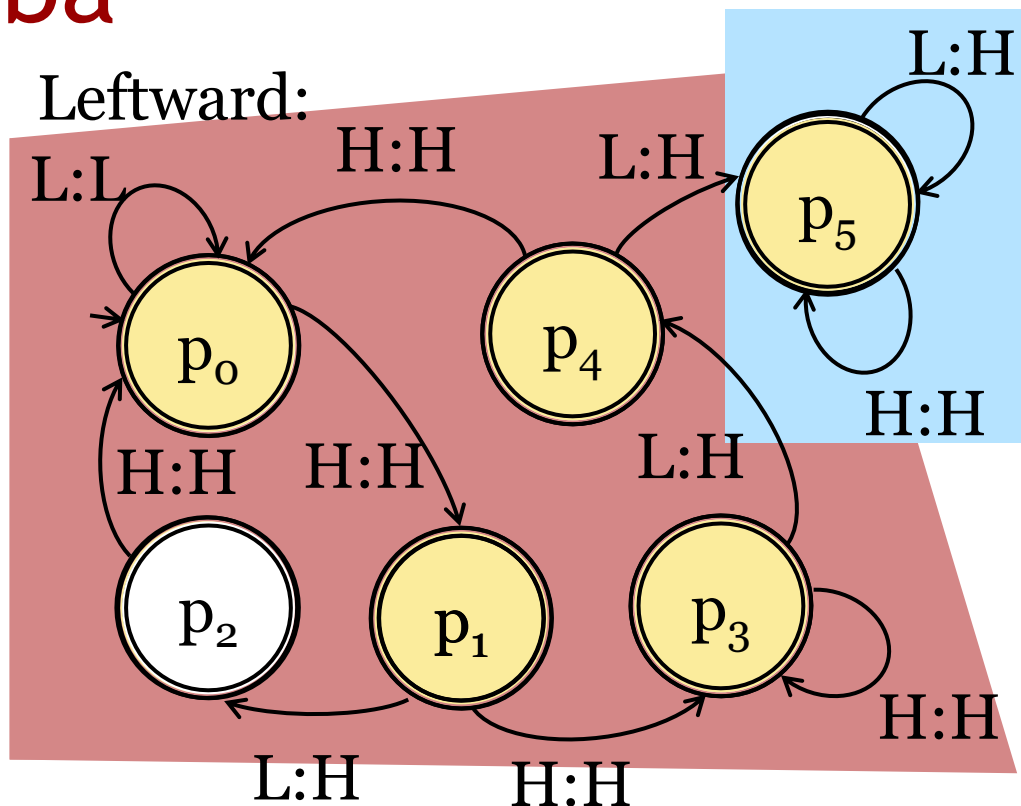

/ H L L L H L /

H L H L H H

[H H H L H H]₃₄

Copperbelt Bemba

Rightward:
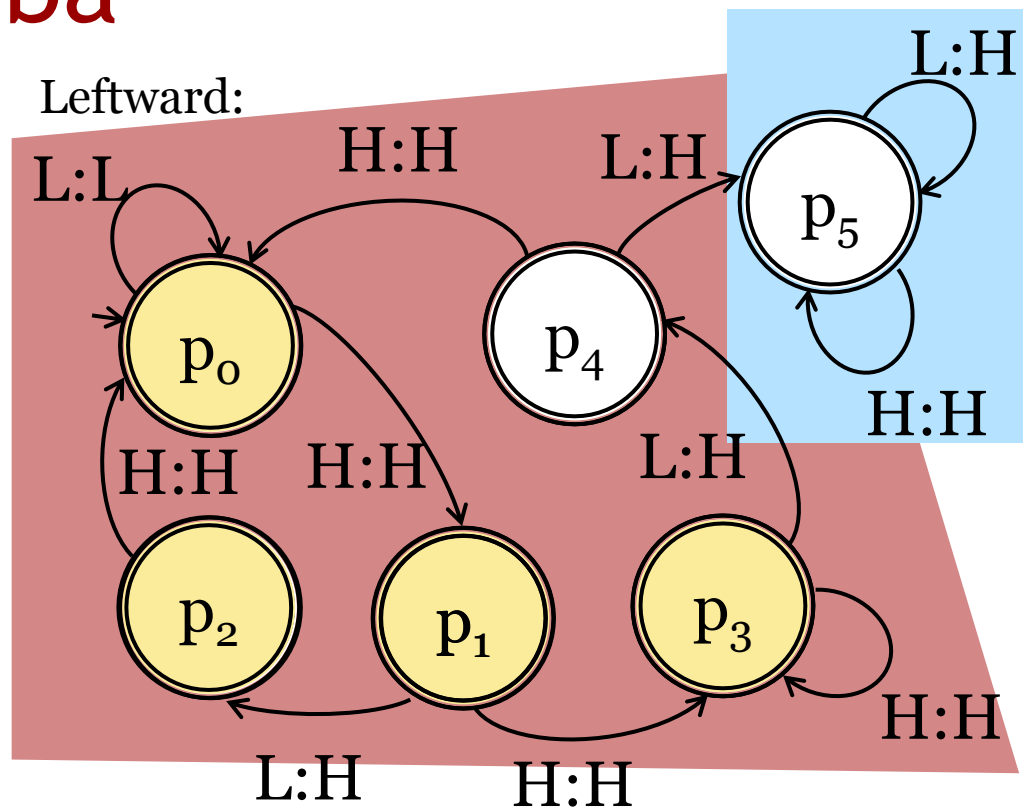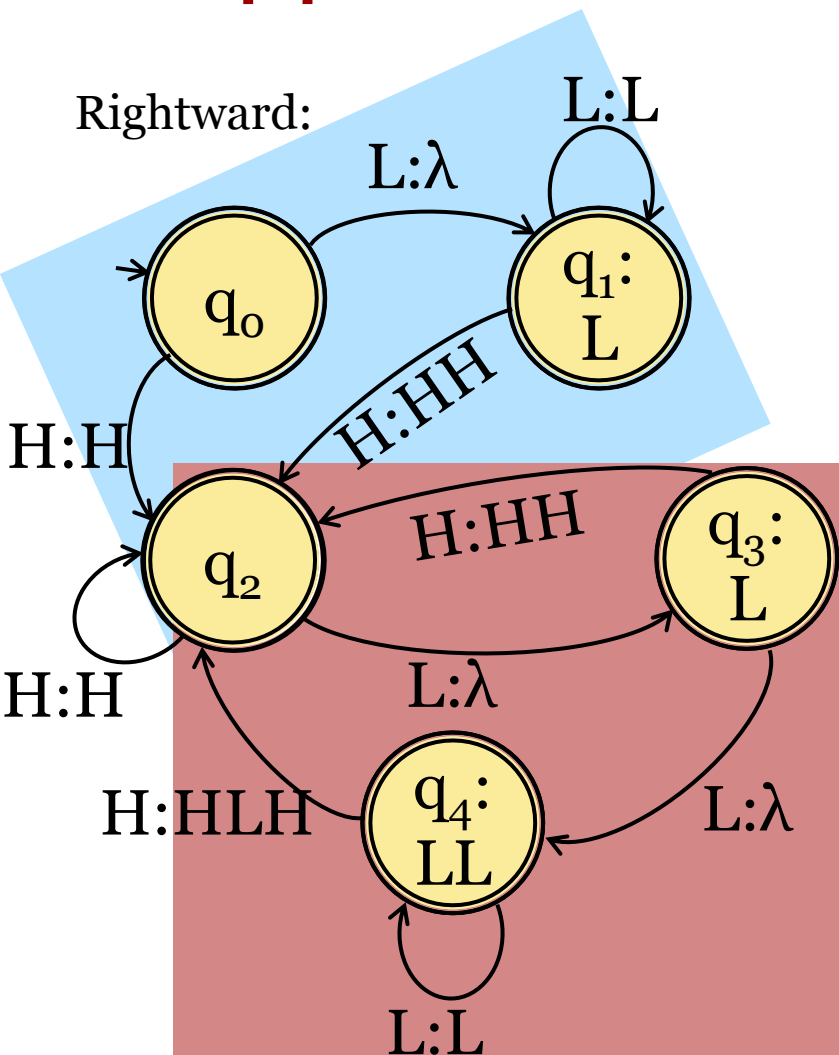
Leftward:

/ H L L L H L /

  H L H L H H

[H H H L H H] 34

Copperbelt Bemba

Rightward:

Leftward:

/	H	L	H	L	L	L	/
	H	H	H	H	L	L	
[	H	H	H	H	H	H	]

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Results Thus Far

| Tonal Plateauing	First Trigger	Last Trigger
	XL<u>H</u>H (HL<u>H</u>)	L<u>H</u> (H<u>H</u>)
Copperbelt Bemba	Last Triggers	Pre-Blocker Triggers
	<u>H</u>HLL	<u>H</u>LH
Sour Grapes	Post-Blocker Triggers	Pre-Blocker Triggers
	???	???

True Sour Grapes Markup

- Before the last H (blocker), there is no spreading
  - Before the blocker, Sour Grapes is one-to-one:
  - H??...H→H??...H
  - So the markup mapping must be one-to-one before the blocker

t ——————————→ t
d ——————————→ d

k ——————————→ k
g ——————————→ g
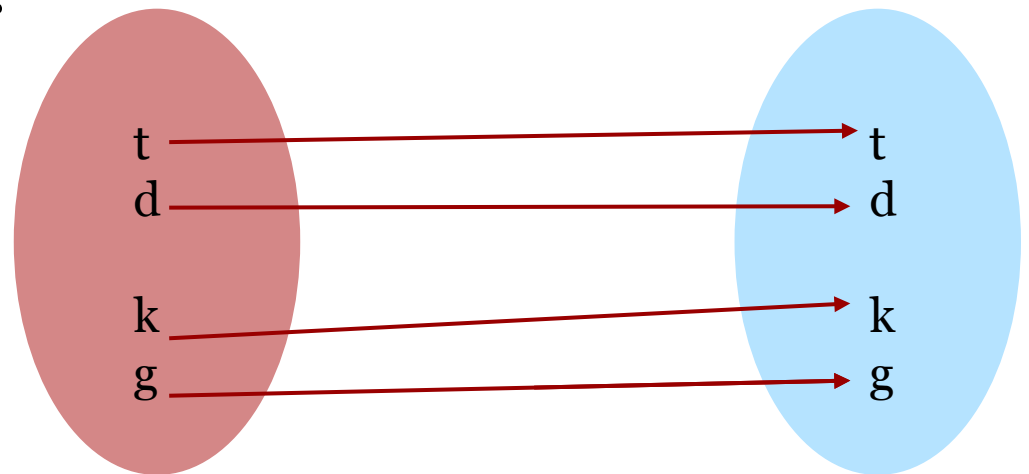
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  - H??...H→H??...H
  - So the markup mapping must be one-to-one before the blocker

Nothing pre-blocker can be marked up
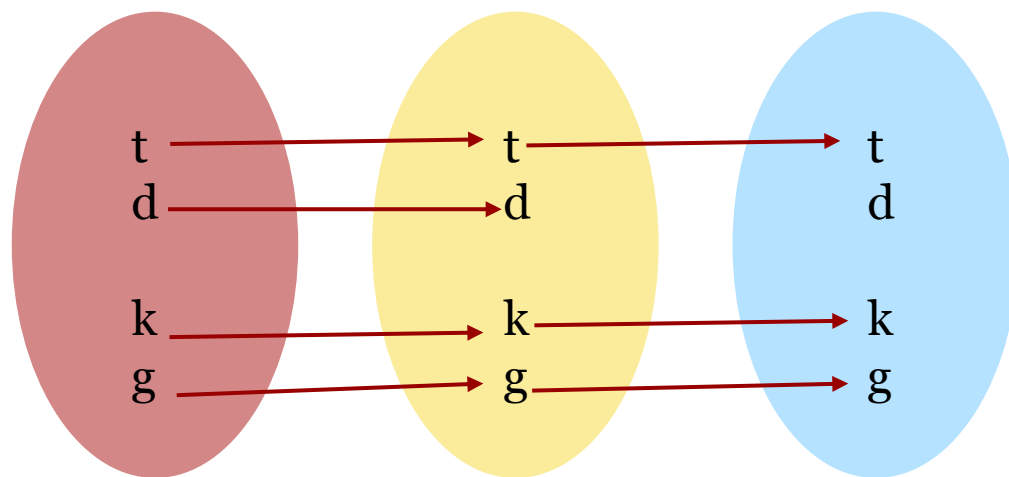
Let's Try: True Sour Grapes Markup

- All TBUs following last H are predictable
  - H…?→H…H
  - Suppose we can mark up H as some string XY
  - If all elements of XY are in the alphabet, XY could appear underlyingly before the last H
    - /XY…HL/→[XY…HH]
    - /XY…HL/ cannot markup to XY…XY, (XY is unique)
    - /XY…HL/ is marked up as ZW…XY→$_{LFST}$ XY…HH
    - Now ZW…HL cannot markup to ZW…XY
  - Some AB must mark up to XY (markup is injective)
- Contradiction: no such markup exists
- Sour Grapes is not weakly deterministic

Conclusion

- Attested unbounded circumambient processes (tonal and featural) are weakly deterministic

Tonal Plateauing	First Trigger	Last Trigger
	XL<u>H</u>H (HL<u>H</u>)	L<u>H</u> (H<u>H</u>)
Copperbelt Bemba	Last Triggers	Pre-Blocker Triggers
	<u>H</u>HLL	<u>H</u>LH
Sour Grapes	Post-Blocker Triggers	Pre-Blocker Triggers
	???	???

- Unattested sour grapes patterns are regular, but not weakly deterministic