Gradient similarity in Lezgian laryngeal harmony: representation & computation

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Take-home message

Given a well-defined **representational structure** and gradient **similarity metric**, gradient representation is **not** orthogonal to universal feature system and discrete symbolic computation.

The slides and code can be found on `http://hutengdai.com`

Similarity we live by

- Similarity defines the natural classes that interact in **phonology**.
- “perceptual distinctness”, “perceptibility”, “contrast” ……

#	Related research programs	Selected works
1.	Output-driven Phonology	Tesar (2014)
2.	Base-Reduplicant Correspondence	McCarthy & Prince (1995)
3.	Paradigm Uniformity	Benua (1997)
4.	**Agreement by Correspondence**	Rose & Walker (2004)
5.	Dispersion Theory	Flemming (2013)
6.	P-map	Steriade (2001)
7.	Similarity avoidance principle	Frisch et al. (2004)
8.	Contrastive Hierarchy	Dresher (2009)
9.	Learning bias	Wilson (2006)
10.	Exemplar phonology	Bybee (2003)

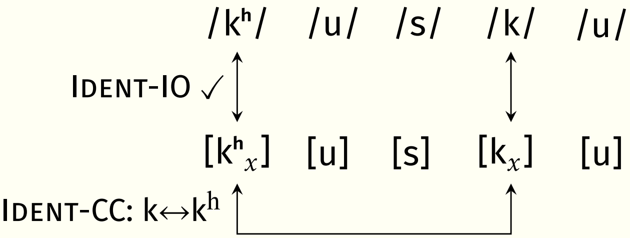
Lesson from ABC

	/kʰ/	/u/	/s/	/k/	/u/
IDENT-IO ✓	↕			↕	
	[kʰ]	[u]	[s]	[k]	[u]

Bolivian Aymara (Rose & Walker, 2004)

IDENT-IO[SG]

Lesson from ABC



Bolivian Aymara (Rose & Walker, 2004)

CORR(Tʰ↔T) > IDENT-IO[SG]

Lesson from ABC

/k^h/ /u/ /s/ /k/ /u/

IDENT-IO: k↔k^h

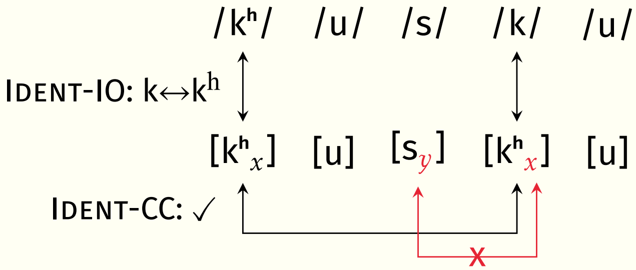
[$k^h{}_x$] [u] [s] [$k^h{}_x$] [u]

IDENT-CC: ✓

Bolivian Aymara (Rose & Walker, 2004)

IDENT-CC[SG], CORR(T^h↔T) > IDENT-IO[SG]

Lesson from ABC



Bolivian Aymara (Rose & Walker, 2004)

IDENT-CC[SG], CORR(Tʰ↔T) > IDENT-IO[SG]

Similarity and ABC

Similarity is encoded in the **correspondence (Corr) hierarchy**:

$$\textsc{Corr}[T\leftrightarrow T] \gg \textsc{Corr}[T\leftrightarrow D] \gg \textsc{Corr}[K\leftrightarrow T] \gg \textsc{Corr}[K\leftrightarrow D] \gg \ldots$$

T'=Ejective, T=Voiceless, T^h=Aspirated, D=Voiced, D'=Implosive, T vs. K: the difference on Place.

(Rose & Walker, 2004)

The probabilistic nature of similarity

- CORR hierarchy is grounded on **categorical** featural similarity metrics:

$$\textit{similarity}(x, y) = \frac{\text{the number of shared features between } x \text{ and } y}{\text{the total number of shared and nonshared features}}$$

as in natural classes-based metrics (Frisch et al., 2004)

- A Bayesian perspective:
  - Similarity is the **belief** that two segments x and y are **(non-)identical**;
  - This belief is updated by the observed shared features.

(Tenenbaum & Griffiths, 2001; Jaynes, 2003)

Structural assumption in feature system

- The distance from [+] to [-] is 1 step for any feature.
  - Any pairs of phonemes with the same amount of shared features have exactly the same similarity;
  - If T↔T' is sufficiently similar to be in agreement, then T↔T^h, T↔D, and T↔K must be in agreement as well.

Lezgian laryngeal harmony

- *T'↔T is a categorical constraint in Lezgian ($N = 0$), and always triggers laryngeal harmony, while Tʰ↔T and T↔D are sufficiently **dissimilar** to escape the impetus to agree.
  - *Underrepresented co-occurrences* ($O/E < 1$)

    T↔T', T'↔T, T'↔D, T'↔Tʰ, D↔T', D↔Tʰ, Tʰ↔D, Tʰ↔T', ...
  - *Overrepresented co-occurrences* ($O/E \geq 1$)

T'↔T'	[q'at͡s'un]	'get dirty'	T↔T	[qaqa]	'ready'
Tʰ↔Tʰ	[tʃʰipʰ]	'fool'	D↔D	[midad]	'grieve'

(Ozburn & Kochetov, 2018)

Lezgian laryngeal harmony

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    T↔T', T'↔T, T'↔D, T'↔$\mathrm{T^h}$, D↔T', D↔$\mathrm{T^h}$, $\mathrm{T^h}$↔D, $\mathrm{T^h}$↔T', ...
  - *Overrepresented co-occurrences* ($O/E \geq 1$)

T'↔T'	[q'at͡s'un]	'get dirty'	T↔T	[qaqa]	'ready'
$\mathrm{T^h}$↔$\mathrm{T^h}$	[tʃ^{h}ip^h]	'fool'	D↔D	[midad]	'grieve'
$\mathrm{T^h}$↔T	[k^{h}ut͡sun]	'to flush'	T↔D	[et͡sigun]	'put'

(Ozburn & Kochetov, 2018)

Challenge to categorical similarity metrics

The calculated similarity neither aligns with the **co-occurrence** constraints, nor fits the distribution of **speech errors**.

(Rose & King, 2007)

Inventory	minimally dissimilar pairs	Languages
T’, T, T^h, D	***T↔T’**, ✓T↔D, ✓T^h↔T ...	Lezgian, Ndebele
T’, T, D	***T↔T’**, ✓T↔D	Amharic, Chaha, Chontal
T’, T, T^h	***T↔T’**, *T↔T^h	Peruvian & Bolivian Aymara
T’, T, D’	***T↔T’**, ✓T’↔D’	Tzotzil, Tzutujil, Yucatec
T’, T, D, D’	***T↔T’**, ***D’↔D**, ✓T↔D ...	Hausa
T, D, D’	***D’↔D**, ✓T↔D	Bumo Izon, Kalabari Ijo

(Ozburn & Kochetov, 2018; Hansson, 2010, adapted)

Analysis: the special status of [cg]

- Cross-linguistically, different features play different roles in similarity.
- Only the difference on [cg] **always** triggers harmony
- Hypothesis: the distance from [+cg] to [-cg] is systematically shorter than in other Laryngeal features.

(Gallagher & Coon, 2009; Kochetov & Ozburn, 2014)

Acoustic cues

Cross-linguistically, the difference of VOT and preceding vowel duration on [CG] is less distinctive than [VOICE] and [SG].

(Beguš, 2017; Gallagher, 2010a)

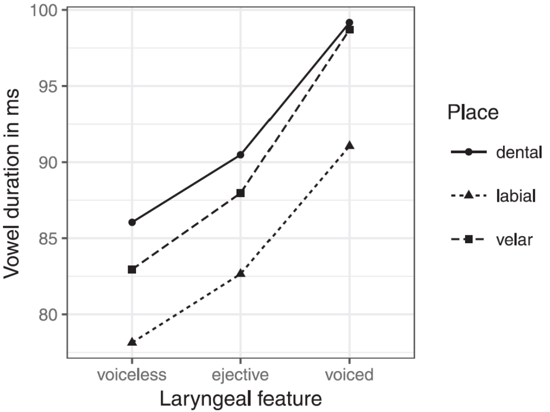


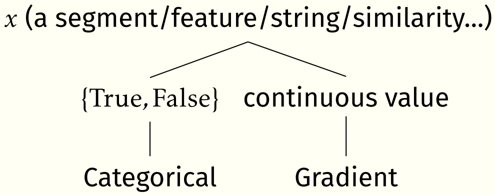
FIG. 2. Estimates of the effects of Laryngeal Features and Place of articulation on preceding vowel duration in ms (from a linear mixed effects model).

Georgian (Beguš, 2017)

Representation

What's representation?

- Representation is the **abstraction** of phonetic and/or phonological knowledge;



Gradient representation: Pros and Cons

- Pros: weighted/gradient (sub-)featural representation can easily handle language-specific granularity;

  (Ladefoged, 1969, 1972, 1973; Keating, 1985; Smolensky & Goldrick, 2016)

- Cons:
  - High degree of freedom (cf. tone numbers);
  - The empirical/laboratory evidence is not always available;
  - Trade-off between granularity and **generality**;

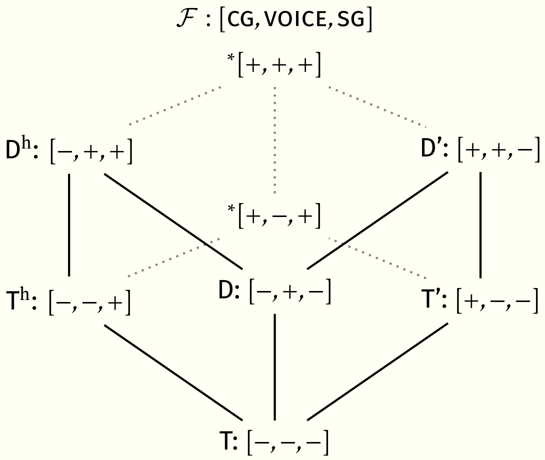
    e. g. universal feature system; typology; similarity metrics; modular representation, etc.

    see criticism in Mackenzie (2009)

Proposal: weighted featural lattice

- Lattice: the universal feature system:
  - Partial order (relative distance);
  - Bounds;

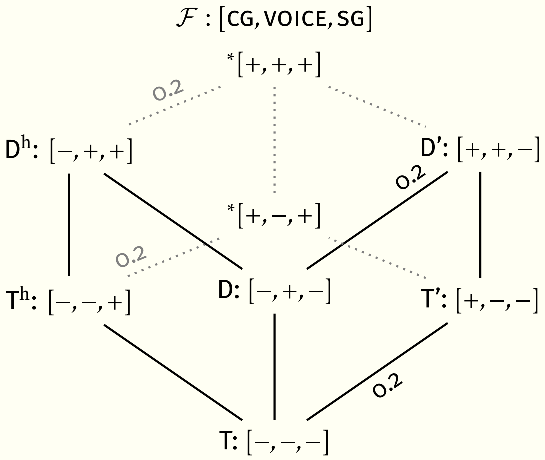
(Tesar, 2014; Magri, 2018)



Proposal: weighted featural lattice

- Weight: the phonetic distance between [+] and [-]
- $w_{[\text{CG}]} < w_{[\text{VOICE}]}, w_{[\text{SG}]}$
- Restriction: $0 < w_f < 1$

  "How likely two **features** are non-identical, given the observed phonetic cues?"



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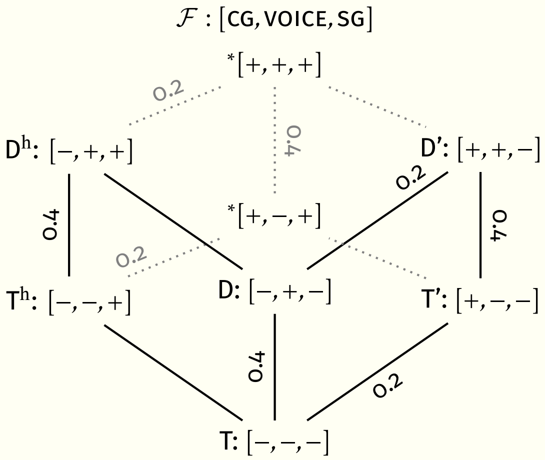

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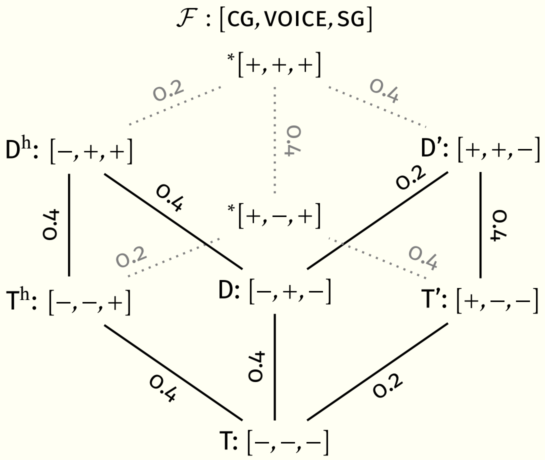
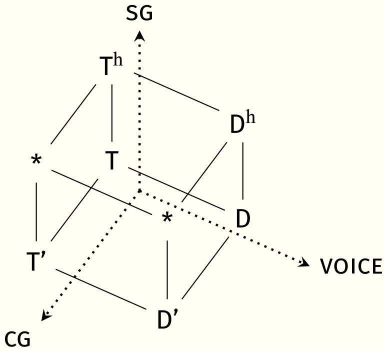
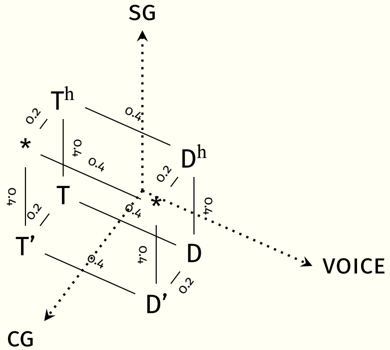


Representational space



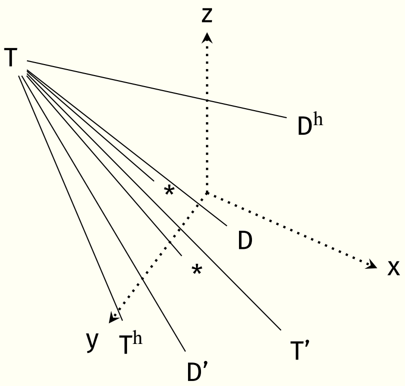
phonological structure $\Longleftrightarrow$ discrete lattice

Representational space



phonetic information $\Longleftrightarrow$ weighted lattice: scaled by [0.2, 0.4, 0.4]

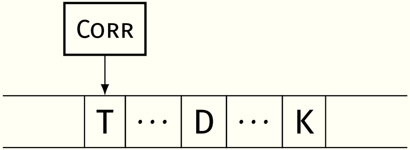
Unconstrained representational space



e. g. *Hilbert space* (Smolensky et al., 2014)

Alternative: segmental similarity scale

- One-dimensional totally-ordered (weighted) similarity scale;
- The relative similarity is encoded by **adjacency**.



(Rose & Walker, 2004, P.505)

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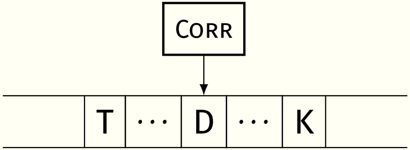

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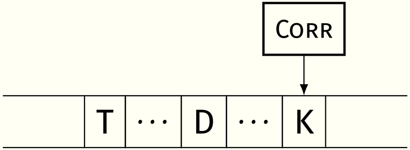

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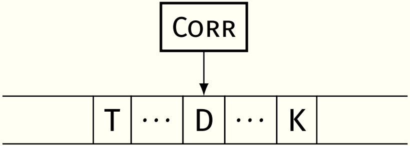
Alternative: segmental similarity scale

CORR[T↔D] ≫ CORR[K↔T] ≫ CORR[K↔D]

✓ *similarity*(T,D) > *similarity*(T,K)



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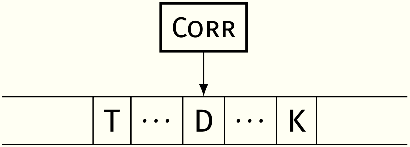
CORR[T↔D] ≫ CORR[K↔T] ≫ CORR[K↔D]

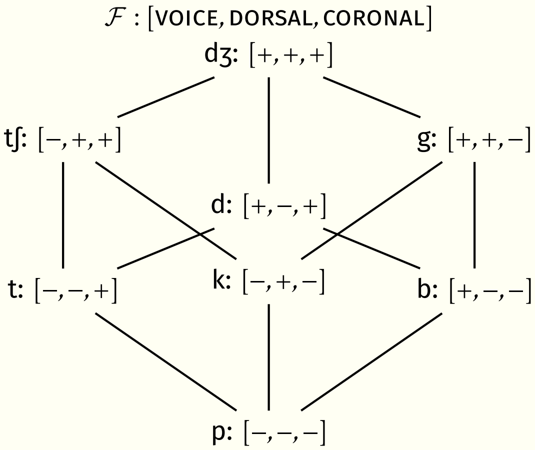
✓*similarity*(T,D) > *similarity*(T,K)

*similarity(K,D) > similarity(K,T)



Alternative: segmental similarity scale

A lattice represents a higher dimensional space which captures the insights lost in an one-dimensional similarity scale.



Computation

Phonetic distance

- The phonetic distance between two segments x and y is computed over a weighted featural lattice $\mathbf{w}$:

$$\textit{distance}_{\mathbf{w}}(x, y) = \sum_{f \in \mathcal{F}} w_f \cdot \delta_f(x, y), \qquad \text{(summed weights of nonshared features)}$$

$$\delta_f(x, y) = \begin{cases} 0, & \text{if } x \text{ and } y \text{ share the feature } f \\ 1, & \text{else} \end{cases}$$

(Wilson & Obdeyn, 2009)

Similarity as Bayesian probability

- Phonological similarity is the belief that x and y are (non-)identical, which is updated by the observed **phonetic distance** between two segments.

$$\begin{aligned} \textit{similarity}_{\mathbf{w}}(x,y) &= 1 - \textit{dissimilarity}_{\mathbf{w}}(x,y) \\ &= 1 - \frac{\textit{distance}_{\mathbf{w}}(x,y)}{\sum_{f \in \mathcal{F}} w_f} \end{aligned}$$

  - This function converts the *phonetic distance* to a probability in $[0,1]$.
  - $\sum_{f \in \mathcal{F}} w_f$ is the **maximal distance** between two segments.

Similarity of LARYNGEAL pairs

C1↓C2→	T’	T	D’	D	T^h	D^h
T’	1	0.8	0.6	0.4	0.4	0
T	0.8	1	0.4	0.6	0.6	0.2
D’	0.6	0.4	1	0.8	0	0.4
D	0.4	0.6	0.8	1	0.2	0.6
T^h	0.4	0.6	0	0.2	1	0.6
D^h	0	0.2	0.4	0.6	0.6	1

Tractable: the set of thresholds is always **finite** whatever the alphabet is.

Agreement by similarity

- IDENT-CC(LARYNGEAL, *SIMILARITY* $\geq k$):
  if *similarity* $\geq k$ in a 2-long **subsequence**,
  penalize any difference in LARYNGEAL.
- IDENT-IO[LARYNGEAL]:
  penalize any input-output difference in LARYNGEAL.
- The critical threshold is determined by the lowest similarity that triggers harmony.

ID-CC(LARYN., *S.* ≥ 1)

↓

ID-CC(LARYN., *S.* ≥ 0.8)

↓

ID-IO[LARYNGEAL]

↓

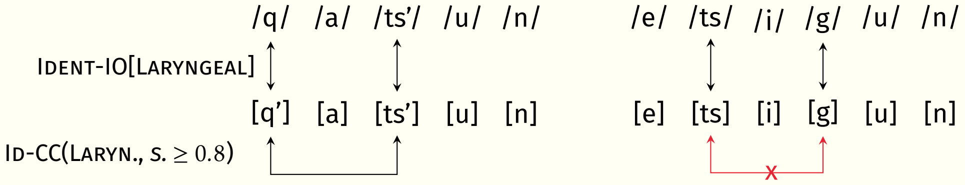
ID-CC(LARYN., *S.* ≥ 0.6)

↓

ID-CC(LARYN., *S.* ≥ 0.4)

Formal language-theoretic computation

- The 2-long **subsequences** in *[qats'un] include {q…a, **q…ts'**, q…u, q…n, a…ts', a…u, a…n, ts'…u, ts'…n, u…n} (Heinz, 2010)



(Q & A: "Agreement by similarity vs. by projection")

Constraint-based analysis

/qats'un/	ID-CC(LARYN., $s. \geq 0.8$)	ID-IO[LARYN.]	ID-CC(LARYN., $s. \geq 0.6$)
a. q…ts' [s. = 0.8]	*!		*
b. ☞ q'…ts' [s. = 1]		*	

/etsigun/	ID-CC(LARYN., $s. \geq 0.8$)	ID-IO[LARYN.]	ID-CC(LARYN., $s. \geq 0.6$)
a. dz…g [s. = 1]		*!	
b. ☞ ts…g [s. = 0.6]			*

Classical OT (Prince & Smolensky, 2004)

Typology

The typology of laryngeal harmony is predicted by varying critical thresholds.

Inventory	Thresholds	Pairs	Languages
T', T	0.8	*T↔T'	Gitksan, Chol
T', T, D'	0.8	*T↔T', ✓T'↔D', ✓T↔D'	Tzotzil, Tzutujil, Yucatec
T', T, D, D'	0.8	*T↔T', *D'↔D, ✓T↔D, ...	Hausa
T', T, T^h, D	0.8	*T↔T', ✓T↔D, ✓T^h↔T ...	Ndebele, Lezgian
T, D, D'	0.8	*D'↔D, ✓T↔D, ✓T↔D'	Bumo Izon, Kalabari Ijo
T', T, D	0.8	*T↔T', ✓T↔D, ✓T'↔D	Amharic
	0.4	*T↔T', *T↔D, *T'↔D	Chaha
T', T, T^h	0.4	*T↔T', *T↔T^h, *T'↔T^h	Peruvian & Bolivian Aymara

(Ozburn & Kochetov, 2018; Hansson, 2010, adapted)

Theoretical implications

Balance between structure and substance

- Substance-free approach: similarity relevant for motivating phonological processes is based on underlying abstract phonological representations;

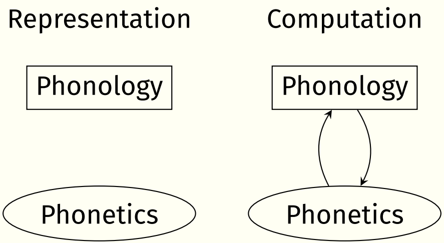
  e.g. Contrastive hierarchy (Mackenzie, 2009, 2011), GSR (Smolensky & Goldrick, 2016)

- Phonetically grounded approach: supplement the universal feature system with **language-specific** (sub)features, such as [long VOT], to account for perceptual similarity.

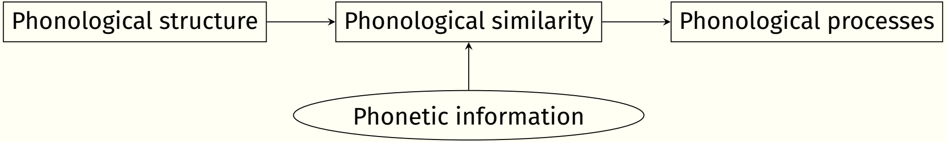
  (Gallagher, 2010a,b, 2012; Lionnet, 2017)

Modular representation

- Lattice:
  - the phonological, abstract, symbolic, universal structure of feature system;
- Weight:
  - the phonetic, fine-grained, gradient, language-specific **information**;
  - not in UR, and **only** available to SR in the **computation** of input-output and surface correspondence;



The interplay of phonology and phonetics



The similarity is computed *w.r.t.* both **phonological** structure and **phonetic** information, and this information is further used in phonological computation.

Future works

- The weighting relation is **testable** in laboratory settings;

  e.g. confusion matrix; neural featural encoding

- Learning from distribution; (Wilson & Obdeyn, 2009; Mayer, 2020)
- Phonological similarity in **Sign Language**. (Keane et al., 2017)

Take-home message

Given a well-defined **representational structure** and **similarity metric**, gradient representation is **not** orthogonal to universal feature system and discrete symbolic computation.

Find the slides and code on `http://hutengdai.com`, and feel free to contact me for questions and collaborations!

Acknowledgement

I thank Adam McCollum, Adam Jardine, Bruce Tesar, Brian Pinsky, Jason Shaw, Keith Johnson, Robin Karlin and audiences at LSA 2020, BLSW 2020, and Rutgers Phonology and Phonetics Research Group (PhonX), for their comments and insights. My special thanks are extended to Alan Yu for providing the valuable recordings of Lezgian.

RUTGERS

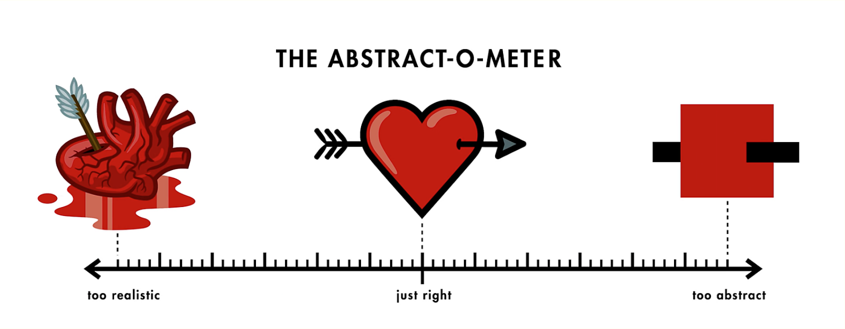
Q&A

Gradient representation as abstraction

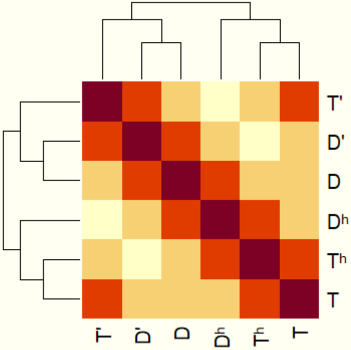
- The weights encode the phonetic information from closely-related dimensions:
  - Distributional (Hall, 2009; Mayer & Daland, 2019; Mayer, 2020)
  - Substantial (Vitevitch & Luce, 1999; Mielke, 2012; Redmon, in prep.)

Abstractness of gradient representation

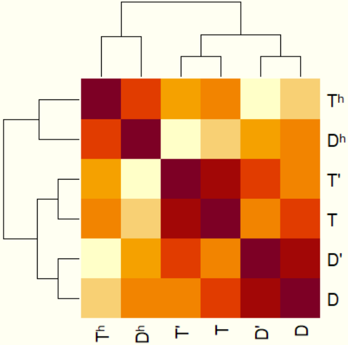
- Phonetic measurement ≠ weight on featural lattice:
  - Phonetic invariance doesn't exist; (Pierrehumbert, 2016; Zellou & Tamminga, 2014)
  - Real-numbered representation is still an **abstraction**!



Categorical vs. weighted similarity metrics

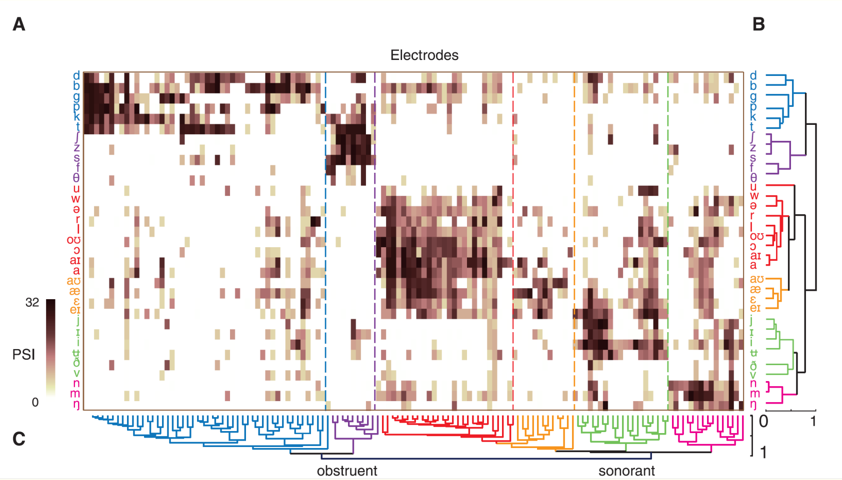


Categorical similarity metrics ☹



Gradient similarity metrics ☺

Neural featural encoding



Mesgarani et al. (2014)

GSR in UR: the road not taken

- Despite the ambition of correlating GSR and phonetics, Gradient Symbolic Representation is a **substance-free** approach *per se* – the weights are represented in **UR** and are not grounded by phonetics.
- Reasons:
  - **Tractable** computing power $\leftrightarrow$ **learnable** grammar;
  - **Restrictive** representational space;
  - **Testable** weighting relation;
  - Well-defined similarity metrics – necessary for any IDENT constraint.

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