IMPLEMENTING FINITE STATE GRAMMARS FOR UNDERSTANDING PROSODIC MANIPULATIONS IN INFANT-DIRECTED SPEECH

KRISTINE M. YU UMASS AMHERST
SAMEER UD DOWLA KHAN REED COLLEGE
MEGHA SUNDARA UCLA

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COLLABORATORS

Sameer ud Dowla Khan

REED COLLEGE

Megha Sundara

The UCLA Phonetics Lab

RESEARCH QUESTION

*Many **subphonemic and gradient** aspects of speech, whether segmental or suprasegmental, which were once considered to be beyond the speaker's control, are now understood as **part of the linguistic system stipulated by the grammar** of a given language.*

What are the linguistic functions of gradient modulations in the fundamental frequency contour?

CHALLENGES

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- the entanglement of **extra-linguistic and linguistic factors** in conditioning f0 variation

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- the **generalizability** of proposed grammars to a wider range of speech styles and contexts

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- the **contextual dependence** of individual tonal elements on one another

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- **evolvin** ... onal gr
- the ... of proposed grammars to a wider ran of speech styles and contexts
- the **contextual dependence** of individual tonal elements on one another

Proposed overall strategy:

To implement finite state intonational grammars


Case study of a *particular speech style/variety*
Infant directed speech
(IDS)
https://timedotcom.files.wordpress.com/2014/10/89845500.jpg

CHALLENGE 1:

ENTANGLEMENT OF EXTRA-LINGUISTIC AND LINGUISTIC FACTORS

CHALLENGE: EXTRA-LINGUISTIC/LINGUISTIC

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Proposed strategy:

Analyze f0 contours using intonational phonology

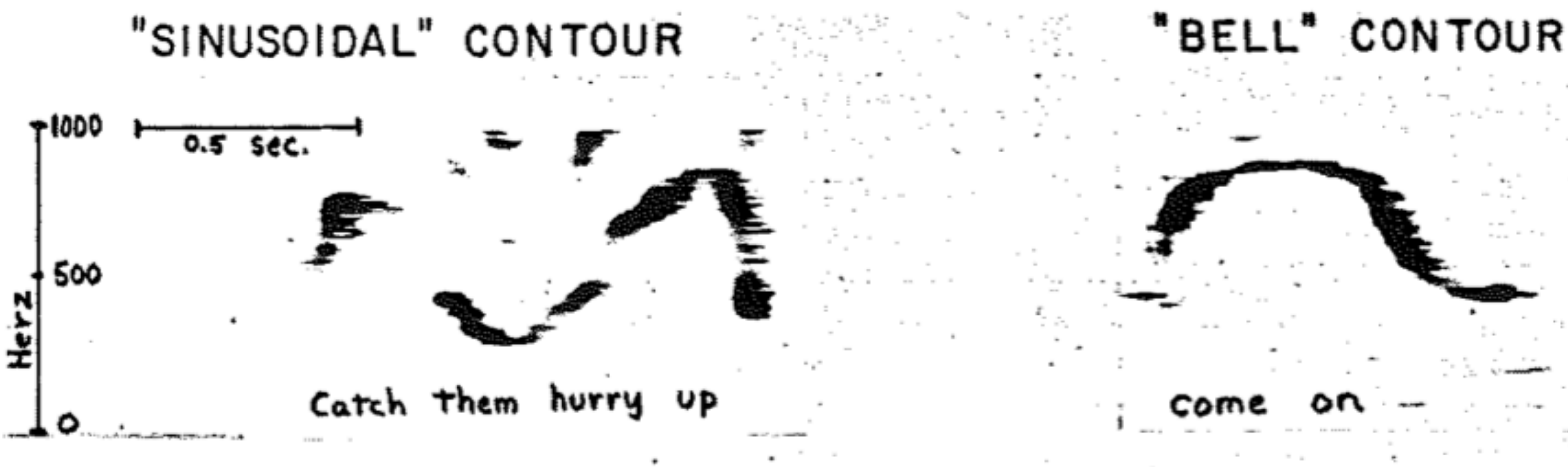
PROPERTIES OF (CANONICAL) INFANT-DIRECTED SPEECH

- Higher and wider fundamental frequency (f0) range
- Slower speech rate; more/longer pauses

Fernald and Simon (1984), Fernald and Mazzie (1991), Albin and Echols (1996), Kitamura et al. (2002), i.a.

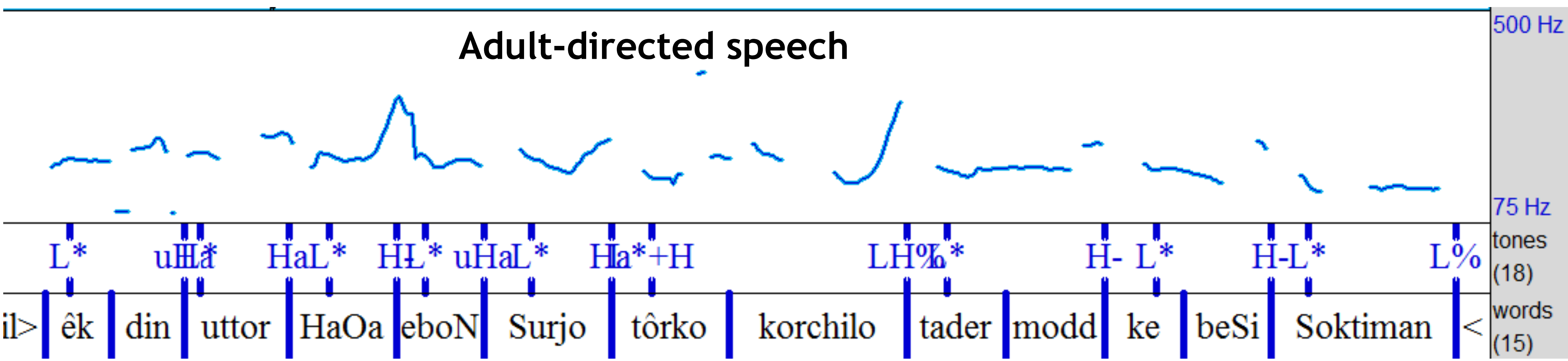
IDS AS A SOCIO-AFFECTIVE SIGNAL

- Rising pitch contours for **eliciting attention**
- Sinusoidal and bell-shaped pitch contours used for **maintaining attention** and **positive rapport**



(Stern et al. 1982)

BENGALI INFANT-DIRECTED SPEECH



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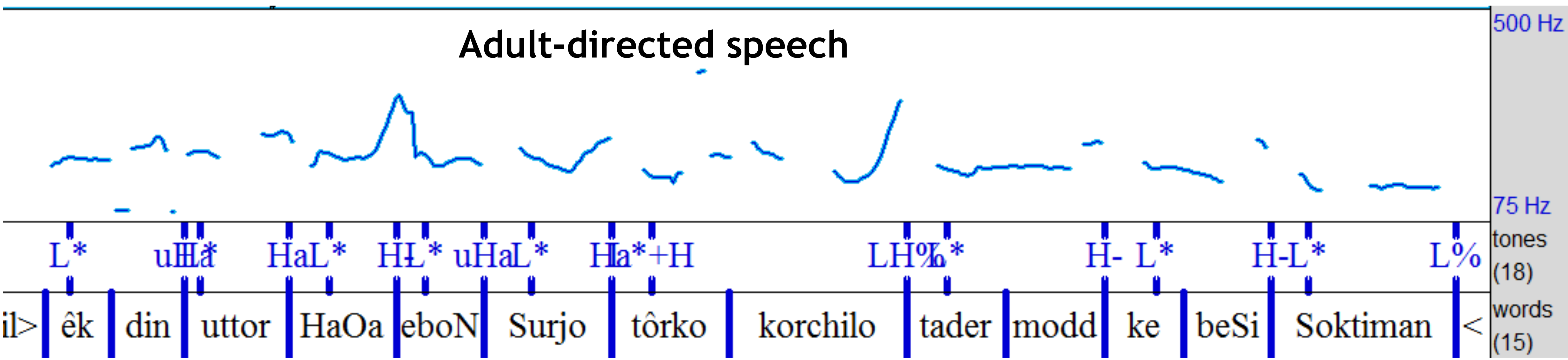

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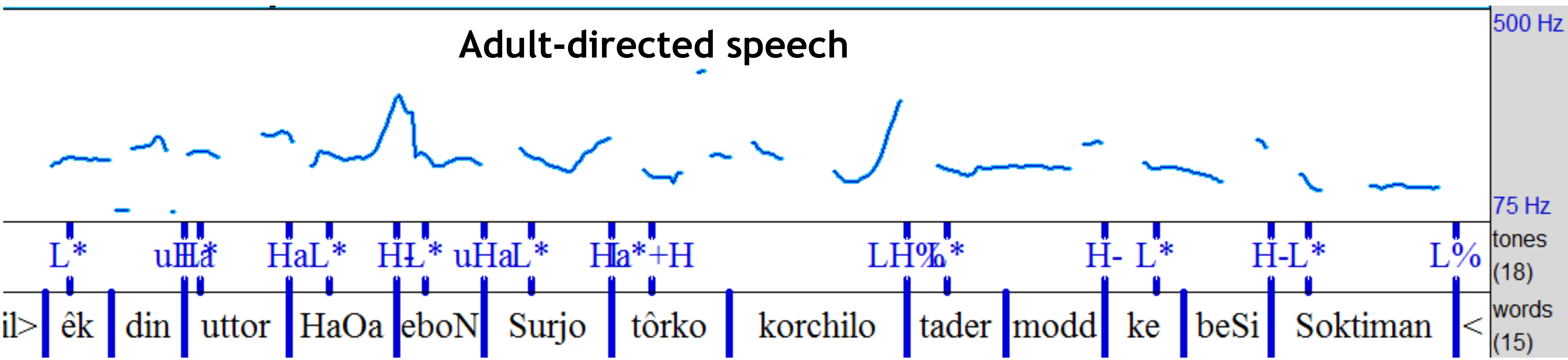

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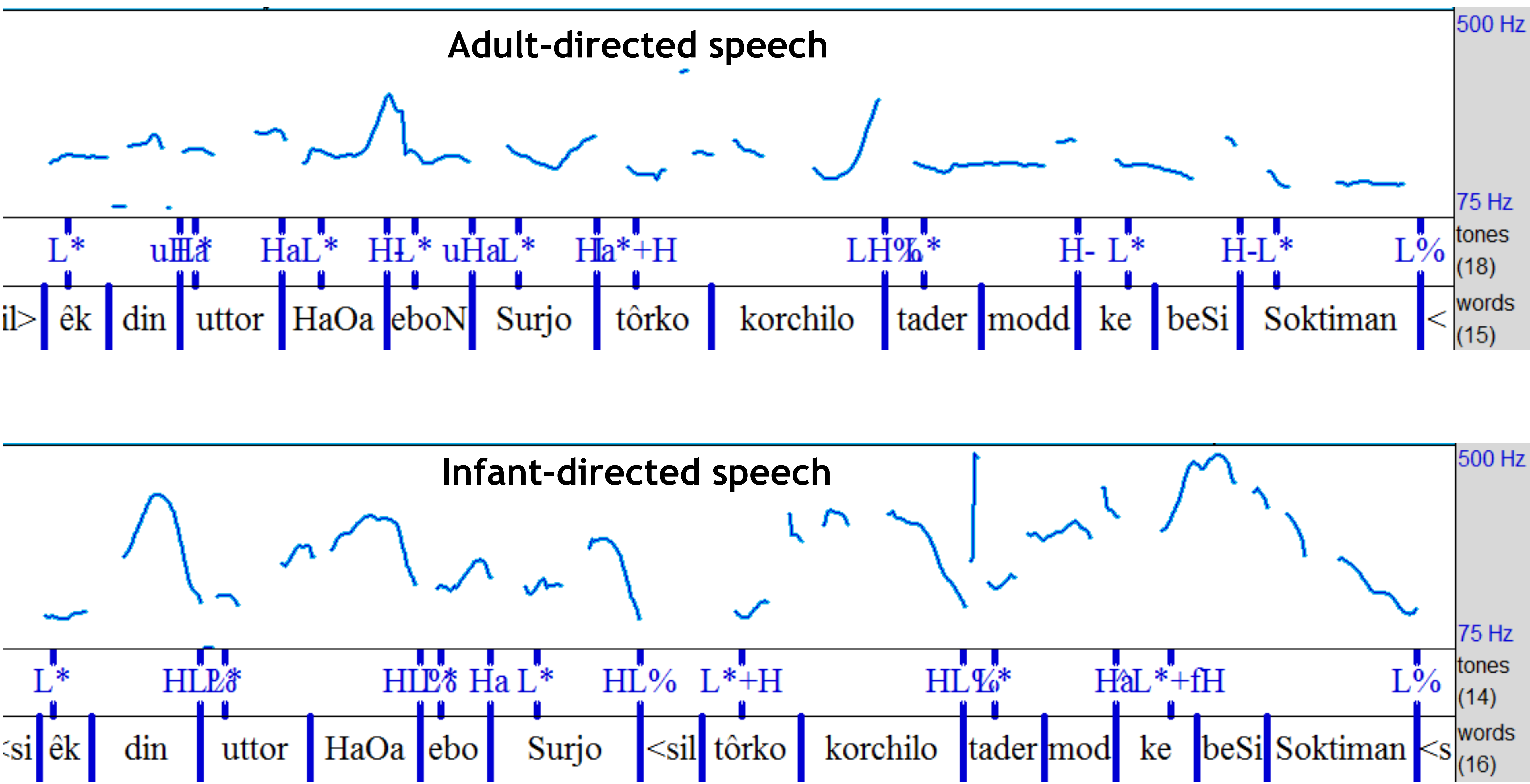

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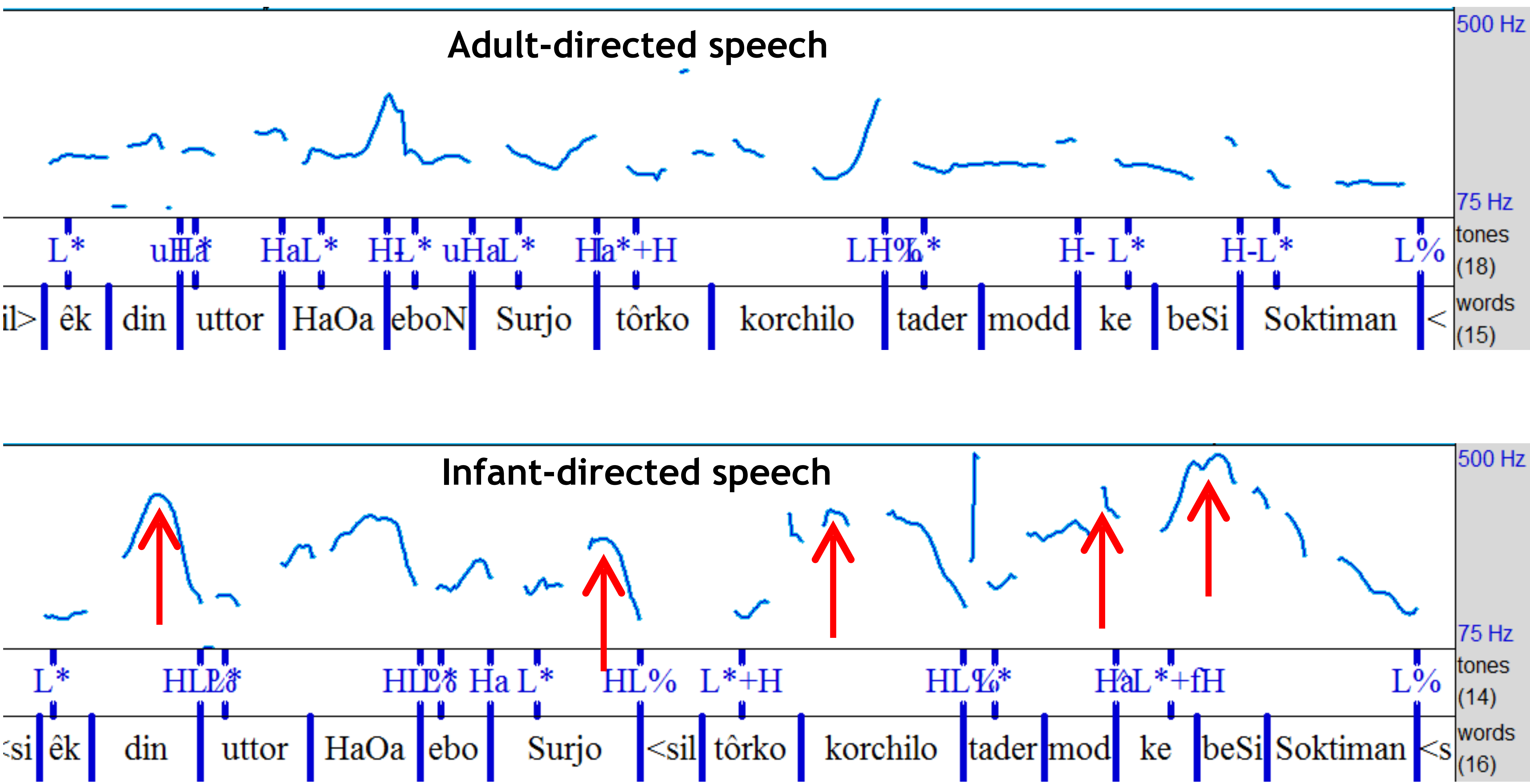

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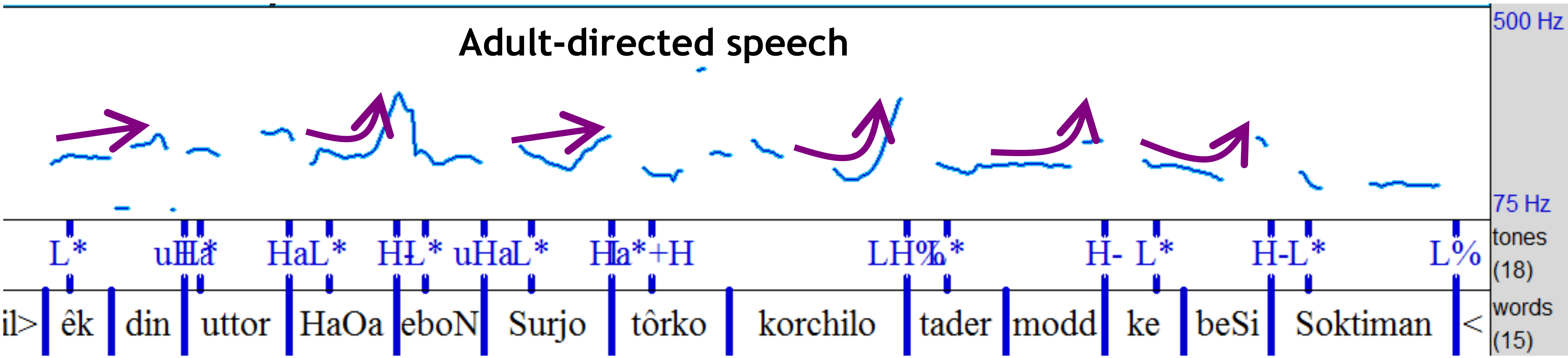

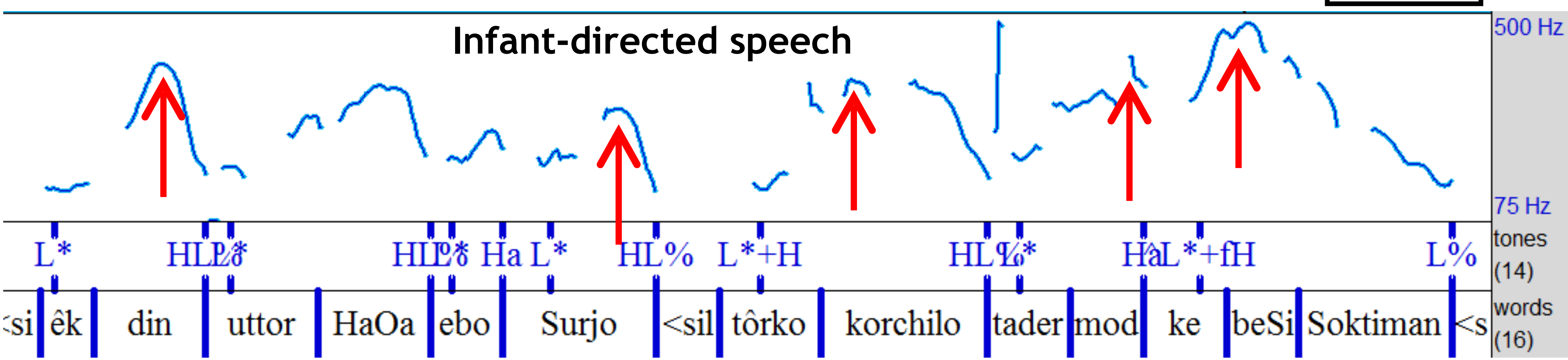

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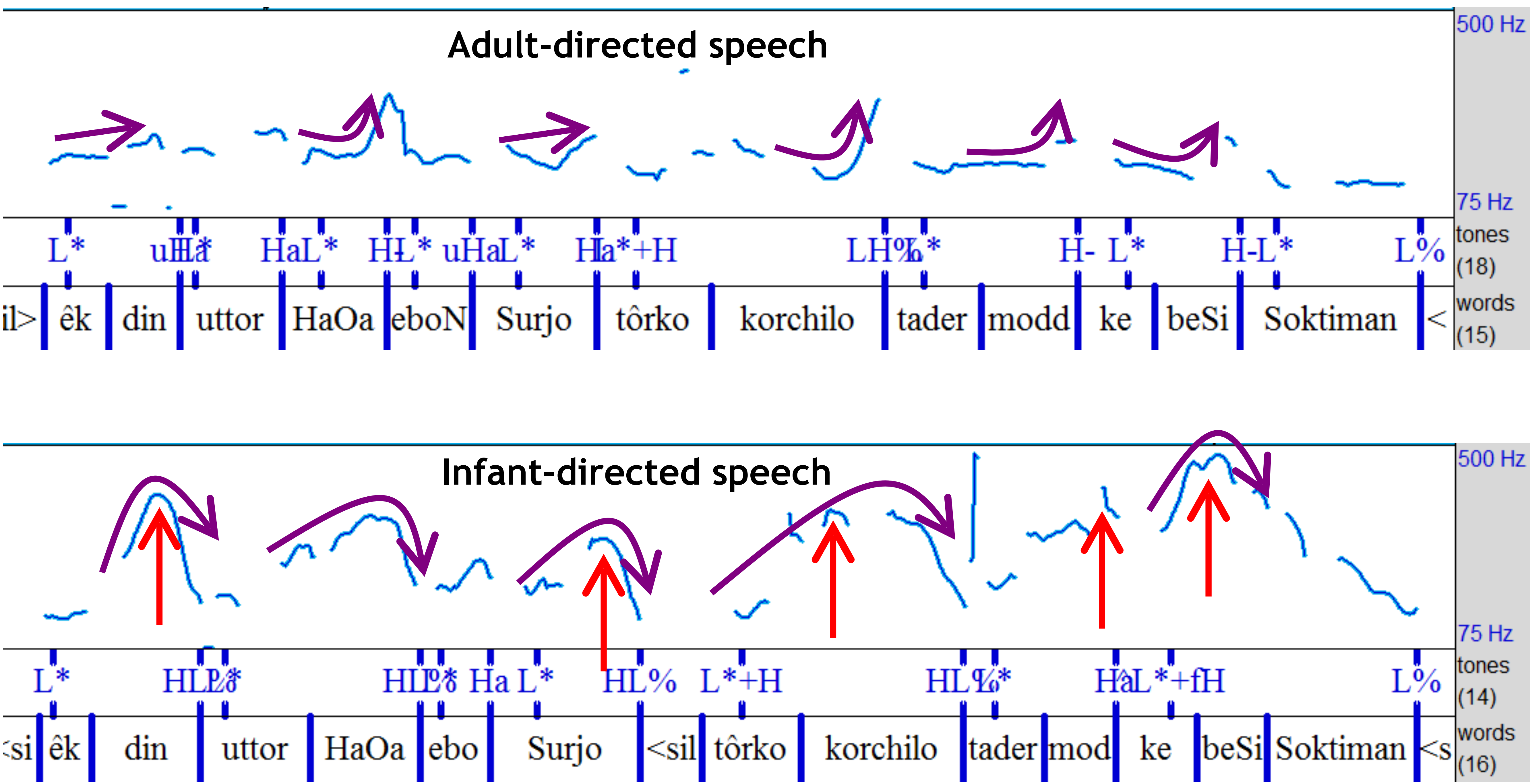

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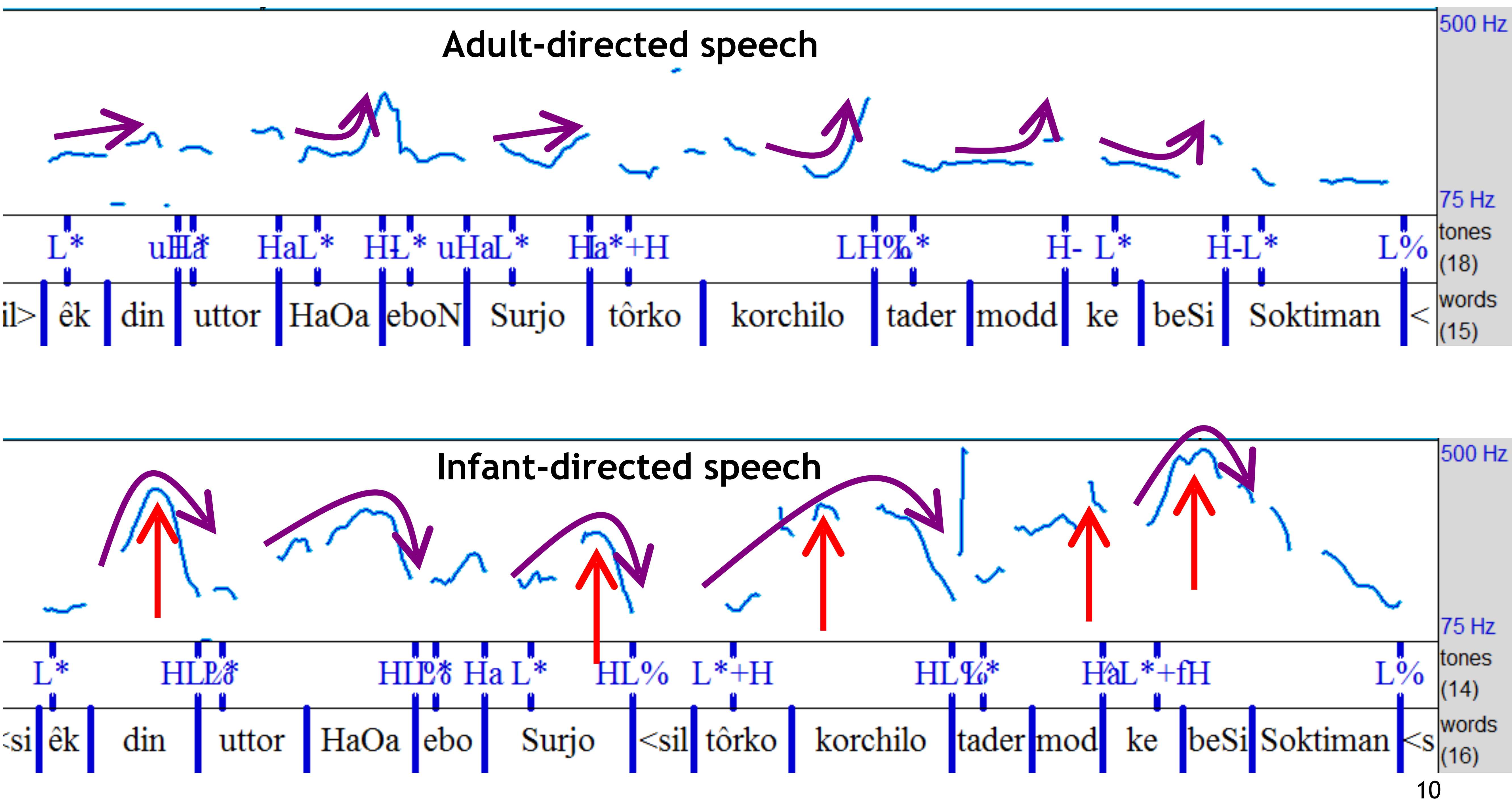

Not just wider f0 range, but different _kinds_ of tones

STRATEGY: INTONATIONAL PHONOLOGY

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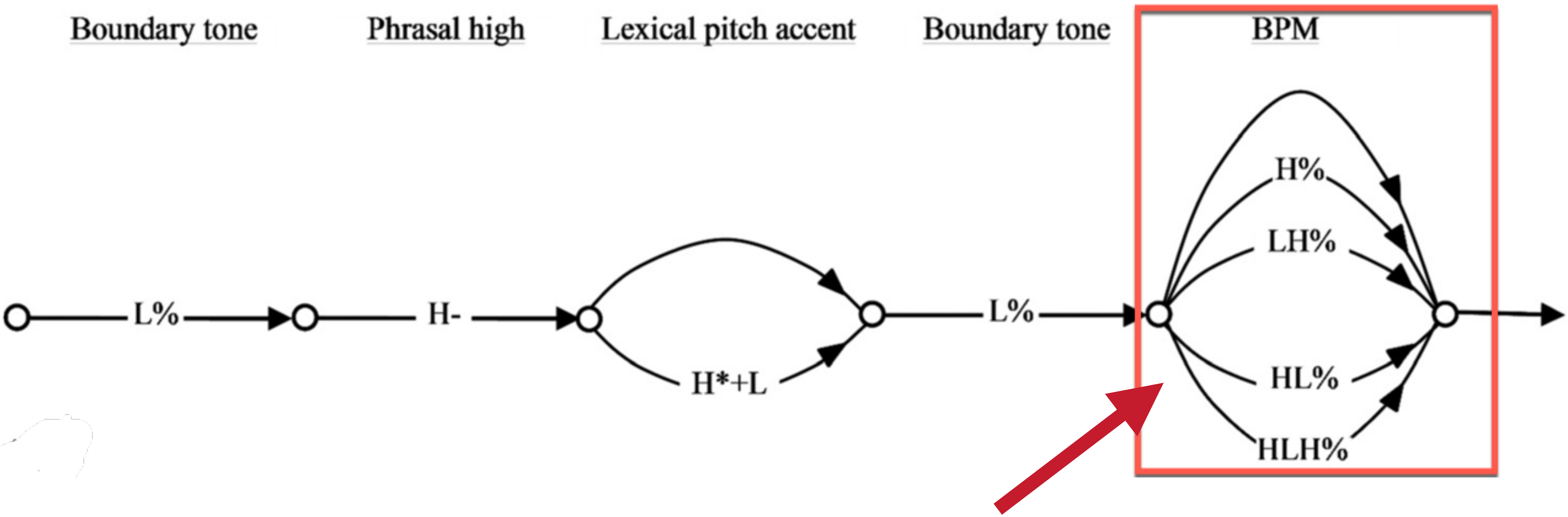
TONOTACTIC GRAMMARS: TOKYO JAPANESE



(Pierrehumbert and Beckman, 1988; Maekawa et al., 2002; Venditti, 2005; Igarashi et al. 2013)

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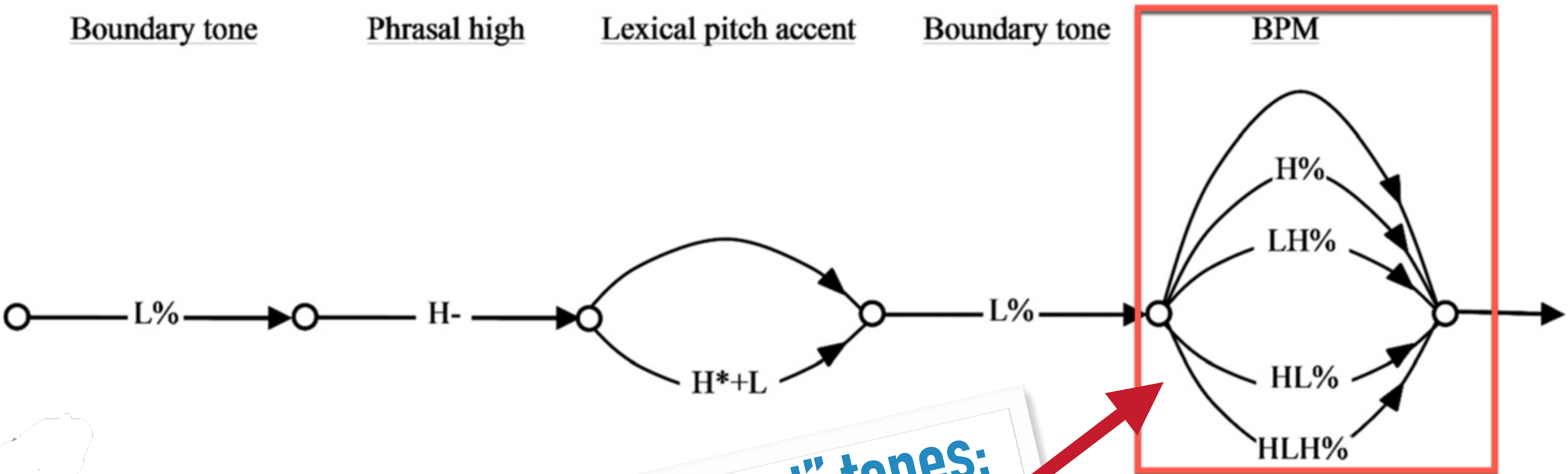
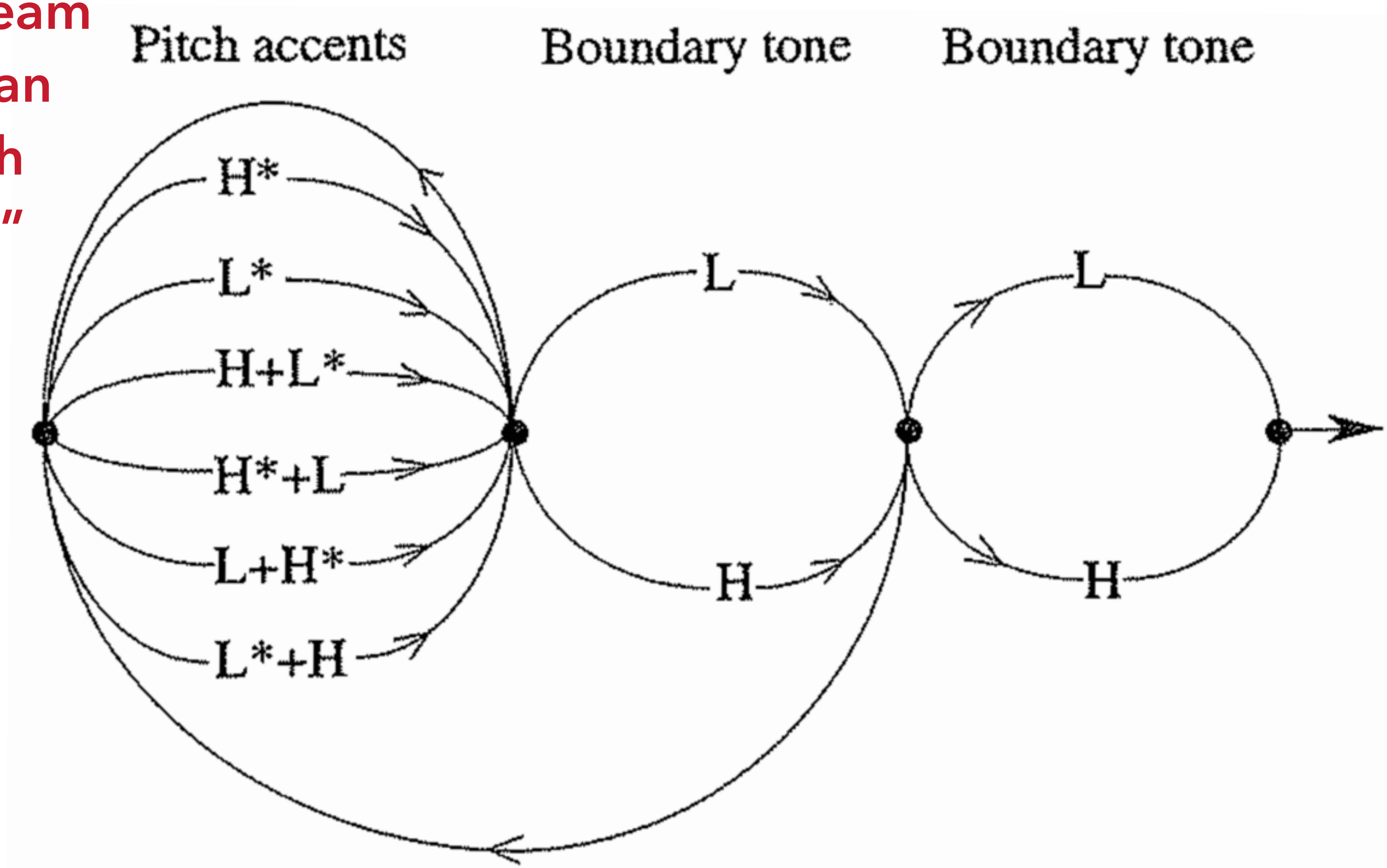


"Boundary pitch movement" tones: locus of f0 range expansion

(Pierrehumbert and Beckman, 1988; Maekawa et al., 2002; Venditti, 2005; Igarashi et al. 2013)

TONOTACTIC GRAMMARS: ENGLISH

"Mainstream American English (MAE)"



Pierrehumbert (1980), Pierrehumbert & Beckman (1986), Pierrehumbert (2000), Beckman et al. (2005), i.a.

TONOTACTIC GRAMMARS: ENGLISH

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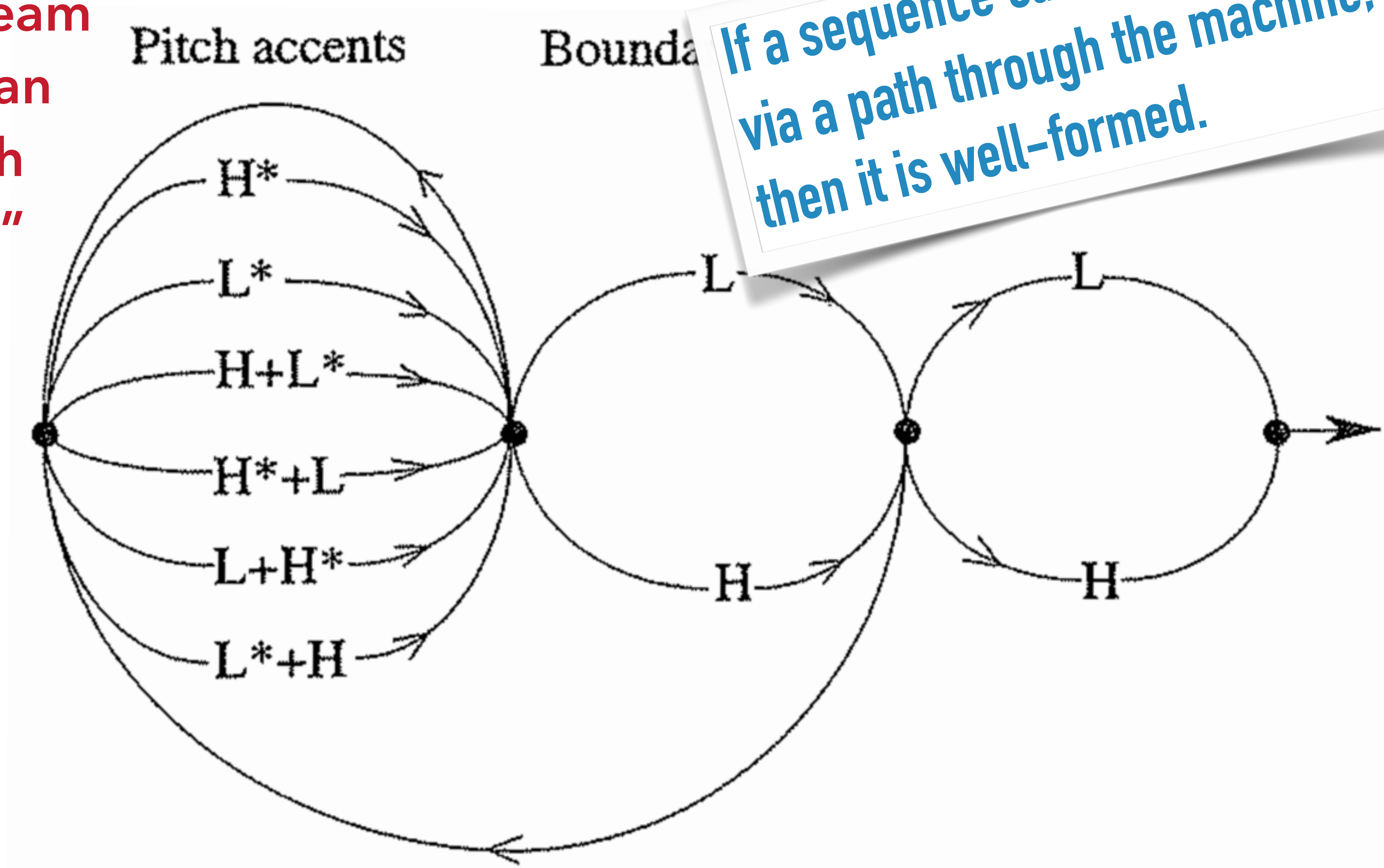

If a sequence can be generated via a path through the machine, then it is well-formed.

Pierrehumbert (1980), Pierrehumbert & Beckman (1986), Pierrehumbert (2000), Beckman et al. (2005), i.a.

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STRATEGY: INTONATIONAL PHONOLOGY

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- the entanglement of **ex** ... **factors** in conditioning f0 variation

Why finite state grammar?

Strategy:

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LEXICON AND FINITE/FINITE STATE GRAMMARS

- A grammar derives the set of well-formed tonal sequences over a **lexicon** of tonal elements, i.e., a **tonal inventory**

Common for intonational grammars to be expressed/summarized as a **lexicon**

CHICKASAW INTONATIONAL LEXICON

APPENDIX: SUMMARY OF CHICKASAW INTONATIONAL LABELS

H*	*Nuclear pitch accent*: falls on a syllable in the rightmost word of the IP.
H^{λ}	*Morpholexical pitch accent*: lexically marked pitch accent in certain words.
!H*	*Downstepped pitch accent*: pitch accent with lowered fo peak relative to an earlier pitch accent within the same IP.
<	*Late Fo event*: marked on the actual Fo peak when it occurs after the syllable bearing the phonological pitch accent.
H%	*Boundary tone*: occurs at the end of statements and echo questions.
Ø%	*Boundary tone*: occurs at the end of statements.
L%	*Boundary tone*: occurs at the end of wh- and yes/no questions, non-main clauses, exclamations, and postposed nouns.
HL%	*Boundary tone*: occurs at the end of imperatives.
H, L	*Accentual Phrase tones*: aligned with different positions in the AP.

Gordon (2005)

BENGALI INTONATIONAL LEXICON

TABLE 4.1 Full inventory of pitch accents and boundary tones used in non-focused contexts in the current intonational phonological model of Bangladeshi Standard Bengali

Association	Target
Pitch accents	H*, L*, L*+H
AP boundary tones	Ha, La
ip boundary tones	H-, L-, HL-, LH-
IP boundary tones	H%, L%, HL%, LH%, HLH%

Khan (2014)

LEXICON AND FINITE/FINITE STATE GRAMMARS

- A grammar derives the set of well-formed tonal sequences over a **lexicon** of tonal elements
- A **finite** grammar is just a **list** of these well-formed sequences
  - No generalizations

Also common for intonational grammars to be expressed/summarized as a **finite grammar (list)**

WELL-FORMED ENGLISH TONAL SEQUENCES: LIST

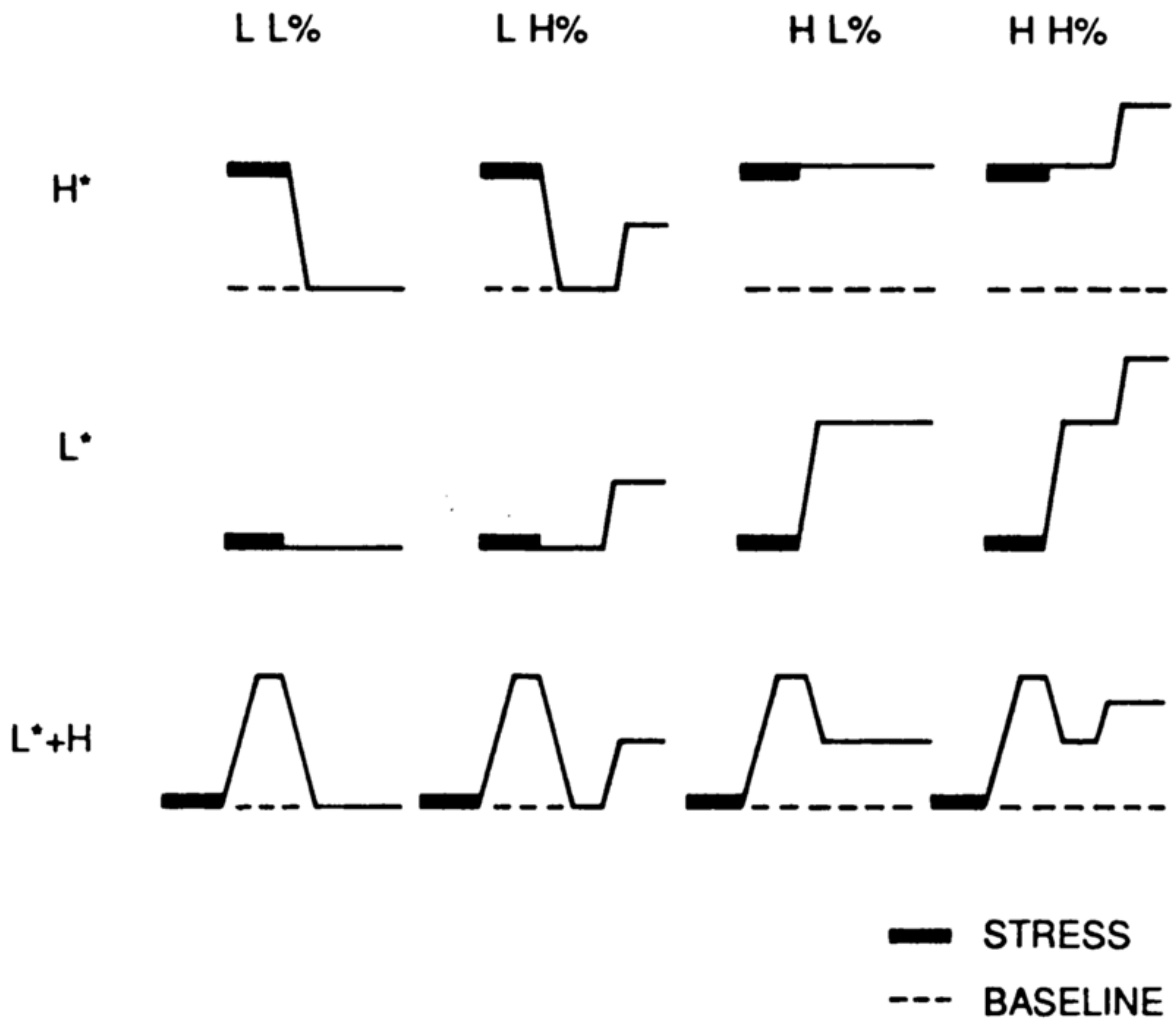
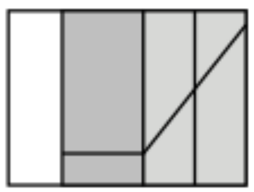
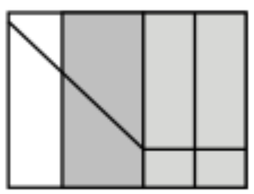
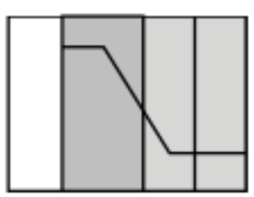
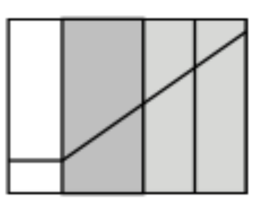


Figure 14.13
Schematic f_0 contours.

Pierrehumbert & Hirschberg (1990)

WELL-FORMED FRIULIAN TONAL SEQUENCES: LIST

TABLE 4.5 Inventory of Friulian nuclear configurations, their schematic representations, and their use in sentence types

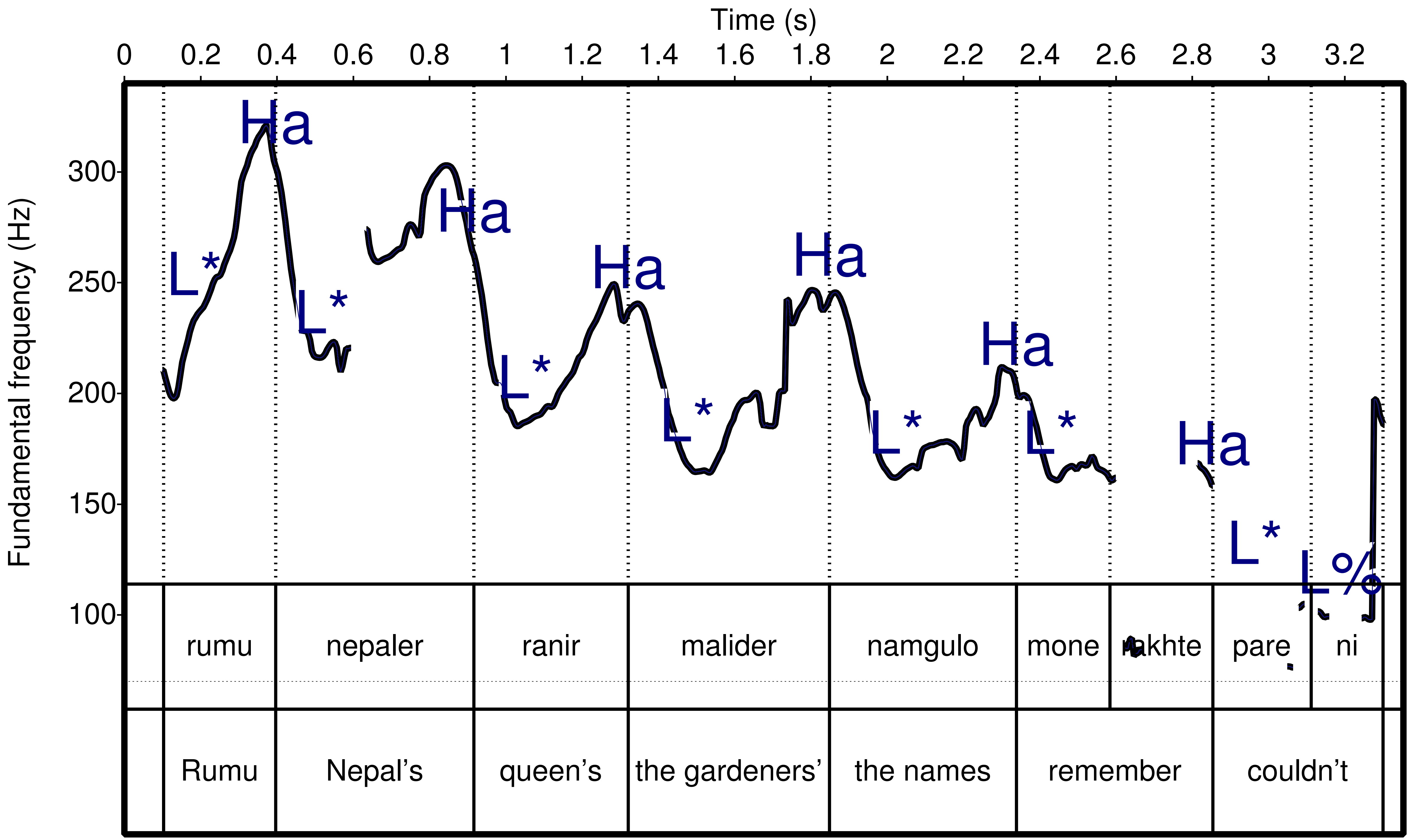
Configuration		Sentence types where it is used
	L* H%	Information-seeking yes/no questions, confirmation-seeking yes/no questions, reclamatory wh-questions, non-final elements of a declarative enumeration
	H+L* L%	Broad-focus statements, commands, imperative wh-questions, final element of an enumeration, final element of a disjunction
	H*+L L%	Epistemically biased statements, information-seeking wh-questions, subject in SVO yes-no questions
	L+H* H%	Counterexpectational wh-questions, non-final elements of a disjunction
	L+H* L%	Contrastive narrow-focus statements, exclamatives, information-seeking yes/no questions, confirmation-seeking yes/no questions, requests

Roseano et al. (2015)

LEXICON, FINITE, AND FINITE STATE GRAMMARS

- A grammar derives the set of well-formed tonal sequences over a **lexicon** of tonal elements
- A **finite** grammar is just a **list** of these well-formed sequences
  - No generalizations
- A **finite state** grammar compresses the list by encoding generalizations from *shared prefixes* in well-formed sequences

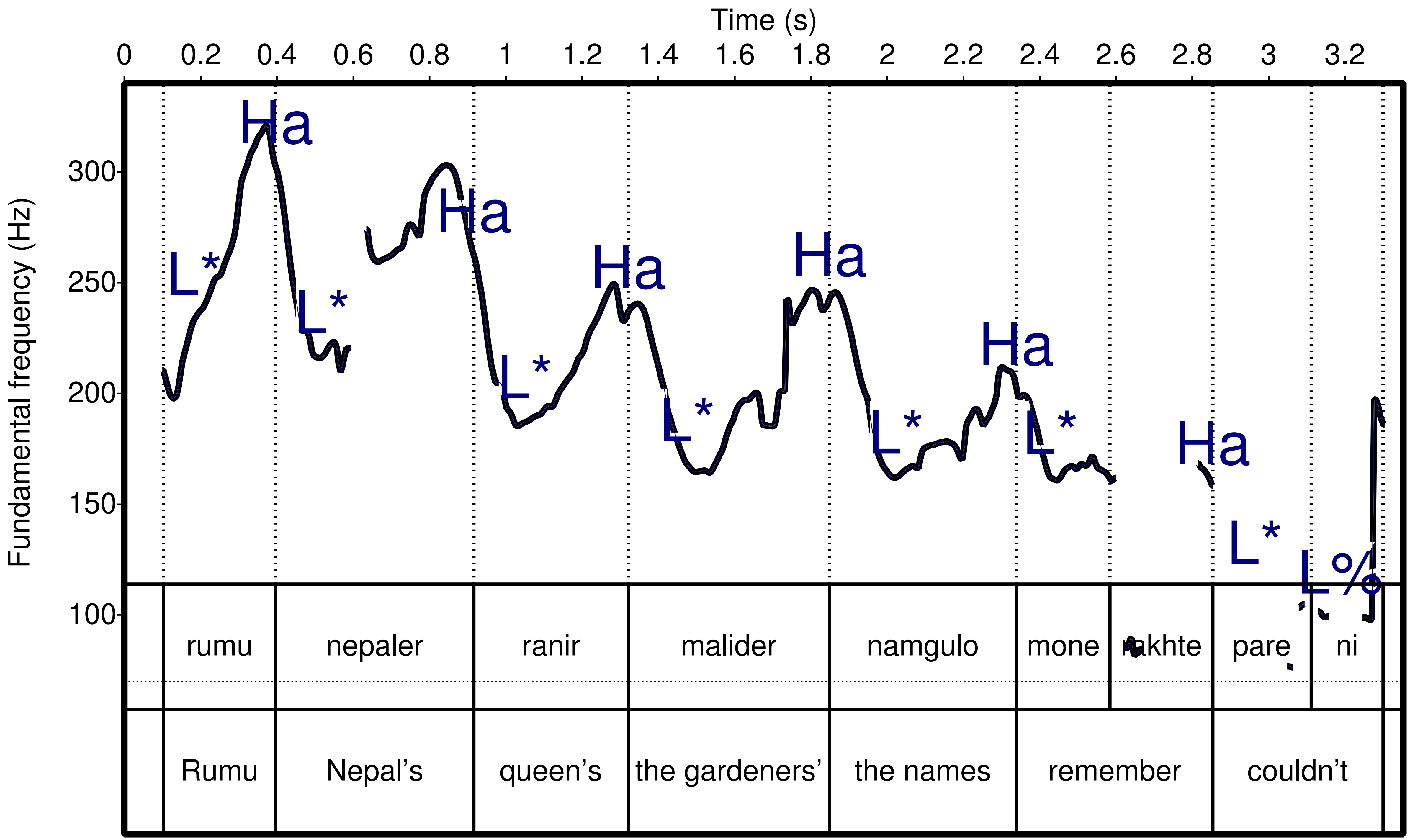
BENGALI ACCENTUAL PHRASES



`Rumu couldn't remember the names of the gardeners of the queen of Nepal.'

Khan (2008)

BENGALI ACCENTUAL PHRASES



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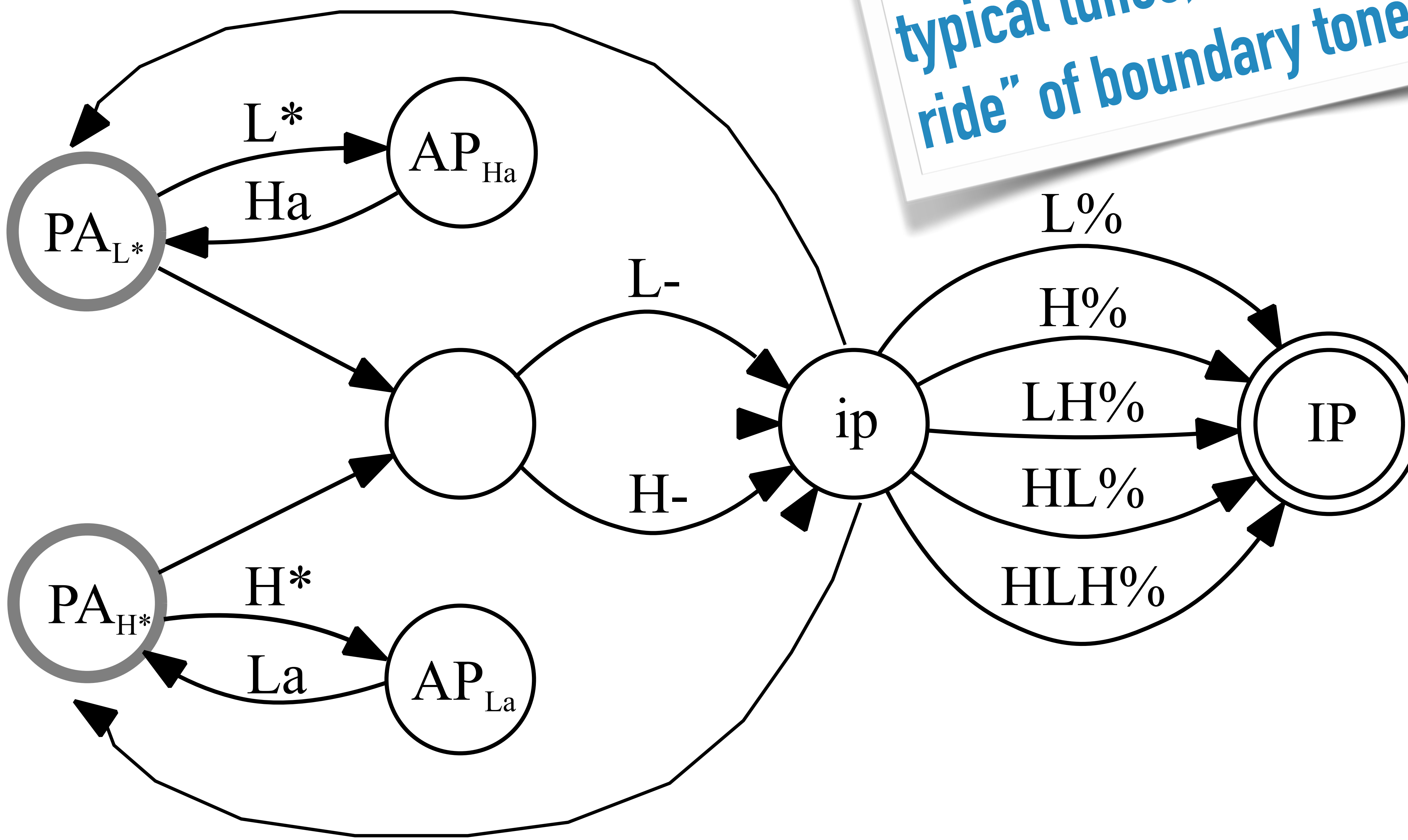
FINITE GRAMMAR (LIST) FOR BENGALI

- L* Ha L* L%
- L* Ha L* Ha L* L%
- L* Ha L* Ha L* Ha L* L%
- L* Ha L* Ha L* Ha L* Ha L* L%
- L* Ha L* Ha L* Ha L* Ha L* Ha L* L%
- L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* L%
- L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* L%
- L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* L%
- L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* Ha L* L%

Repeated L* Ha chunk is a coincidence,
no generalization

FINITE STATE GRAMMAR FOR BENGALI*



*non-focus contexts, typical tunes, no "over-ride" of boundary tones

Khan (2008, 2014), Yu, Khan & Sundara (under revision)

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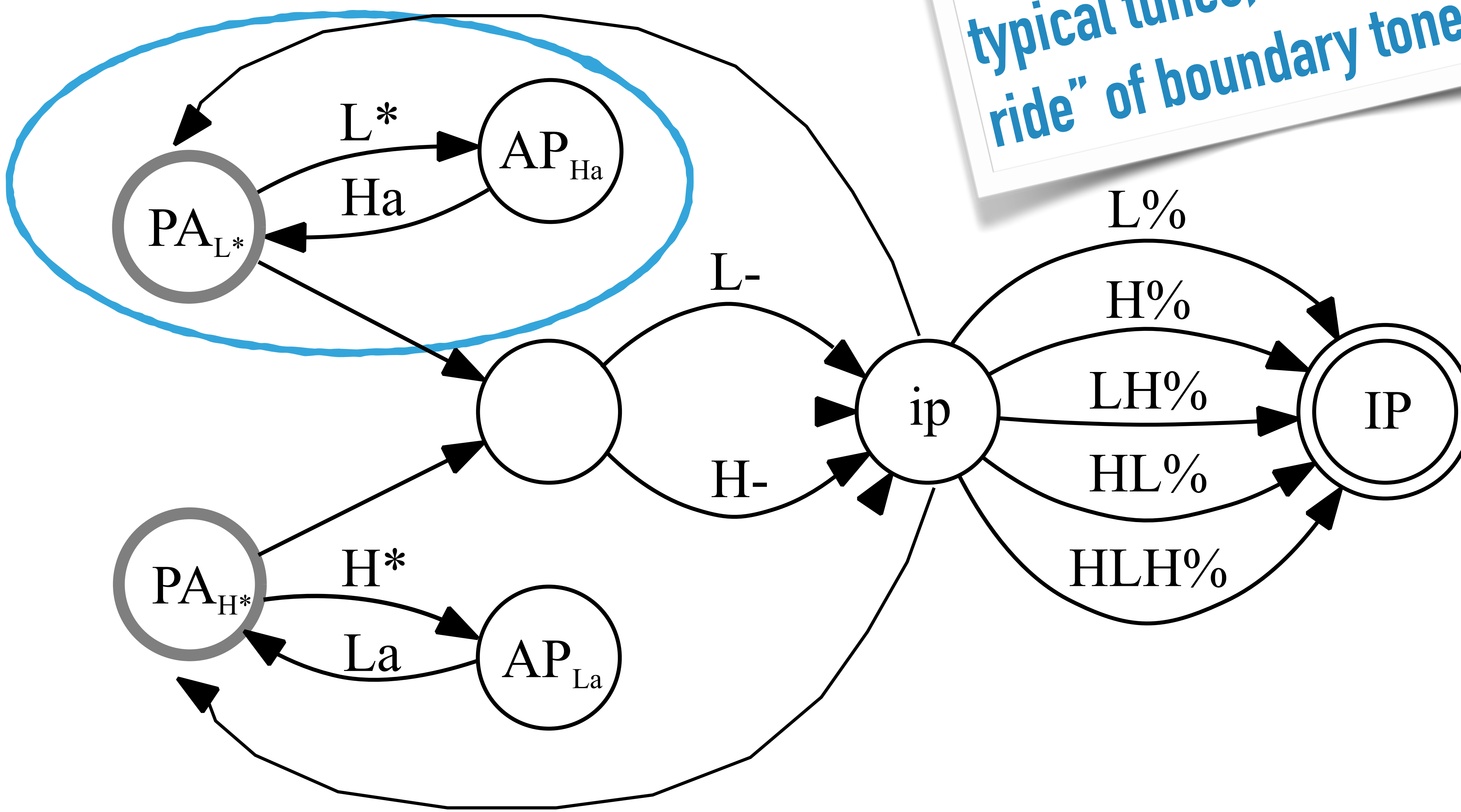

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CHALLENGES 2/3: EVOLVING HYPOTHESES, GENERALIZABILITY TO LANGUAGE VARIETIES

REVISIONS OF MAE TOBI

Revision from Pierrehumbert (1980) to Beckman & Pierrehumbert (1986) to ToBI (1994)

Pierrehumbert (1980) 7 Pitch Accents	B&P (1986) 6 Pitch Accents	ToBI (1994) 5 Pitch Accents with "!"
H*	H*	H*
L*	L*	L*
H⁻+L*	H+L*	**H+!H***
H*+L⁻	H*+L	**H*** (followed by downstep)
L*+H⁻	L*+H	L*+H
L⁻+H*	L+H*	L+H*
H*+H⁻	**H***	
Phrase accent (H-, L-), but no Interm. phrase level	Intermediate phrase tone (H-, L-)	Intermediate phrase tone (H-, L-, !H-)
Boundary tone (X%)	Intonation phrase tone (X%)	Inton. phrase tone (**%X**, X%)
Vocative tag has no pitch accent (X⁻ X%)	Vocative tag does have a pitch accent. (X* X- X%)	

(Jun 2011)

GUSSENHOVEN (2004, 2016): REVISION OF MAE TOBI

	MAE_ToBI		MAE_ToBI (overt tones only)	Off-ramp alternative
1	H* H- H%		H* H%	H* H%
2	H* L- H%		H* L-H%	H*L H%
3	H* H- L%		H*	H*
4	H* L- L%		H* L%	H*L L%
5	L* H- H%		L* H-H%	L*H H%
6	L* L- H%		L* H%	L* H%
7	L* H- L%		L* H-	L*H
8	L* L- L%		L*	L*
9				H*L
10				H* L%
11				L* L%
12	L*+H L- L%		L*+H L%	L*H L%

Table 1: Representations of nuclear contours in MAE_ToBI (column 1) with graphic phonetic implementations, after Pierrehumbert 1980 (column 2). Column 3 repeats the representations without tones that have no overt target. Column 4 gives representations in an off-ramp analysis without phrase tones and with optional IP-boundary tones.

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    - **Diagnose problems → revisions to intonational grammar**

DEFINING BENGALI GRAMMAR IN xfst (excerpts)

```
##########################################
# Define licit AP-internal tone sequences
##########################################

# Generate: { L* fHa, L* Ha }
define RisingAP [ "L*" [ "Ha" | "fHa"] ] ;


# Generate: { fH* La, H* La }
define FallingAP [ [ "fH*" | "H*" ] "La" ] ;


# Generate: { L*+fH, L*+fH La, L*+H, L*+H La };
define TrailingPeakAP [ [ "L*+fH" | "L*+H" ] ("La") ] ;


# Generate: { L+fH*, L+fH* La, L+H*, L+H* La }
define LeadingPeakAP [ [ "L+fH*" | "L+H*" ] ("La") ] ;
```

xfst: Beesley & Karttunen (2003)

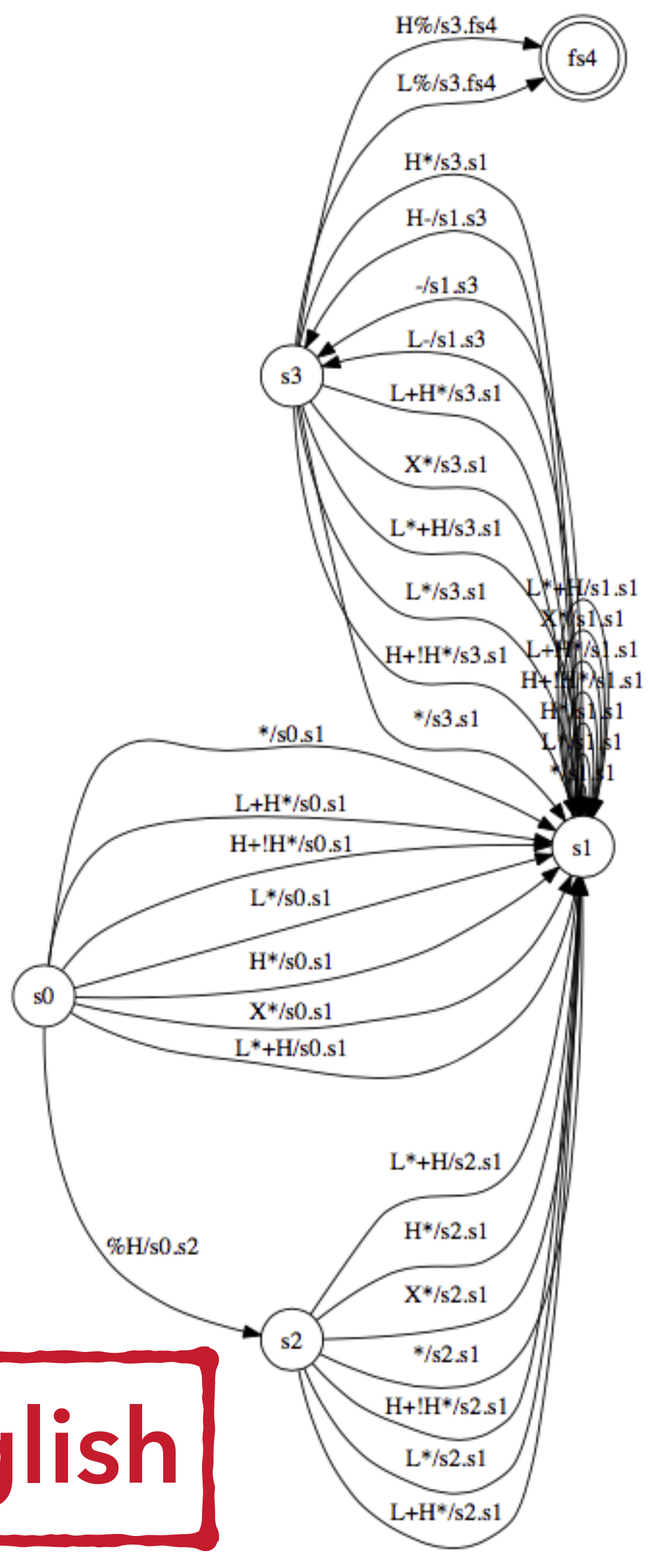
DEFINING BENGALI GRAMMAR IN xfst (excerpts)

```
### Define set of licit pitch accents

# A monotonal PA must not be followed by any other pitch accents (except possibly
*)
# A bitonal PA may be followed by a bitonal or monotonal PA
# Or could just be a * tone
# * tones can intersperse everywhere, as many as you want

define MonotonalPA ["L*" | "fH*" | "H*"] ;

define BitonalPA [ "L*+H" | "L*+fH" | "L+H*" | "L+fH*" ] ;

define PASeq [ [ MonotonalPA | [ [BitonalPA] ( BitonalPA | MonotonalPA ) ] |
"*" ] / "*" ];
```

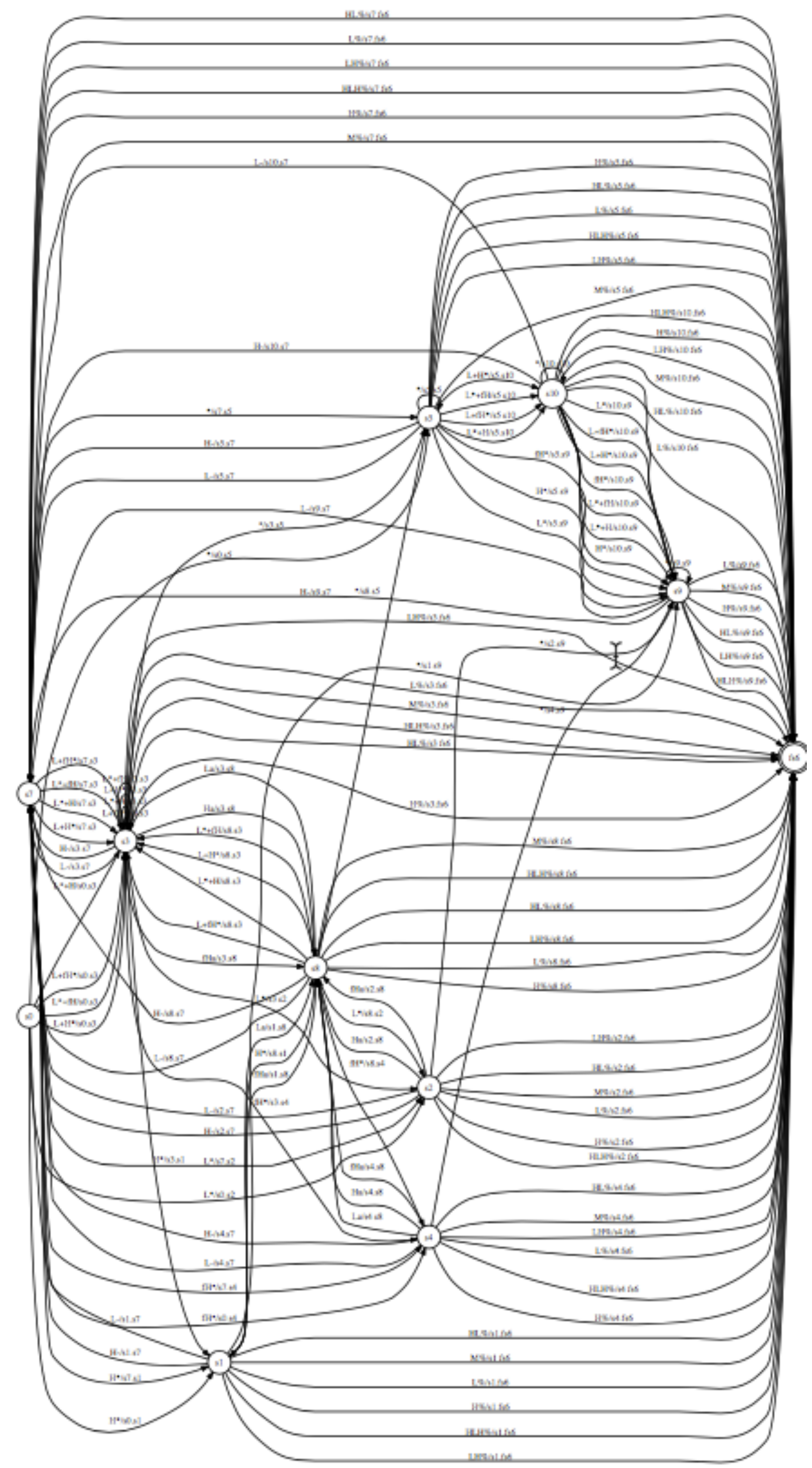
DEFINING BENGALI GRAMMAR IN xfst (excerpts)

```
###############################################
# Define repeating patterns within an ip/IP
###############################################

# An ip tone must be immediately preceded by a pitch accent or a lower boundary
tone (AP tone)

define ipSequence [  [ [ APSequence ]+ (PASeq) ipTone ] | ipEdge];

# An IP tone must be immediately preceded by a pitch accent or a lower boundary
tone (AP or ip tone)

define IPSequence [ [  [ [ ipSequence | APSequence ]+ (PASeq) IPTone ] |
IPEdge ] ];
```

IMPLEMENTED FINITE STATE GRAMMARS

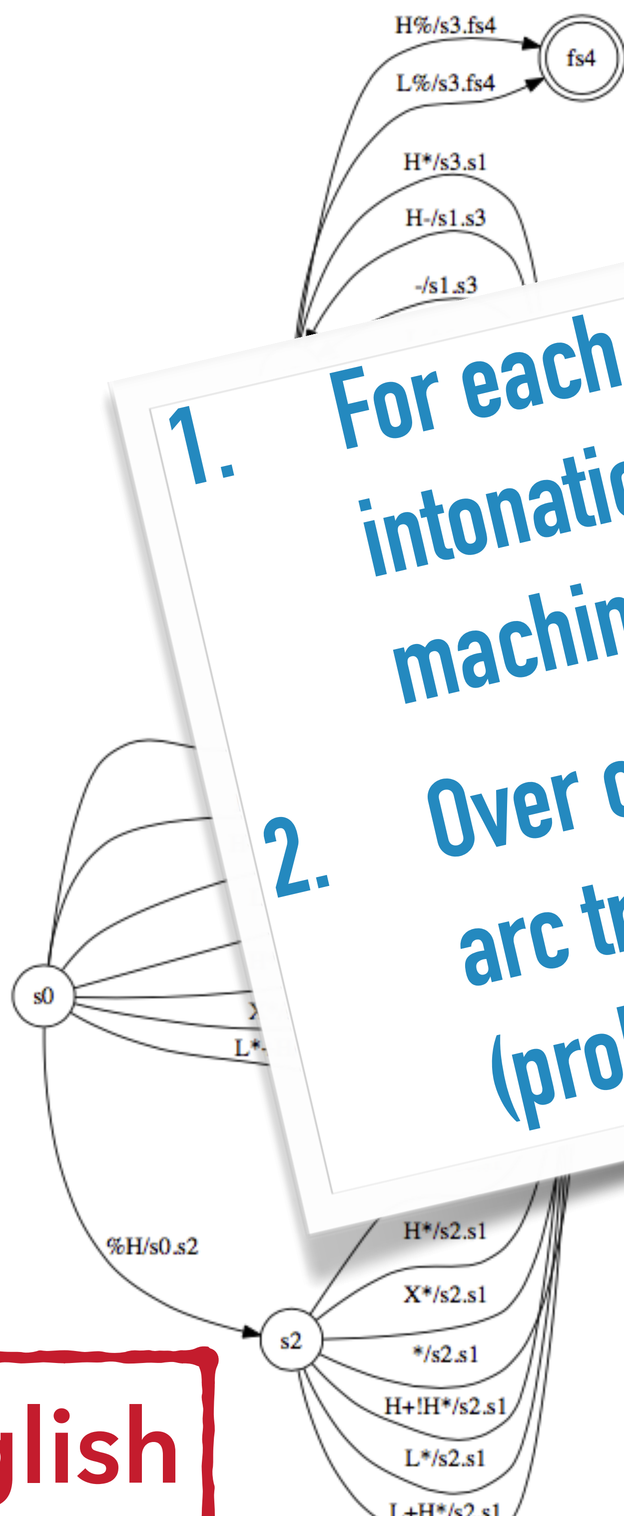


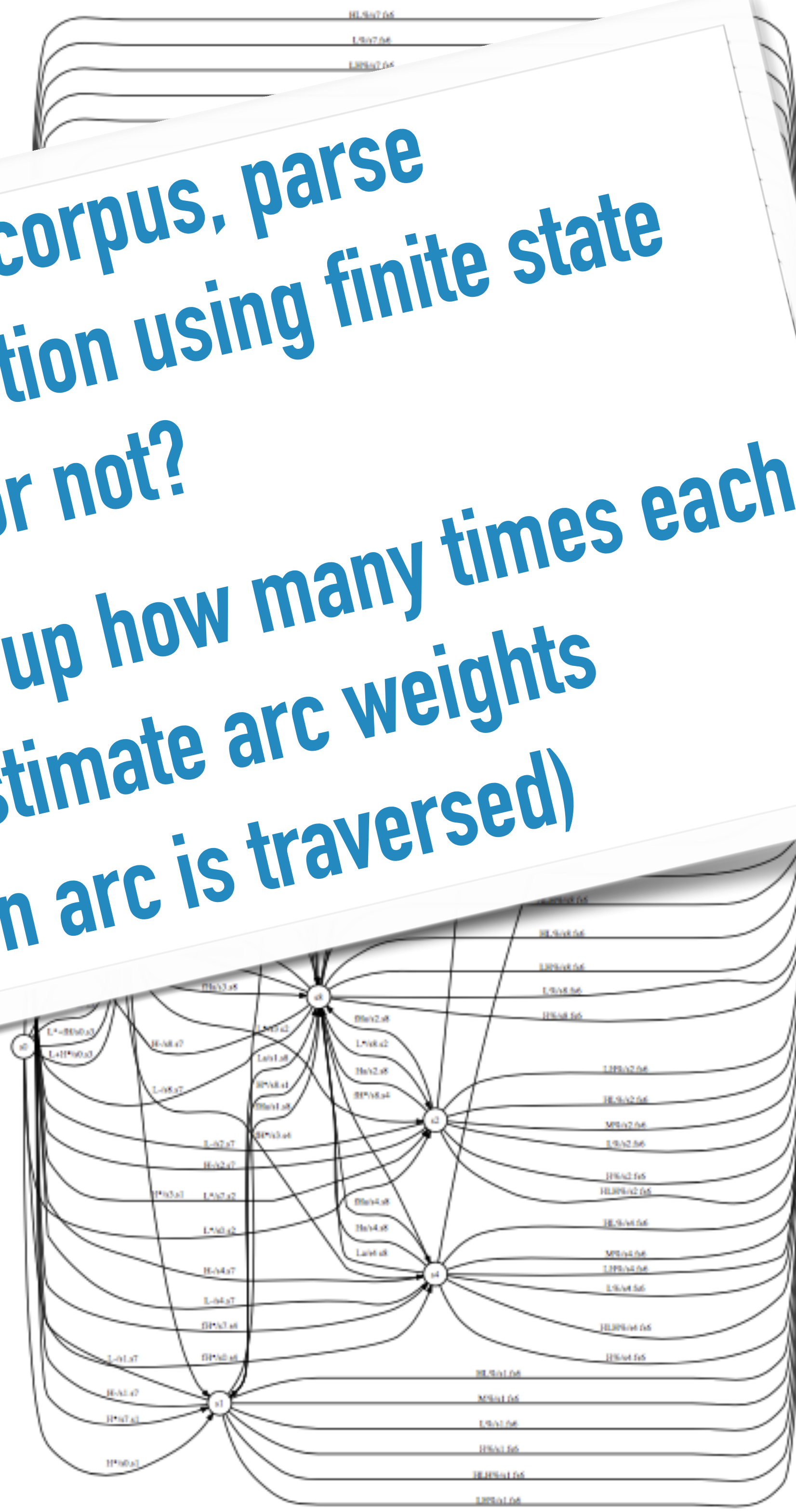
English



Bengali

IMPLEMENTED FINITE STATE GRAMMARS





1. For each utterance in corpus, parse intonational transcription using finite state machine: accepted or not?
2. Over corpus, count up how many times each arc traversed to estimate arc weights (probability that an arc is traversed)

English

Bengali

PARSING WITH BENGALI FINITE STATE MACHINE

- Failed to accept 1.5% of exemplars
  - (21/1367 total; 9/549 in non-IDS, 12/818 in IDS)

- Characteristics of the rejected exemplars were the same across speech styles
  - New `stacked' boundary tone fHaL%
  - Unexpected sequences of pitch accents
  - Distribution of weak accents (*), e.g.,

- **Characteristics of unaccepted tonal sequences provide direction for revisions to grammar (evolving hypotheses)**

STRATEGY: PARSE WITH FINITE STATE GRAMMAR

What are the linguistic functions of gradient modulations in the fundamental frequency contour?

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Challenges:

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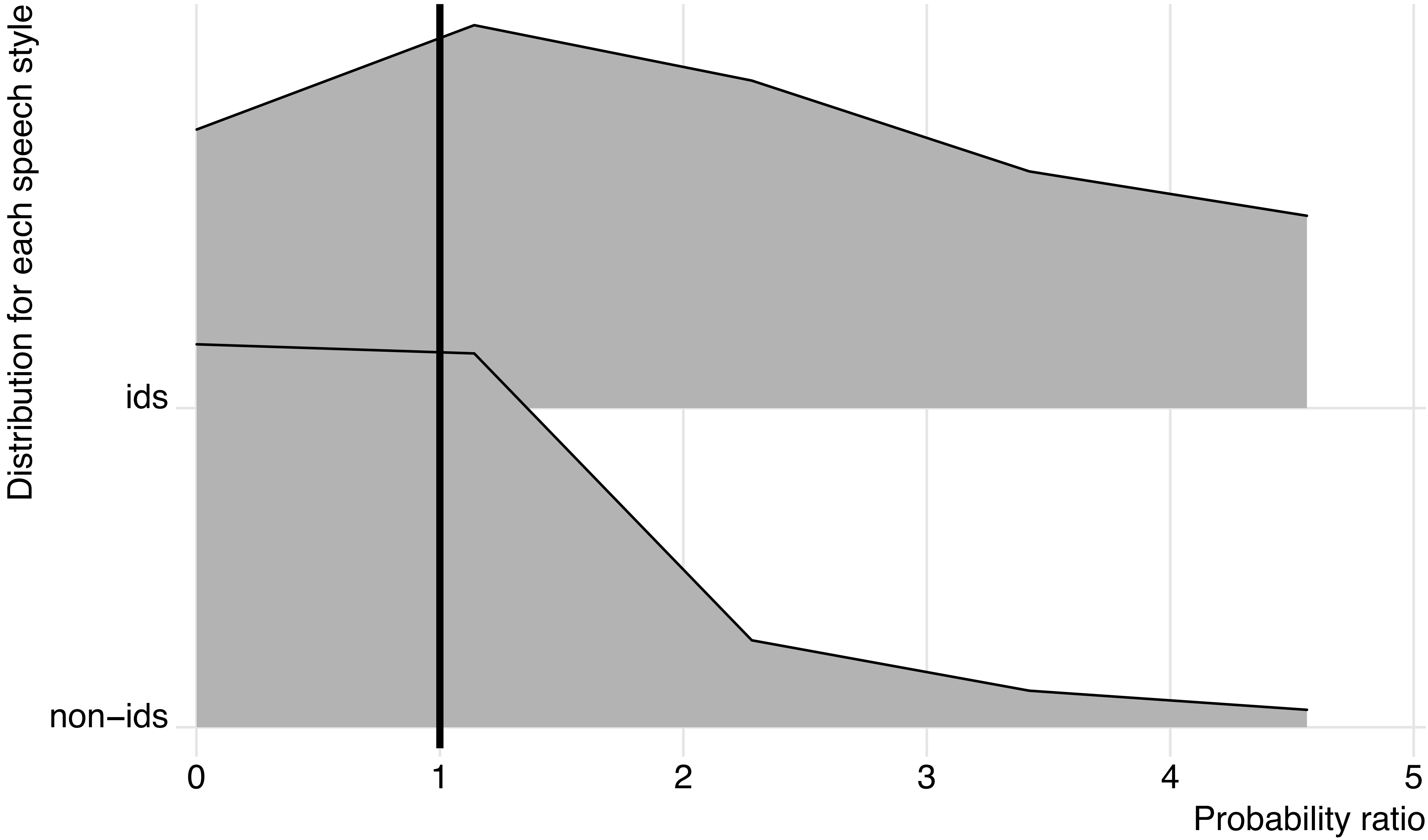
- Estimate arc weights on finite state machine using: (1) non-IDS corpus, (2) IDS corpus.
- See how probable IDS transcriptions are using non-IDS arc weights and vice versa

HOW PROBABLE ARE IDS SEQUENCES?



IDS tonal sequences markedly more probable under IDS-tuned FSG than non-IDS-tuned FSG

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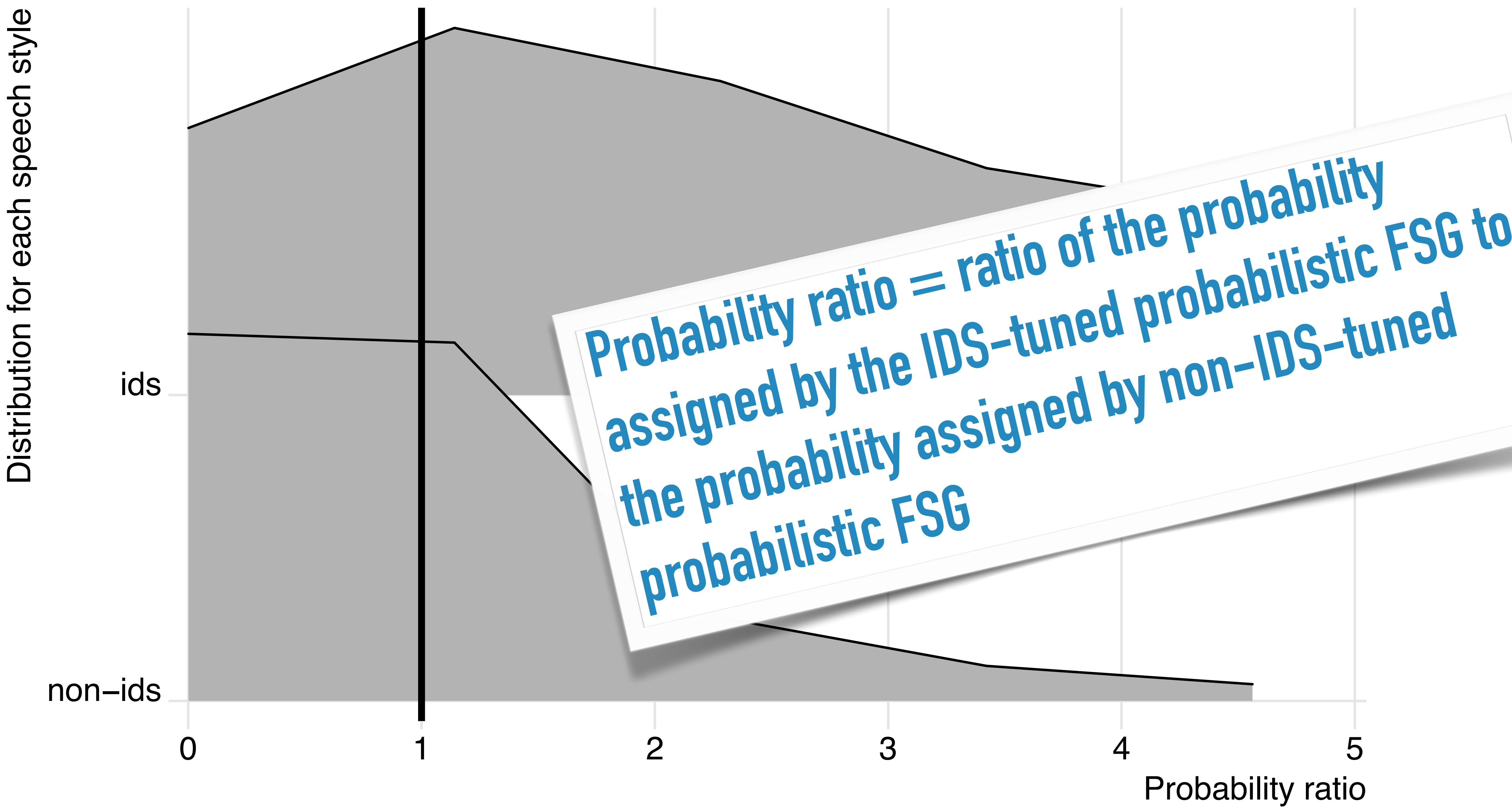

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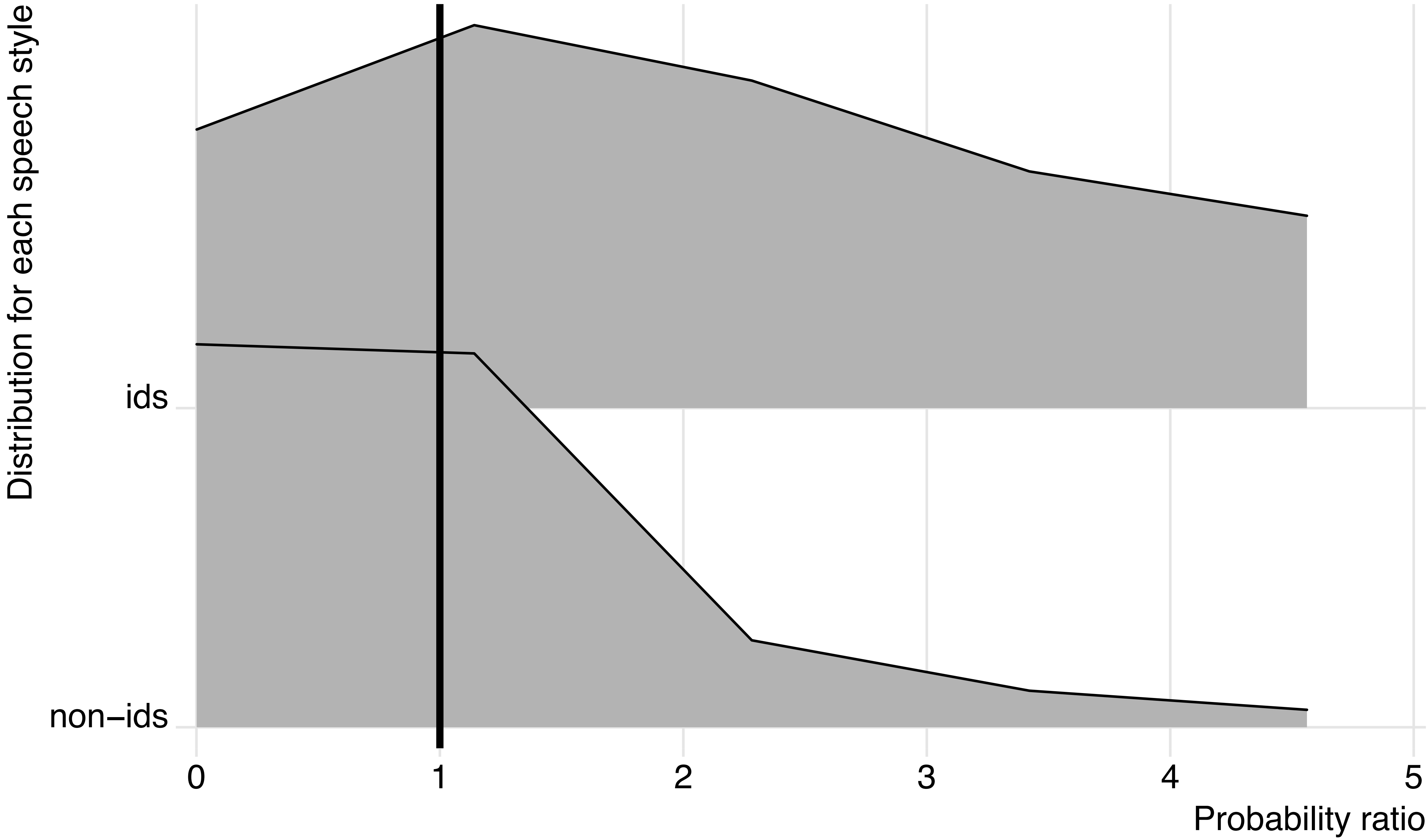

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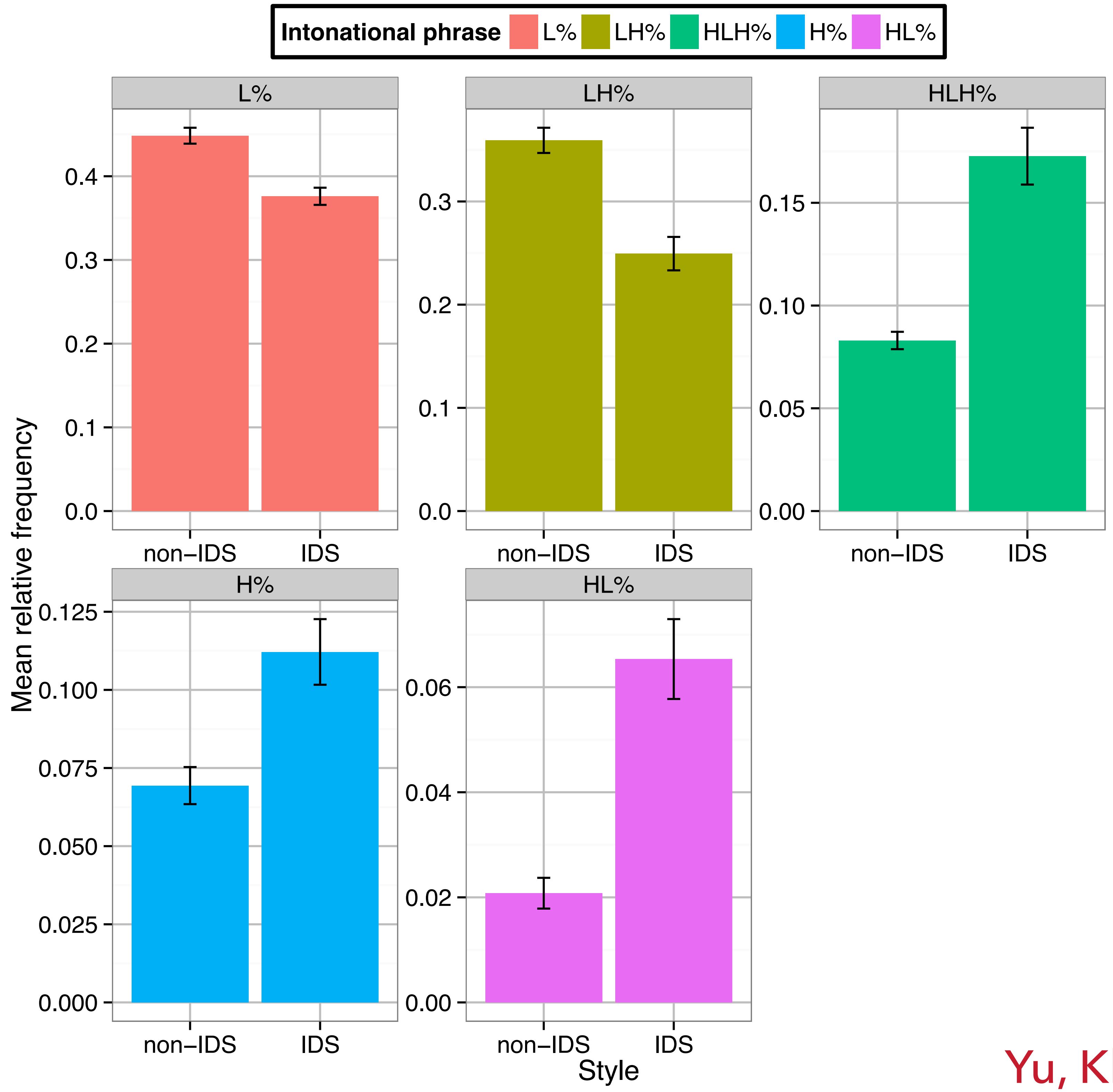
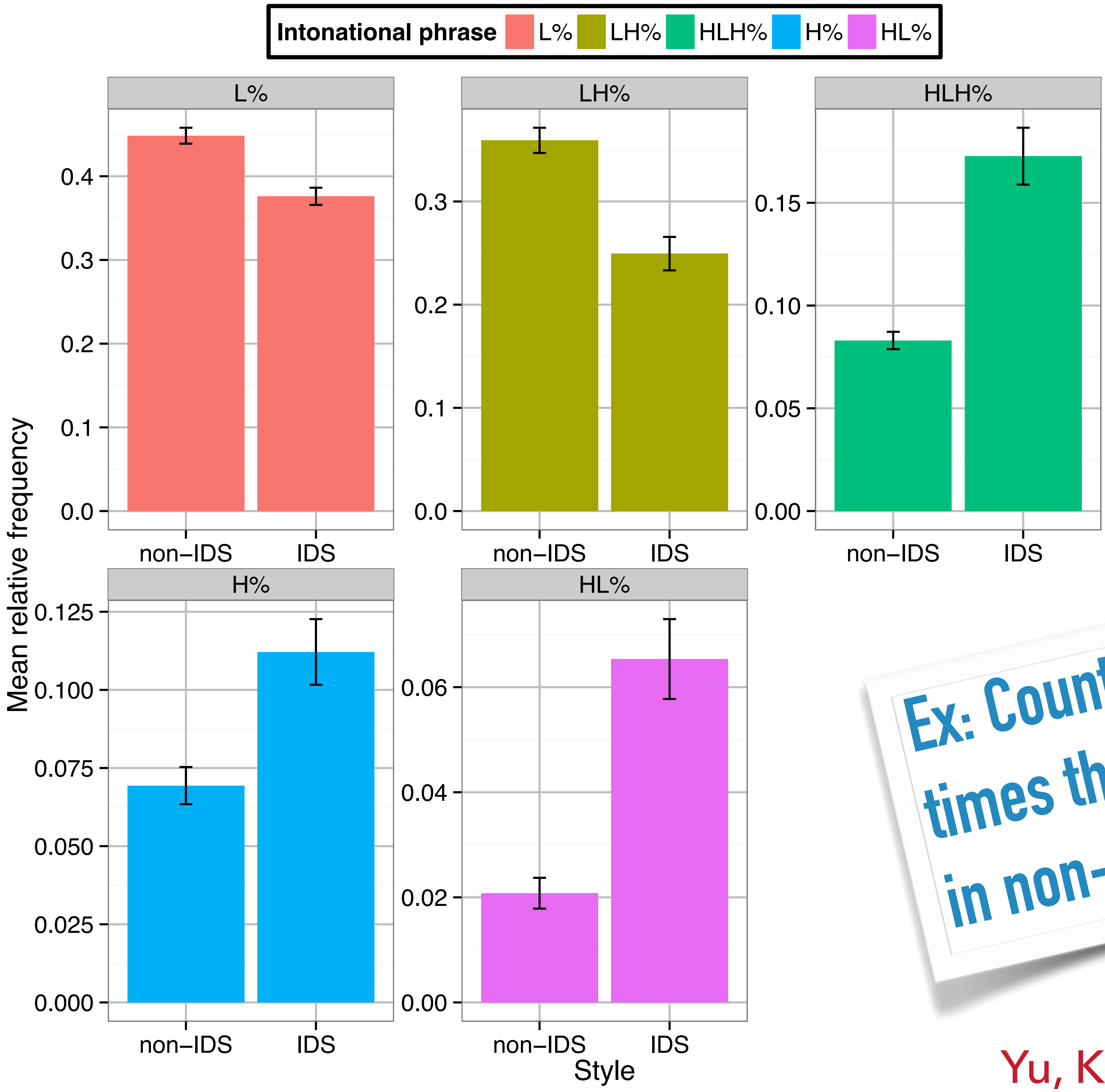
CHALLENGE 4: CONTEXTUAL DEPENDENCE OF TONES

BAG OF TONES MODEL



Yu, Khan & Sundara (2014)

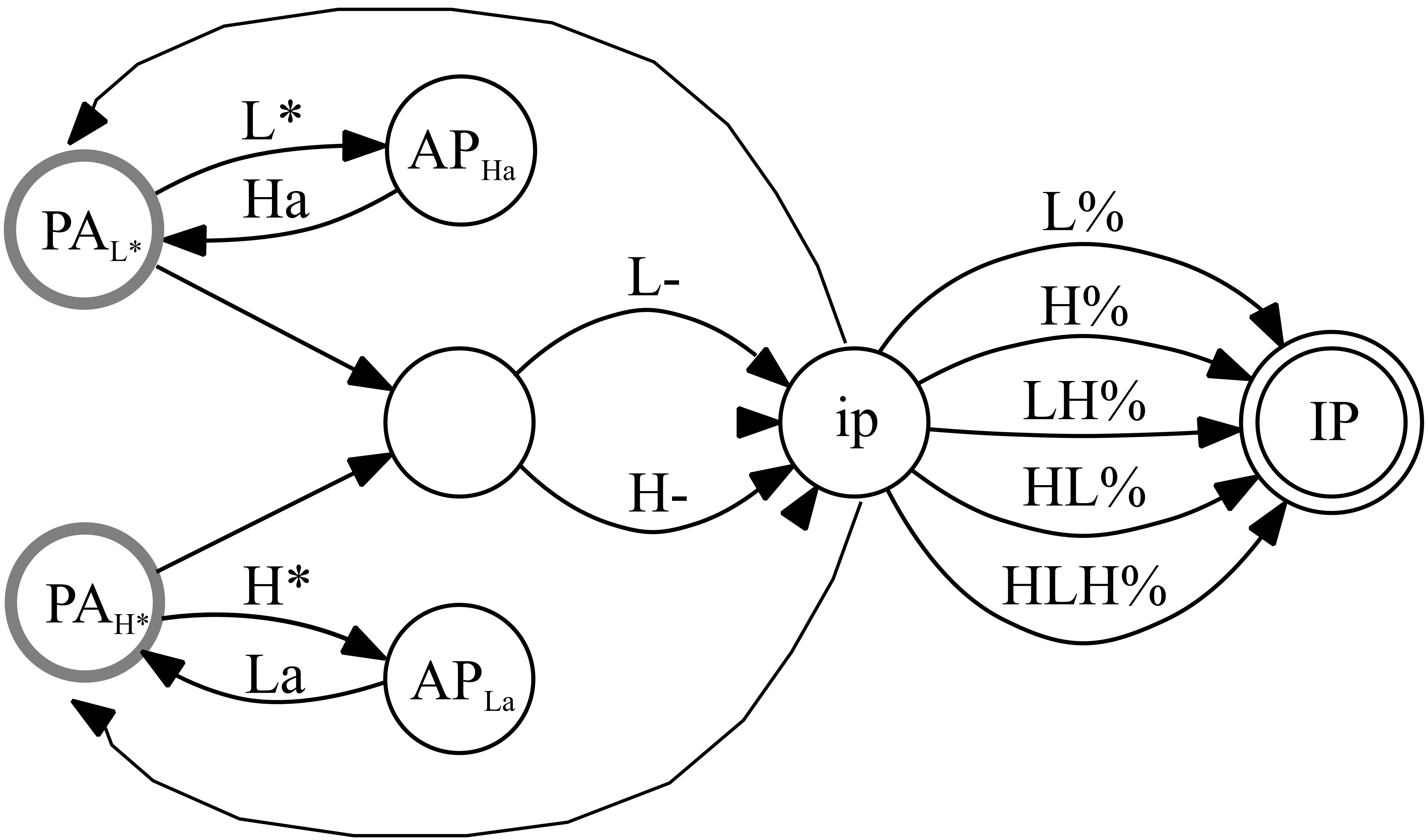
BAG OF TONES MODEL



Ex: Count up how many times there was an HLH% in non-IDS vs. IDS

Yu, Khan & Sundara (2014)

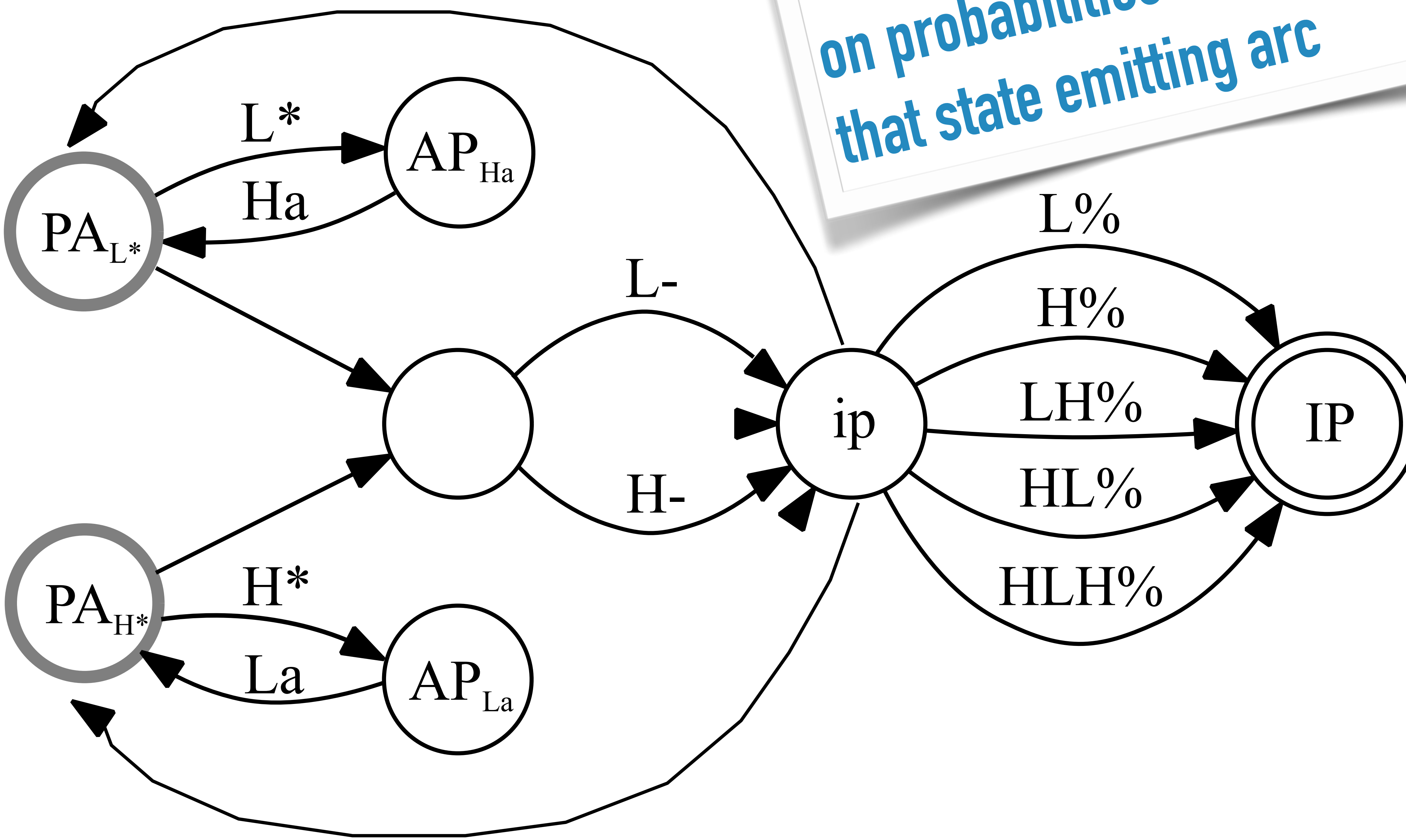
FIRST-ORDER MODEL



Khan (2008, 2014), Yu, Khan & Sundara (under revision)

FIRST-ORDER MODEL

Computed probabilities of traversing an arc conditioned on probabilities of reaching that state emitting arc



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STRATEGY: INTONATIONAL PHONOLOGY

What are the linguistic functions of gradient modulations in the fundamental frequency contour?

STRATEGY: INTONATIONAL PHONOLOGY

What are the linguistic functions of gradient modulations in the fundamental frequency contour?

Challenges:

- the **contextual dependence** of individual tonal elements on one another

Strategy:

- **Compute probability of an individual tonal element conditioned on probability of paths that arrive at that state**

STRATEGY: IMPLEMENT FINITE STATE GRAMMARS

What are the linguistic functions of gradient modulations in the fundamental frequency contour?

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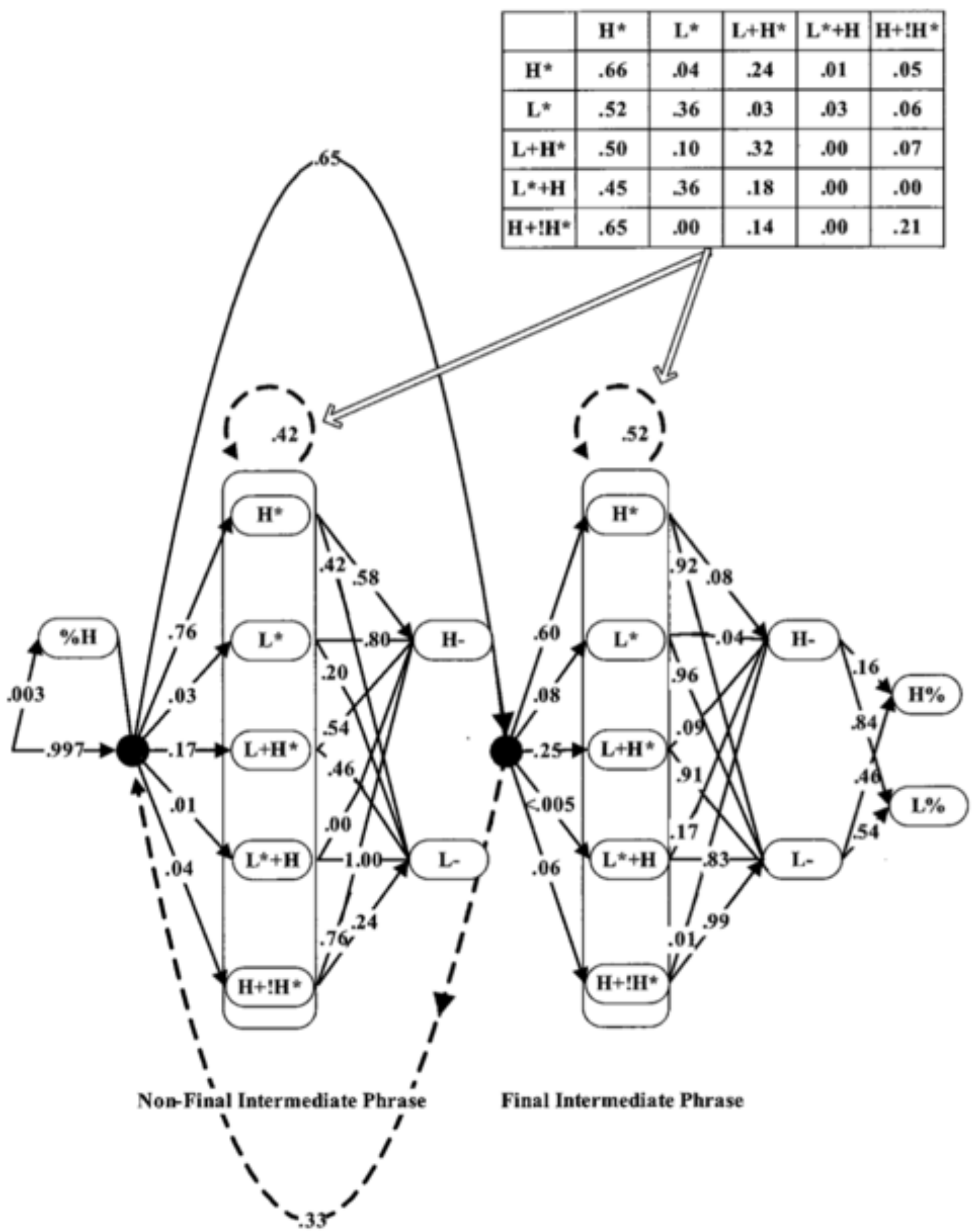
What are the linguistic functions of gradient modulations in the fundamental frequency contour?

- the entanglement of **extra-linguisti**… **factors** in conditioning f0…
- **evolvin**… …onal gr…
- the… …y of proposed grammars to a wider rang… of speech styles and contexts
- the **contextual dependence** of individual tonal elements on one another

Proposed overall strategy:
To implement finite state intonational grammars

(2ND ORDER MODEL, IF MORE DATA)



	H*	L*	L+H*	L*+H	H+!H*
H*	.66	.04	.24	.01	.05
L*	.52	.36	.03	.03	.06
L+H*	.50	.10	.32	.00	.07
L*+H	.45	.36	.18	.00	.00
H+!H*	.65	.00	.14	.00	.21

Figure 2. A probabilistic model of intonation in American English

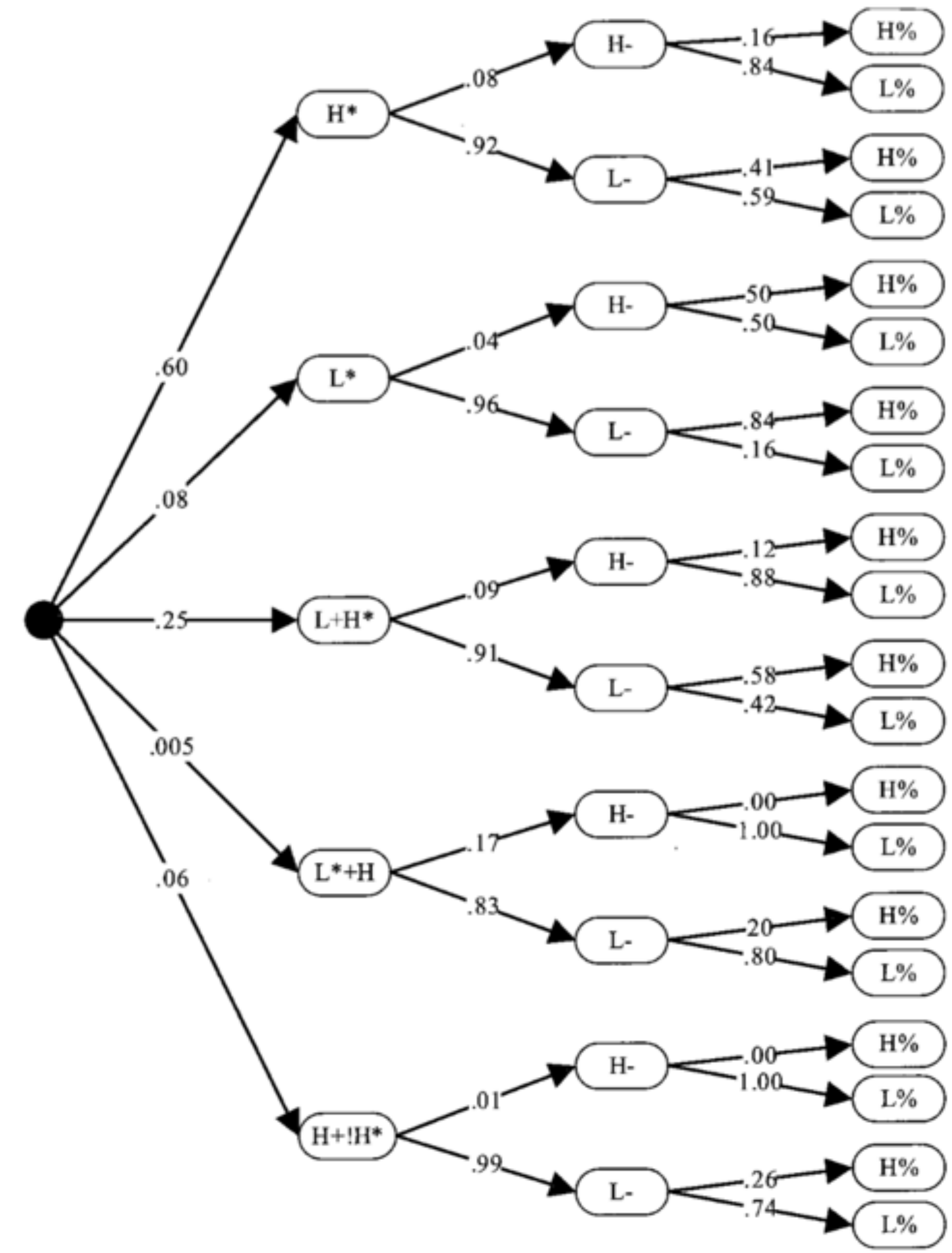


Figure 3. Second-order Markov model showing interactions between pitch accents and boundary tones

(Dainora 2006)

FSG FOR ENGLISH INTONATION

(22)
$$\left\{\begin{array}{l}\%\mathrm{H}\\ \%\mathrm{L}\end{array}\right\} \left\{\begin{array}{l}(L^*)\mathrm{H}^*(\mathrm{L}(\mathrm{H}))\\ \mathrm{L}^*(\mathrm{H})\end{array}\right\} (H) \left\{\begin{array}{l}(L^*)\mathrm{H}^*(\mathrm{L})\\ \mathrm{L}^*(\mathrm{H})\\ (L^*)\mathrm{H}^*{+}\mathrm{H}\end{array}\right\} \left\{\begin{array}{c}\mathrm{H}\%\\ \mathrm{L}\%\\ \emptyset\end{array}\right\}$$

(23) I. a. The last trailing tone of a prenuclear pitch accent aligns rightmost.
b. Other trailing tones align leftmost.
II. a. Within a pitch accent, interpolations are linear.
b. Otherwise, unspecified speech is governed by the leftmost tone.
III. a. Within a pitch accent, downstep of H after H is obligatory.
b. Otherwise, downstep of H* is optionally triggered by a preceding H.

Gussenhoven (2004, 2016)

COMPARING FSGS FOR FRENCH AND ENGLISH

(35) French tonal grammar: $\begin{Bmatrix} H_\iota \\ L_\iota \end{Bmatrix} (H^*(L))_0 \quad (H+)H^* \begin{Bmatrix} H_\iota \\ L_\iota \\ \varnothing \end{Bmatrix}$

15.5.5 An extended tonal grammar

If the pre-nuclear fall–rise, downstep, L-prefixations, and leading-H are added to the mini-grammar of section 15.2.3, we arrive at (43). Clearly, although we still do not have a sizeable collection of exhaustive descriptions of intonation systems to measure this by, the intonation of English must be fairly complex. A coarse impression of the difference between English and French can be obtained by just comparing (43) as a typographical object with (35) in chapter 13. And we are not done yet, as English also has a vocative chant, to be discussed in the next section.

(43)

$$([\text{DOWNSTEP}]) \begin{Bmatrix} H_\iota \\ L_\iota \end{Bmatrix} (L) \begin{Bmatrix} H^*(L(H)) \\ L^*(H) \end{Bmatrix}_0^n (H+)(L) \begin{Bmatrix} H^*(L) \\ L^*(H) \end{Bmatrix} \begin{Bmatrix} H_\iota \\ L_\iota \\ \varnothing \end{Bmatrix}$$

NOSLUMP