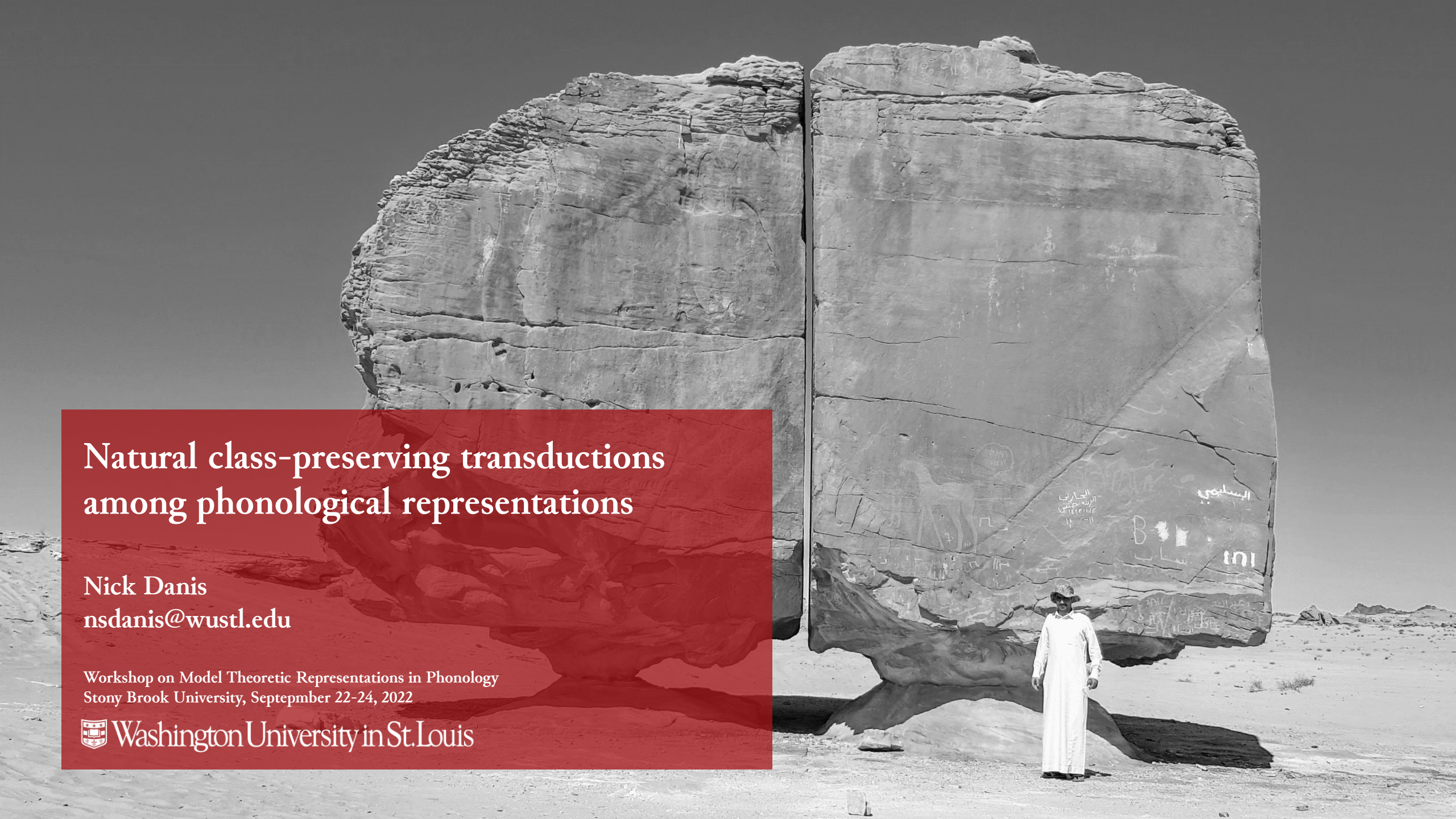

Natural class-preserving transductions among phonological representations

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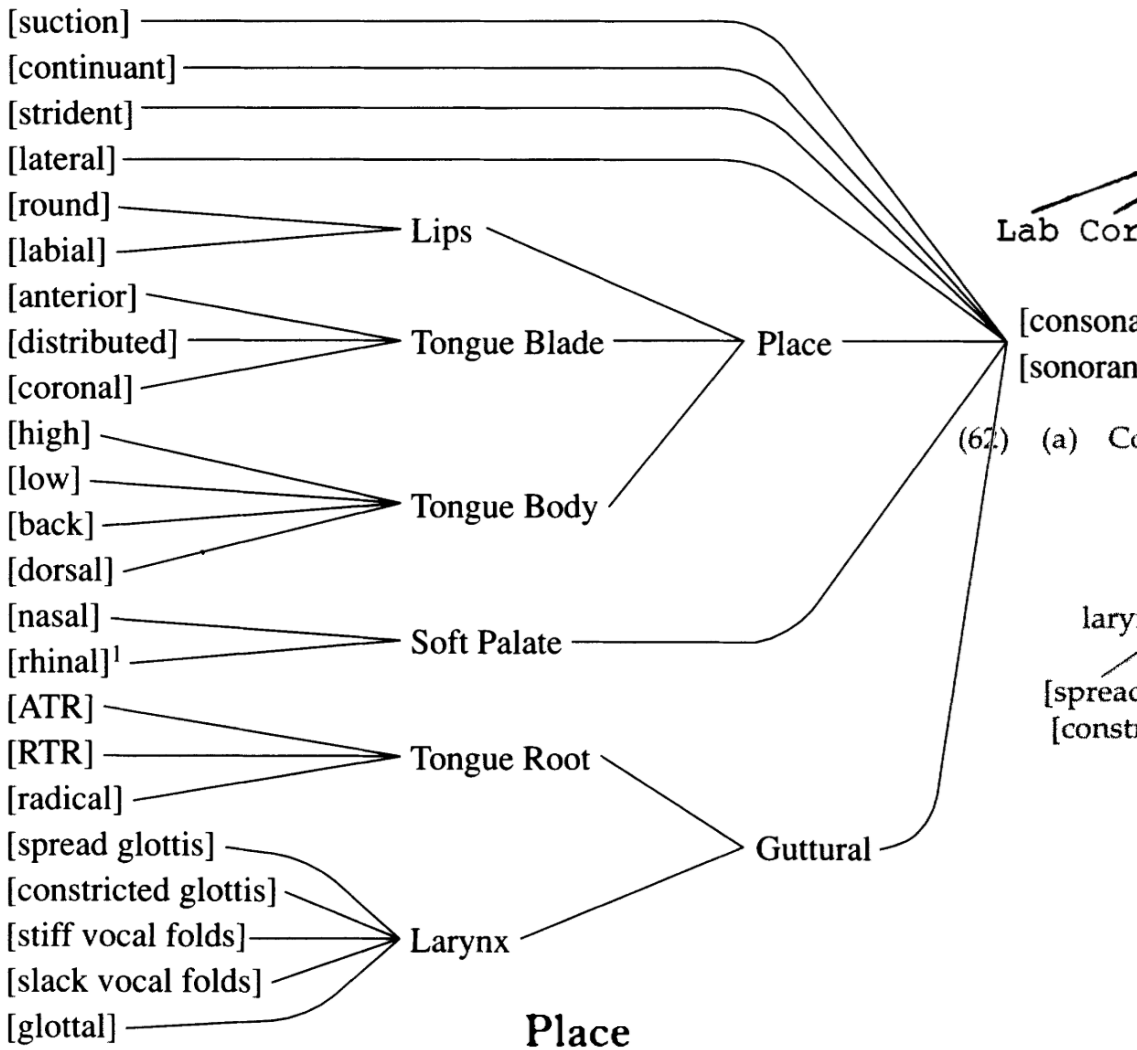
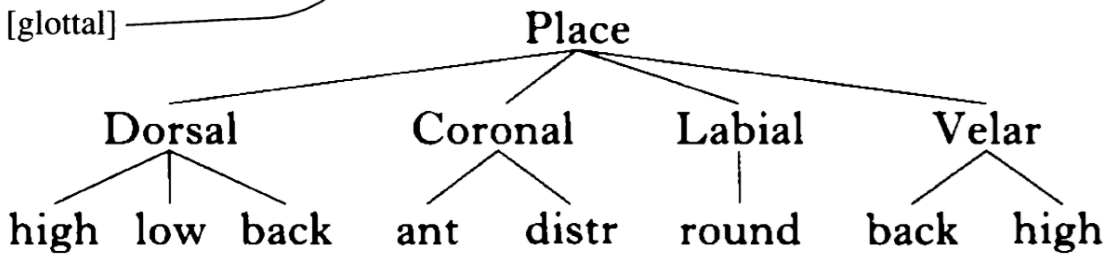
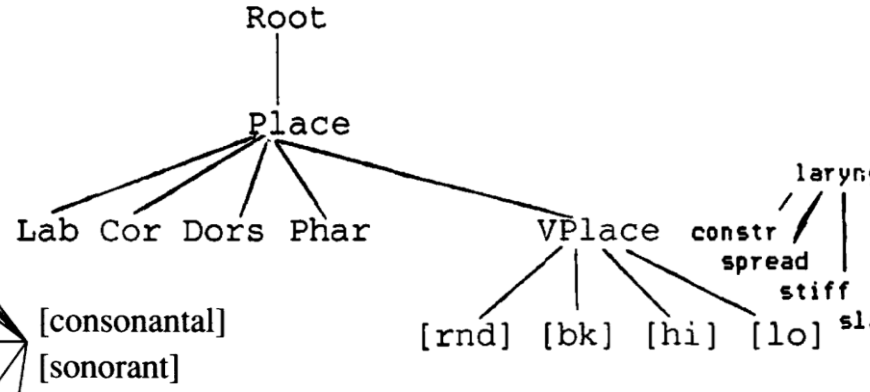
Workshop on Model Theoretic Representations in Phonology
Stony Brook University, Septepmber 22-24, 2022

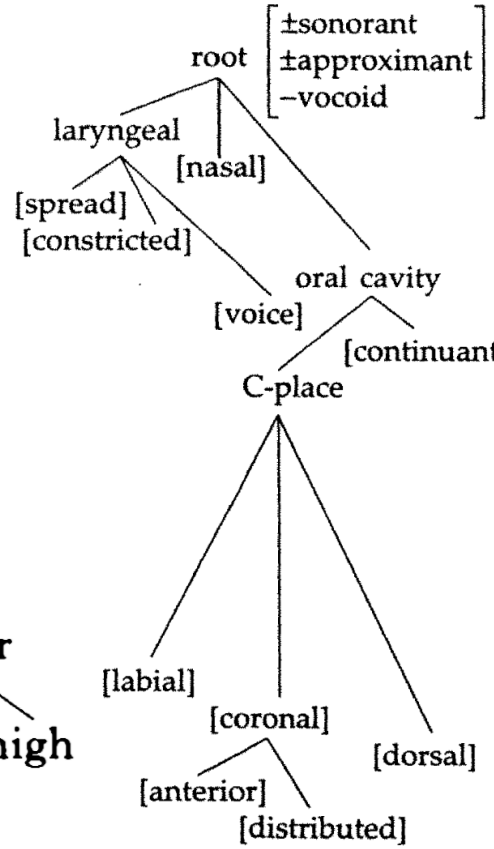
Washington University in St. Louis

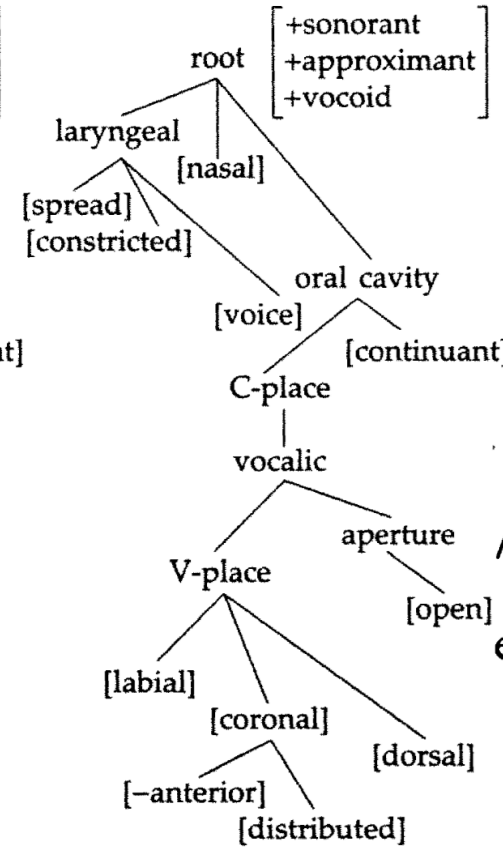


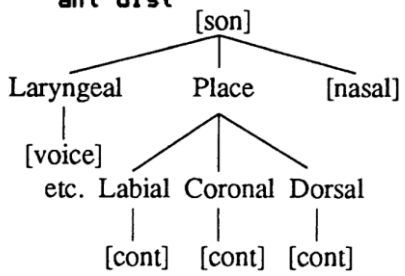


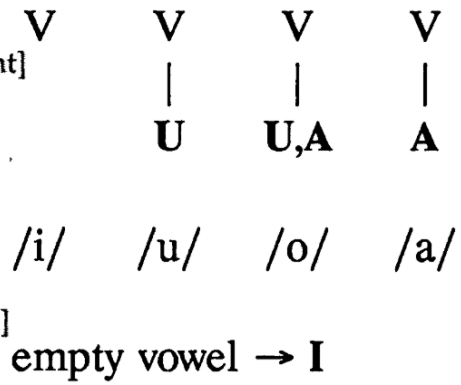


(62) (a) Consonants: (b) Vocoids:



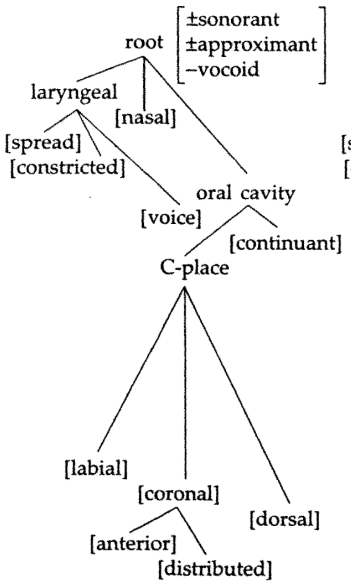




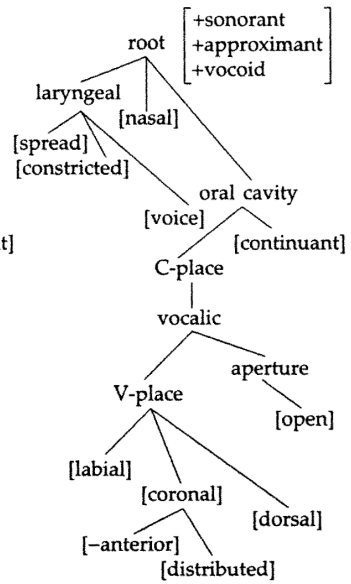


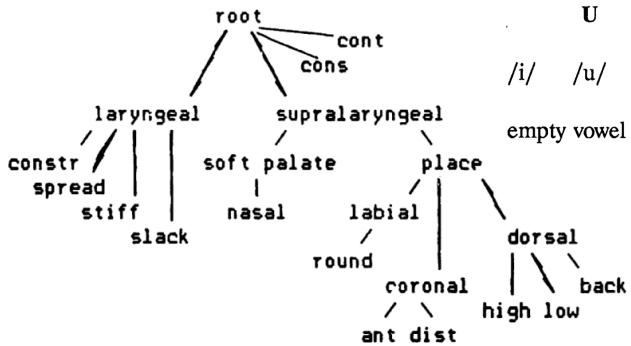
consonants and vowels probably should be natural classes

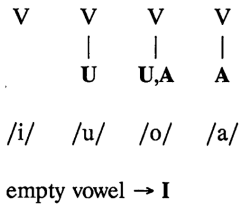
(62) (a) Consonants:



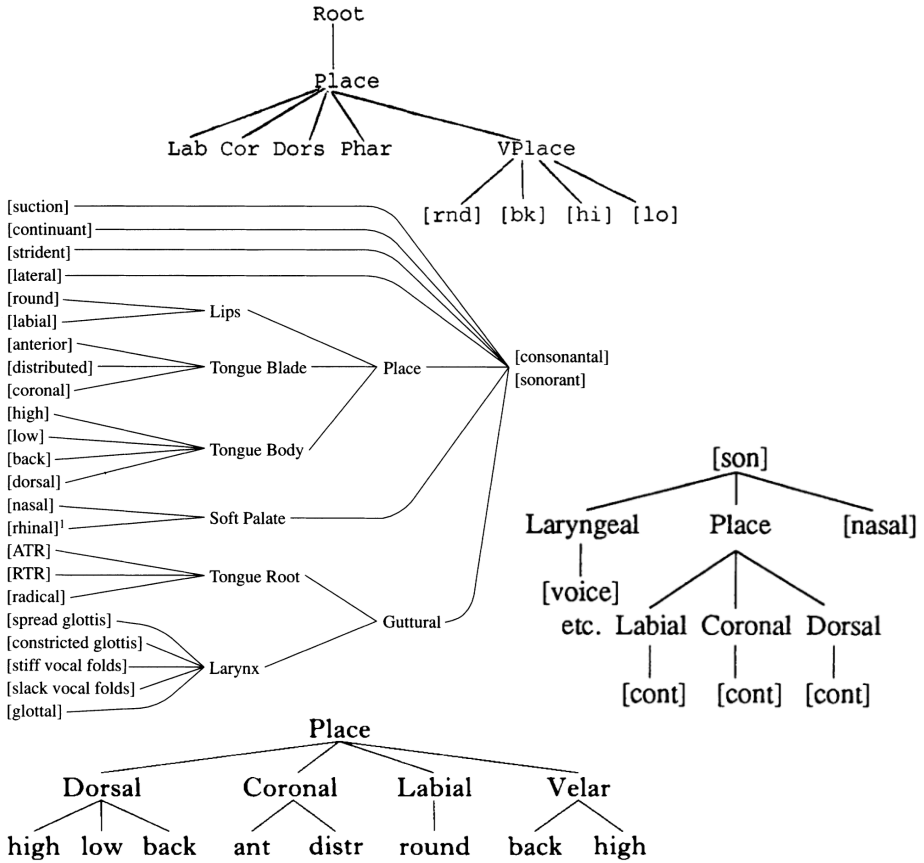
(b) Vocoids:







consonants and vowels probably *shouldn't* be natural classes



big questions

- how can we formally compare phonological representations?
- what can we learn from these comparisons?
- what does it mean for us as linguists?
- what does *anything* mean?

medium answers

- two theories can be shown to be **formally equivalent** using logic and model theory
  - given two representations A and B, a **transduction** between A and B means that any linguistic rule given with structure A can be translated into structure B, and vice versa
  - Strother-Garcia (2019), Danis & Jardine (2019), Oakden (2020), a.o.

Figure 4.5: $\mathcal{M}^{flat}_{plenty}$

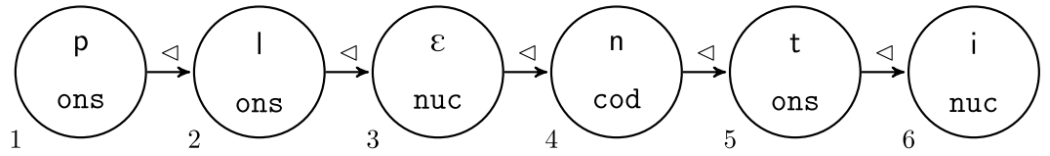
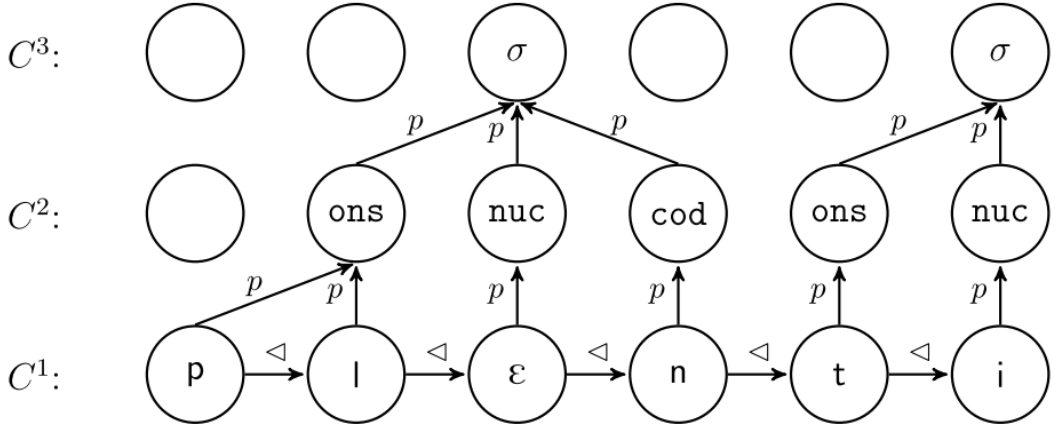


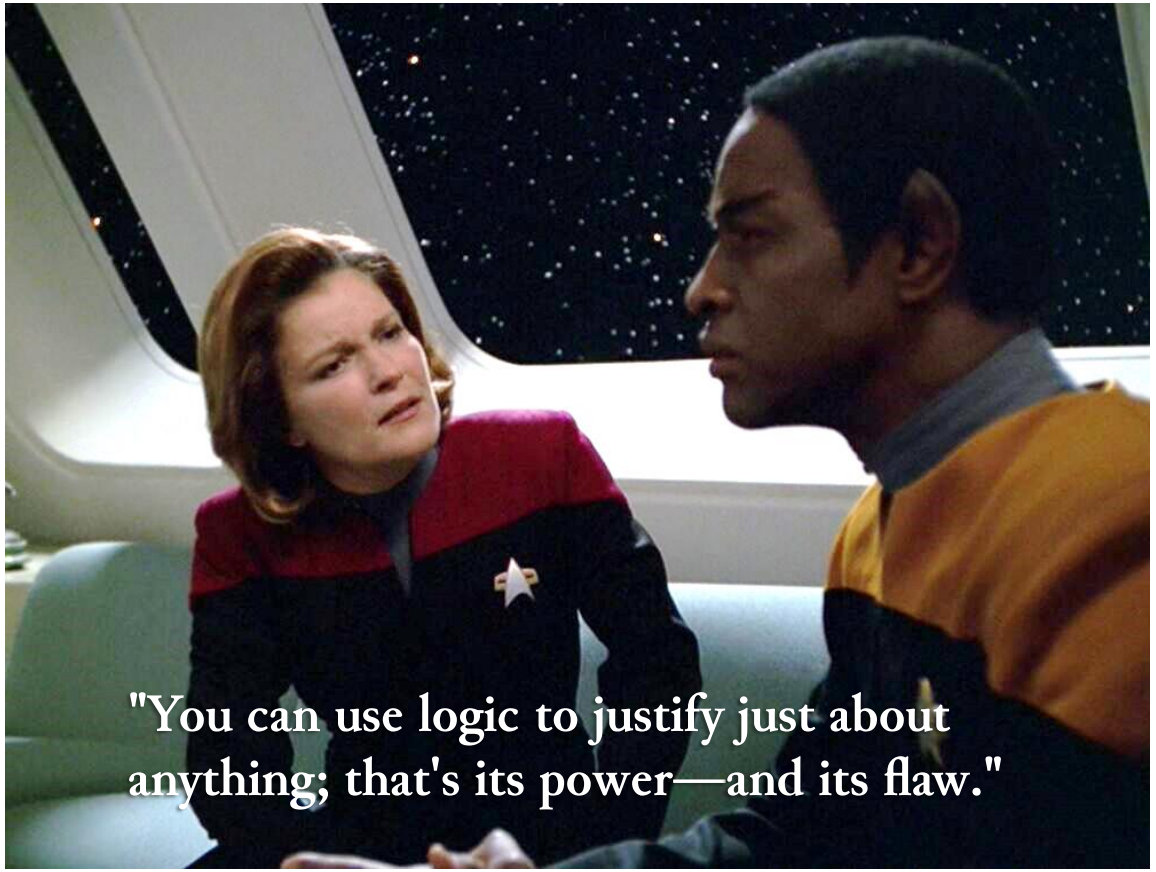
Figure 4.16: $\Gamma_{ft}(\mathcal{M}^{flat}_{plenty})$ fully specified



(Strother-Garcia 2019)

medium answers

- not every transduction preserves ideas of ***linguistic*** equivalence
  - process should respect natural classes, which may be lost in certain transductions
- the property of a **natural-class preserving transduction** is defined to find those logically equivalent representations that also share linguistic intuitions



introduction

definitions

example transduction

empirical basis

existing transductions

conclusion

natural-class preserving transductions

- A transduction between two representations A and B is **natural-class preserving** iff the set of all natural class extensions of A exactly match those of B
  - A **natural class extension** is a maximal set of segments that share some common structural property

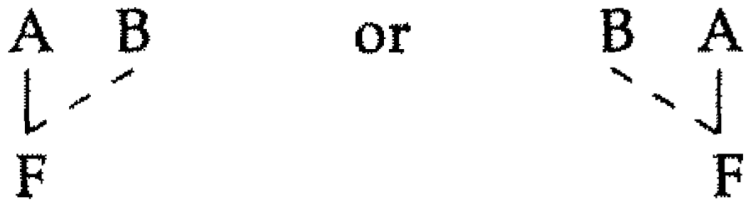
extension: { i u } shared structure: [+high]

i u every segment in this set is [+high]
e o no other segment in the theory is [+high]
a

assimilation: sharing is caring

- assimilation operates over like things
  - Trubetzkoy (1969), Chomsky and Halle (1968), Hyman (1974), Hayes (1986), Clements & Hume (1995) a.o.

$$X \rightarrow [\alpha F] / \underset{Y}{[\alpha F]}$$



Naturalness of Assimilation
the targets and triggers of an assimilation process should constitute a natural class extension

assimilation: sharing is caring

- "Nevertheless, there is empirical evidence in favor of imposing a limitation on the use of variables with different features in different segments. **The great majority of examples involve only a single feature, and in other cases there clearly seems to be some intrinsic connection between the features involved in the process of assimilation**. At the present juncture, however, we are in no position to formulate these restrictions." (SPE 352)

assimilation: sharing is caring

- Clements & Hume (1995):
  - "Phonological rules perform single operations only." (p. 250)
  - "In the present model, in contrast, assimilation rules are characterized as the association (or "**spreading**") **of a feature or node F** of segment A to a neighboring segment B..." (p. 258)

- If assimilation is the result of spreading, then it directly follows from this that the resulting segments will have shared structure and therefore constitute a nontrivial natural class

comparing theories

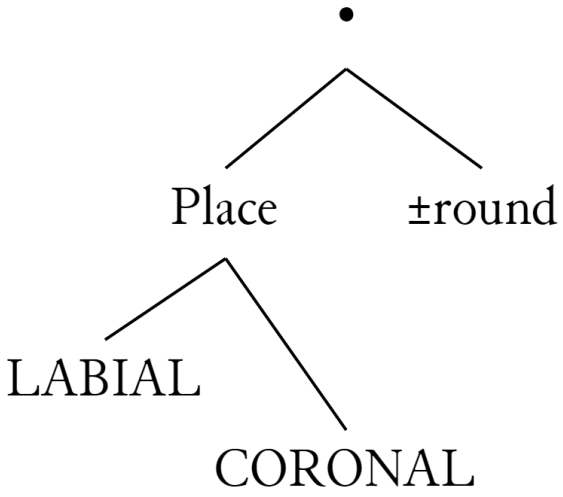
unified place theory

- consonants and vowels share representational primitives
  - e.g. LABIAL C-place, LABIAL V-place
- Sagey (1986), Clements & Hume (1995), a.o.

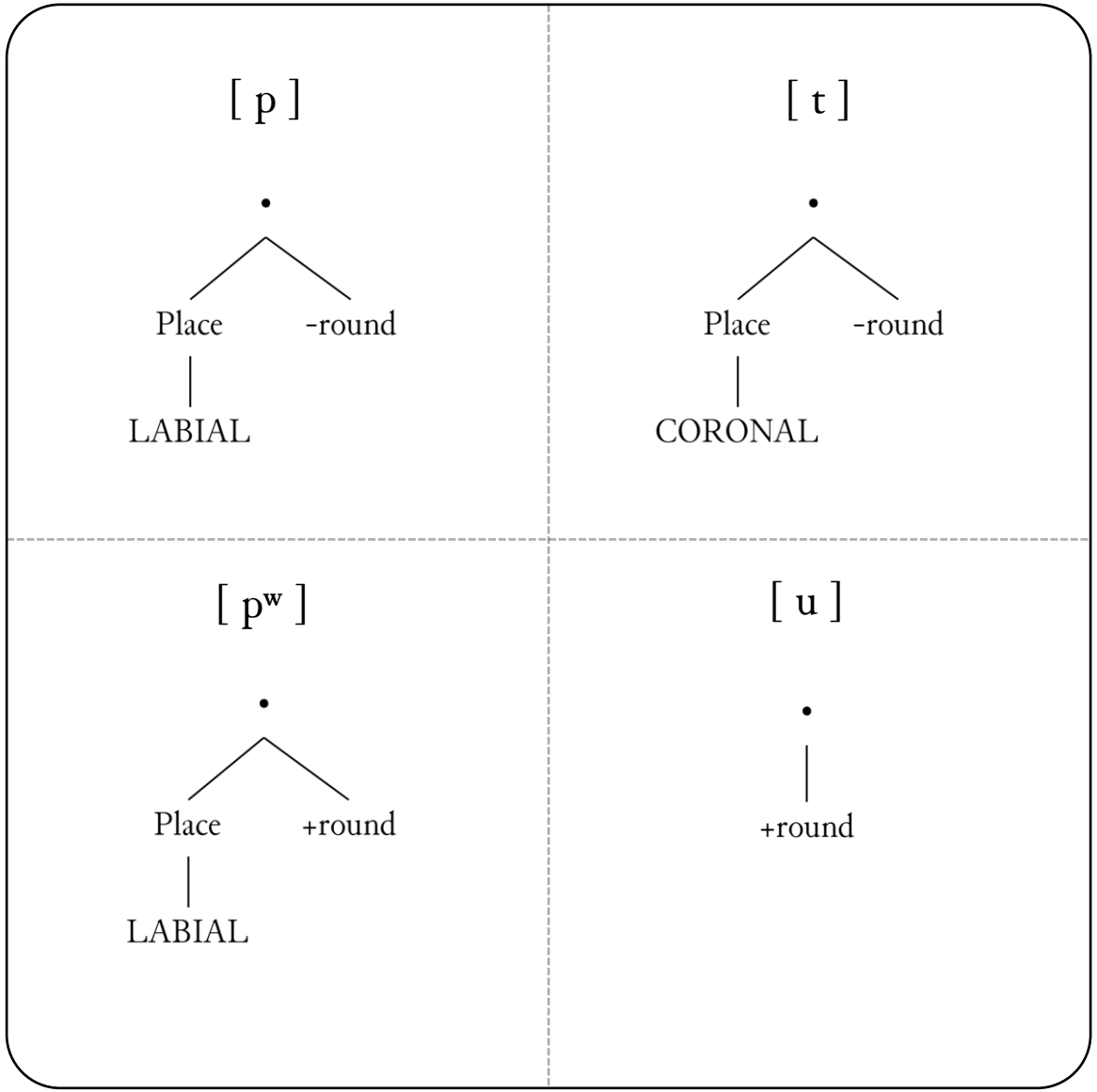
vowel feature theory

- vowel place is largely defined by primitives not used to describe consonant place
  - e.g. [+back], [-round]
- Odden (1991), Ni Chiosain & Padgett (1993), Halle et al. (2000), a.o.

v-feature theory

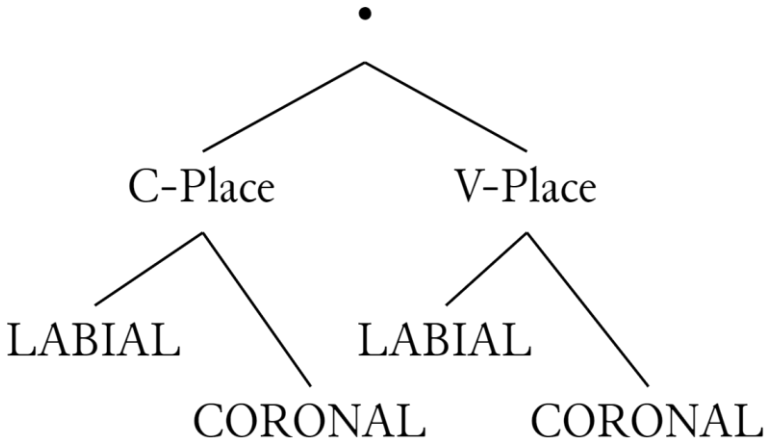


full structure

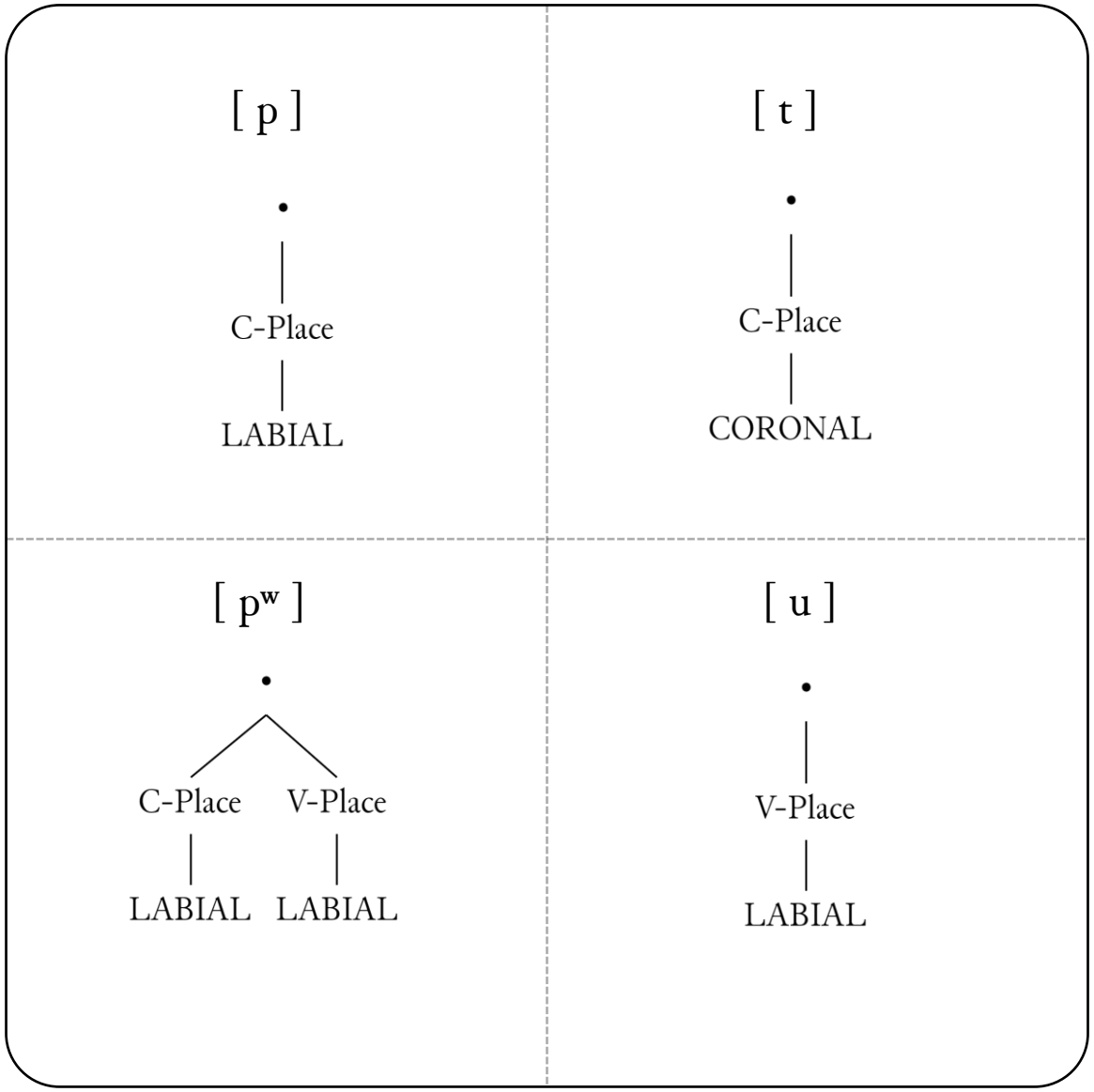


segments

unified place theory



full structure

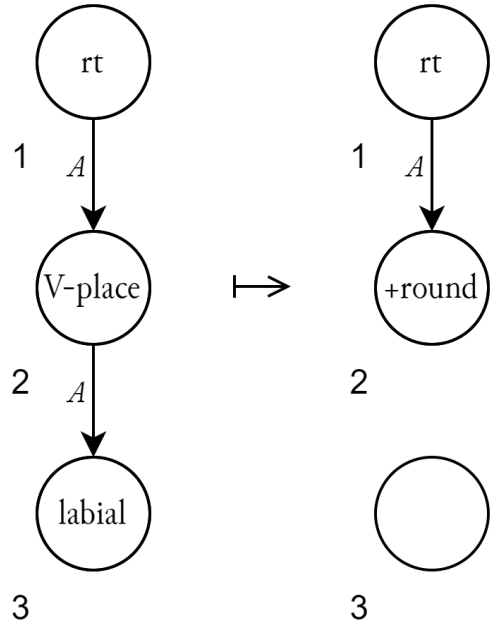


segments

the transduction: unified → v-feature

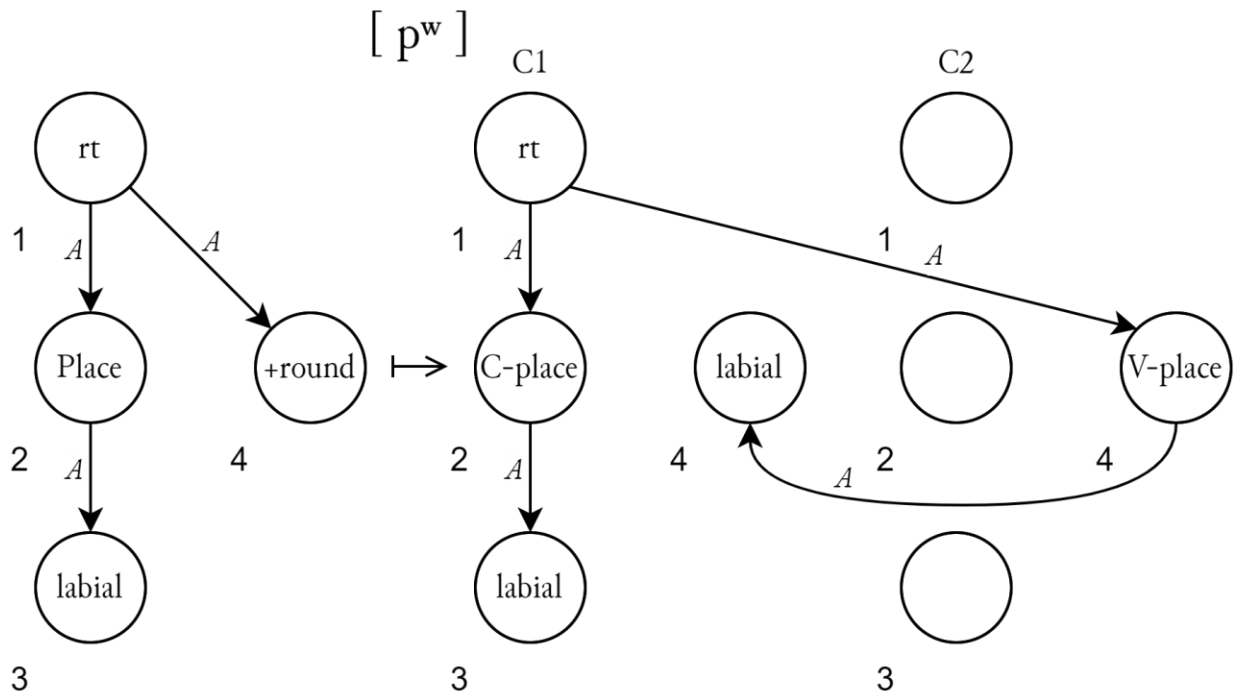
$$\begin{aligned}
\text{rt}(x^1) &= \text{rt}(x) \\
\text{Place}(x^1) &= \text{C-place}(x) \\
\text{labial}(x^1) &= \text{labial}(x) \wedge \text{C-place}(y) \wedge A(y,x) \\
\text{coronal}(x^1) &= \text{coronal}(x) \wedge \text{C-place}(y) \wedge A(y,x) \\
\text{+round}(x^1) &= \text{labial}(x) \wedge \text{V-place}(y) \wedge A(y,x) \\
\text{-round}(x^1) &= \neg\big(\text{labial}(x) \wedge \text{V-place}(y) \wedge A(y,x)\big) \\
\text{+front}(x^1) &= \text{coronal}(x) \wedge \text{V-place}(y) \wedge A(y,x) \\
\text{-front}(x^1) &= \neg\big(\text{coronal}(x) \wedge \text{V-place}(y) \wedge A(y,x)\big)
\end{aligned}$$

[u]



the transduction: v-feature → unified

$$\begin{aligned}
\text{rt}(x^1) &= \text{rt}(x) \\
\text{labial}(x^1) &= +\text{round}(x) \vee \text{labial}(x) \\
\text{coronal}(x^1) &= +\text{front}(x) \vee \text{coronal}(x) \\
\text{C-place}(x^1) &= \text{Place}(x) \\
\text{V-place}(x^2) &= +\text{round}(x) \vee +\text{front}(x) \\
A(x^2, y^1) &= \big(+\text{round}(x) \vee +\text{front}(x)\big) \wedge x = y \\
A(x^1, y^2) &= \text{rt}(x) \wedge \big(+\text{round}(y) \vee +\text{front}(y)\big) \\
A(x^1, y^1) &= A(x, y) \wedge \neg\big(+\text{round}(y) \vee +\text{front}(y)\big)
\end{aligned}$$



unified and v-features are QF-bi-interpretable

and are therefore notational variants?

"A QF transduction is extremely restricted in the degree to which the output can differ from the input because QF is a weak logical language limited to local operations. QF-bi-interpretability can therefore be considered an indication of notational equivalence."

(Strother-Garcia 2019: 39)

enumerating natural class extensions

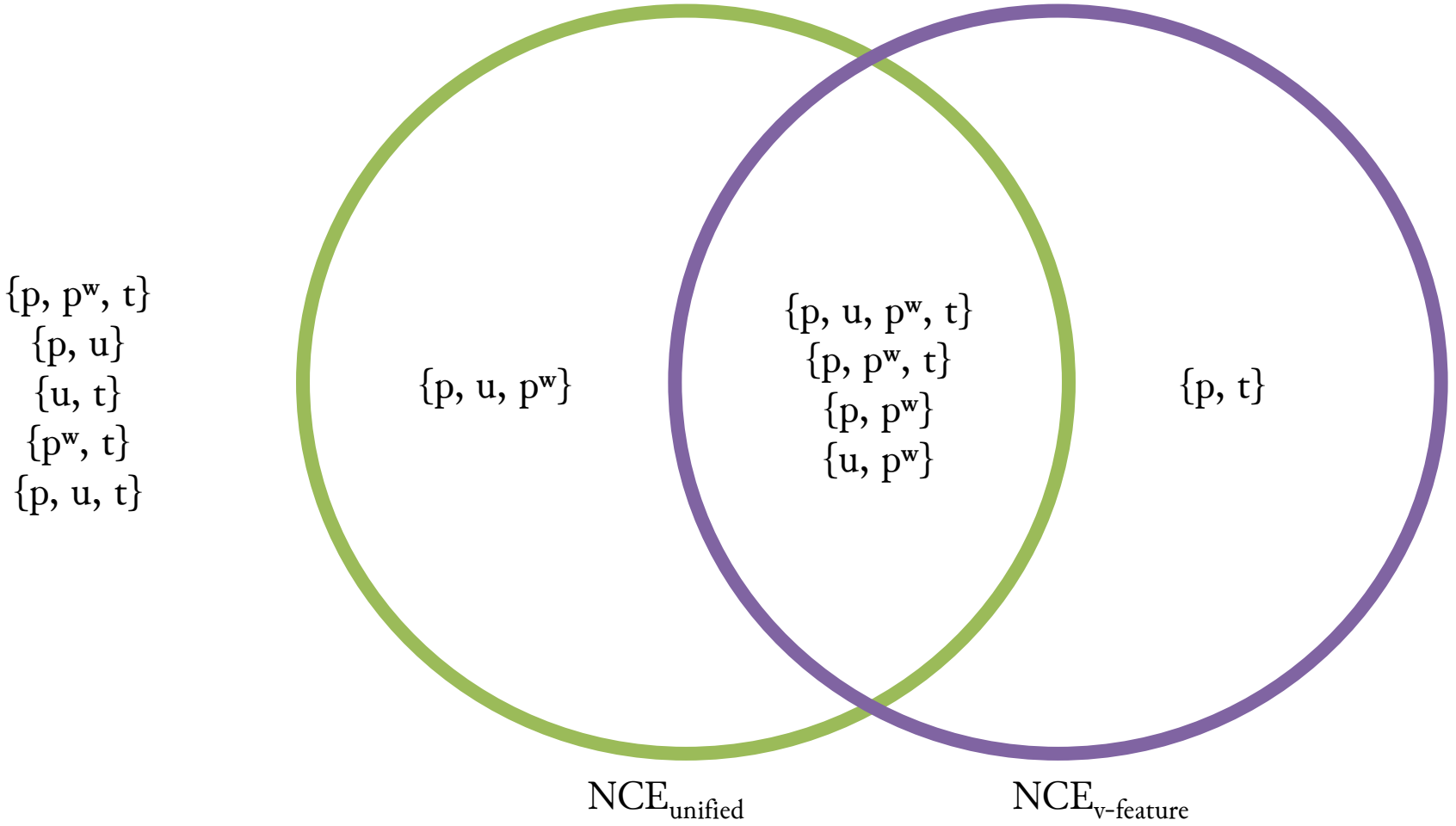
general procedure:

- given the set of possible segments S, find all subsets of S
- for each subset N, find the shared structure G
  - for each segment not in N, check if it also contains G
    - if true, N is not a natural class extension
    - if false, continue
  - N is a natural class extension

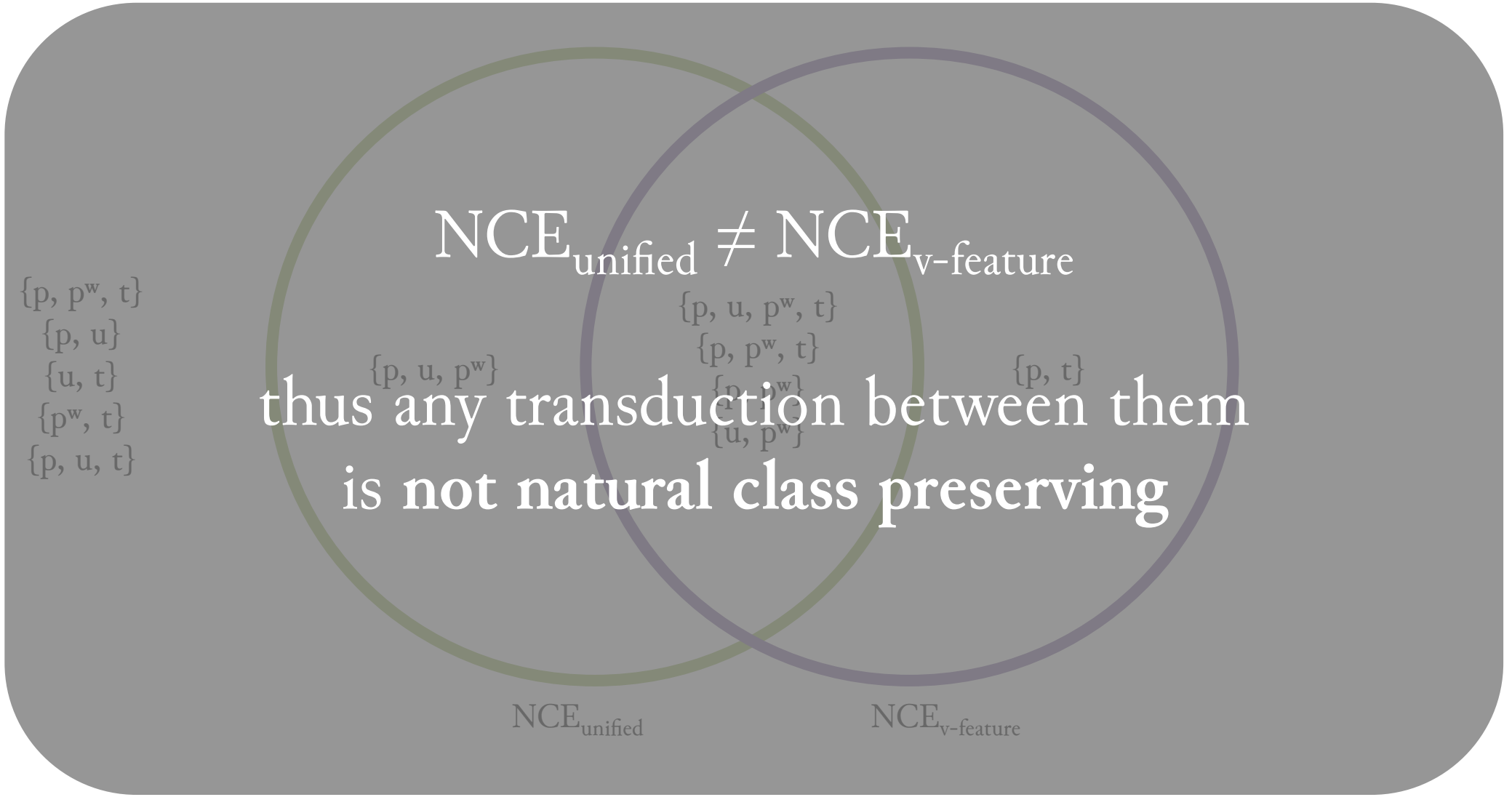
enumerating natural class extensions

	subset	{p, u, p^w, t}	{p, u, p^w}	{p, p^w, t}	{p, p^w}	{p, t}	{u, p^w}
largest unique shared structure	unified	•	• LABIAL	• C-Place	• C-Place LABIAL	∅	• V-Place LABIAL
	v-feature	•	∅	• Place	• Place LABIAL	• Place -round	• +round

comparing natural class extensions



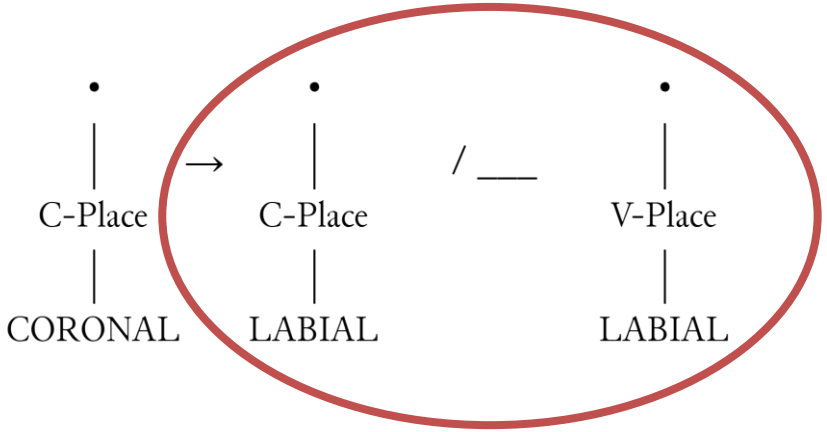
comparing natural class extensions



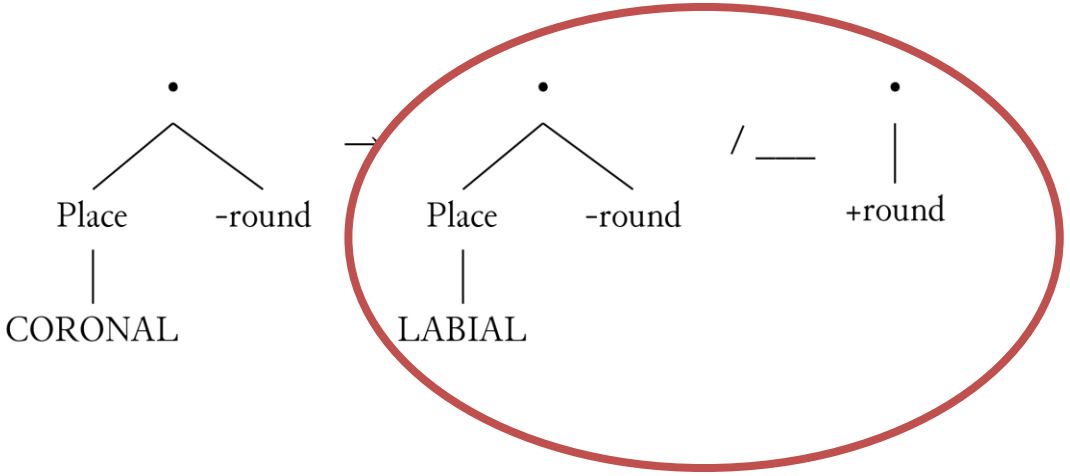
hypothetical assimilation

- t → p / _ u

Naturalness of Assimilation
the targets and triggers of an assimilation process should constitute a natural class extension



natural class extension: {p, u, p^w}
shared structure: LABIAL
- predicts [p^w] also a trigger
- seems reasonable



natural class extension: {t, p, u, p^w}
shared structure: •
- predicts [p^w t] also triggers
- seems wrong
- not even an assimilation rule

comparing theories

(1) *Conditions for notational equivalence*
   a. Two models do not differ in their empirical predictions.
   b. Two models represent the same set of abstract properties, differing only superficially.

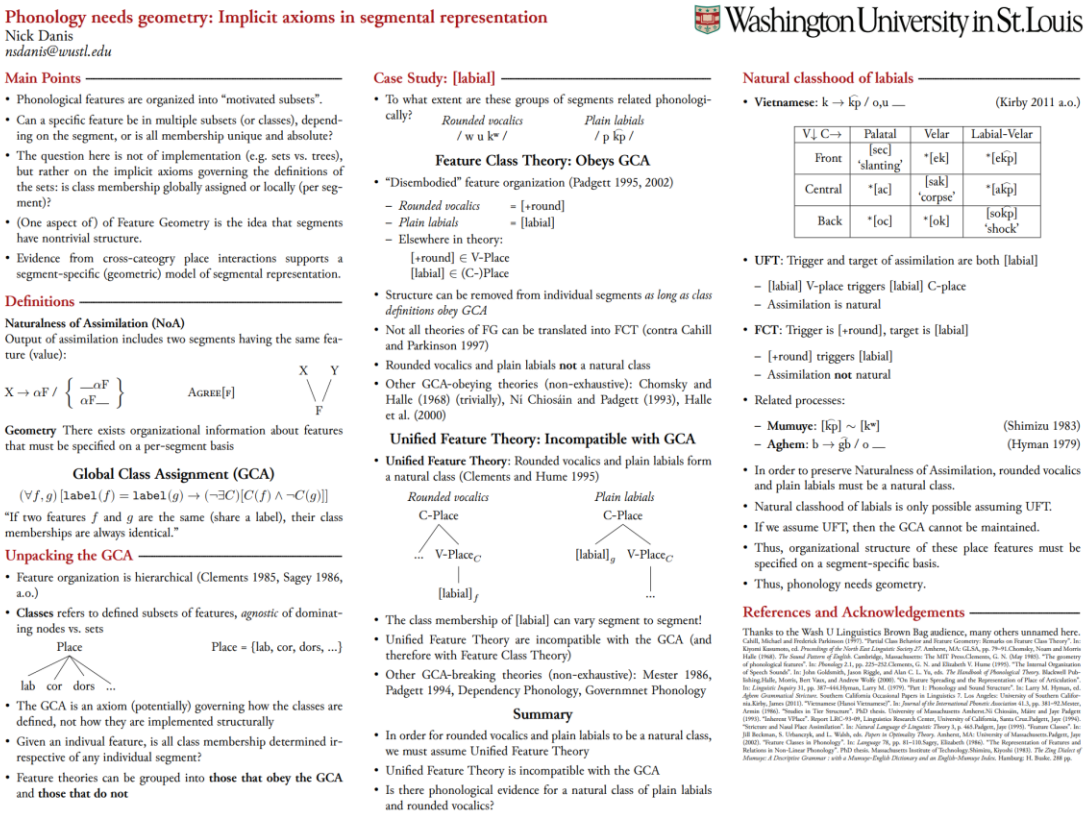
(from Oakden 2021, summarizing Fromkin 2010)

- if we take seriously assumptions like Naturalness of Assimilation 🦎 (in whatever formulation), **then a QF-bi-interpretable contrast-preserving transduction is not enough to satisfy (1a) above**

introduction
definitions
example transduction
empirical basis
existing transductions
conclusion

~~decided to sleep~~ omitted for time, but see the following:

- Danis, Nick. 2020. Phonology needs geometry: Implicit axioms in segmental representation. 2020 Annual Meeting of the LSA. Poster.
- Danis, Nick. Cross-category agreement as reference to general dominance. AMP 2018, UC San Diego. Oct 5-7, 2018. Poster.



Phonology needs geometry: Implicit axioms in segmental representation

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Main Points

- Phonological features are organized into "motivated subsets".
- Can a specific feature be in multiple subsets (or classes), depending on the segment, or is all membership unique and absolute?
- The question here is not of implementation (e.g. sets vs. trees), but rather on the implicit axioms governing the definitions of the sets: is class membership globally assigned or locally (per segment)?
- (One aspect of) of Feature Geometry is the idea that segments have nontrivial structure.
- Evidence from cross-cateogry place interactions supports a segment-specific (geometric) model of segmental representation.

Definitions

Naturalness of Assimilation (NoA)
Output of assimilation includes two segments having the same feature (value):

$X \rightarrow \alpha F \,/ \left\{ \begin{array}{c} \_\_\alpha F \\ \alpha F \_\_ \end{array} \right\}$ AGREE[F]

Geometry There exists organizational information about features that must be specified on a per-segment basis

Global Class Assignment (GCA)

$(\forall f, g)\,[\texttt{label}(f) = \texttt{label}(g) \rightarrow (\neg\exists C)[C(f) \wedge \neg C(g)]]$

"If two features f and g are the same (share a label), their class memberships are always identical."

Unpacking the GCA

- Feature organization is hierarchical (Clements 1985, Sagey 1986, a.o.)
- **Classes** refers to defined subsets of features, *agnostic* of dominating nodes vs. sets

Place = {lab, cor, dors, ...}

- The GCA is an axiom (potentially) governing how the classes are defined, not how they are implemented structurally
- Given an indivual feature, is all class membership determined irrespective of any individual segment?
- Feature theories can be grouped into **those that obey the GCA** and **those that do not**

Case Study: [labial]

- To what extent are these groups of segments related phonologically?

Rounded vocalics	*Plain labials*
/ w u kʷ /	/ p k͡p /

Feature Class Theory: Obeys GCA

- "Disembodied" feature organization (Padgett 1995, 2002)
  - *Rounded vocalics* = [+round]
  - *Plain labials* = [labial]
  - Elsewhere in theory:
    [+round] ∈ V-Place
    [labial] ∈ (C-)Place
- Structure can be removed from individual segments *as long as class definitions obey GCA*
- Not all theories of FG can be translated into FCT (contra Cahill and Parkinson 1997)
- Rounded vocalics and plain labials **not** a natural class
- Other GCA-obeying theories (non-exhaustive): Chomsky and Halle (1968) (trivially), Ni Chiosáin and Padgett (1993), Halle et al. (2000)

Unified Feature Theory: Incompatible with GCA

- **Unified Feature Theory**: Rounded vocalics and plain labials form a natural class (Clements and Hume 1995)

- The class membership of [labial] can vary segment to segment!
- Unified Feature Theory are incompatible with the GCA (and therefore with Feature Class Theory)
- Other GCA-breaking theories (non-exhaustive): Mester 1986, Padgett 1994, Dependency Phonology, Governmnet Phonology

Summary

- In order for rounded vocalics and plain labials to be a natural class, we must assume Unified Feature Theory
- Unified Feature Theory is incompatible with the GCA
- Is there phonological evidence for a natural class of plain labials and rounded vocalics?

Natural classhood of labials

- **Vietnamese**: k → k͡p / o,u __ (Kirby 2011 a.o.)

V↓ C→	Palatal	Velar	Labial-Velar
Front	[sec] 'slanting'	*[ek]	*[ek͡p]
Central	*[ac]	[sak] 'corpse'	*[ak͡p]
Back	*[oc]	*[ok]	[sok͡p] 'shock'

- **UFT**: Trigger and target of assimilation are both [labial]
  - [labial] V-place triggers [labial] C-place
  - Assimilation is natural
- **FCT**: Trigger is [+round], target is [labial]
  - [+round] triggers [labial]
  - Assimilation **not** natural
- Related processes:
  - **Mumuye**: [k͡p] ~ [kʷ] (Shimizu 1983)
  - **Aghem**: b → g͡b / o __ (Hyman 1979)
- In order to preserve Naturalness of Assimilation, rounded vocalics and plain labials must be a natural class.
- Natural classhood of labials is only possible assuming UFT.
- If we assume UFT, then the GCA cannot be maintained.
- Thus, organizational structure of these place features must be specified on a segment-specific basis.
- Thus, phonology needs geometry.

References and Acknowledgements

Thanks to the Wash U Linguistics Brown Bag audience, many others unnamed here.

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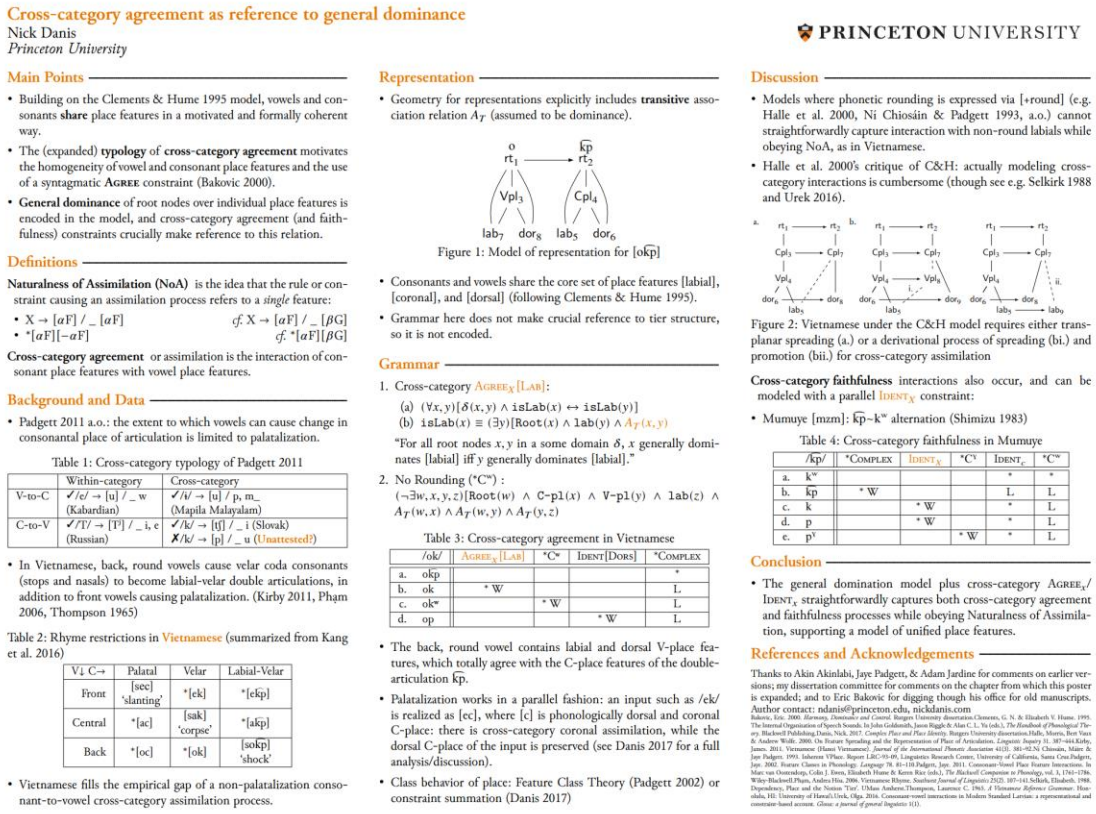

Cross-category agreement as reference to general dominance

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Main Points

- Building on the Clements & Hume 1995 model, vowels and consonants **share** place features in a motivated and formally coherent way.
- The (expanded) **typology** of **cross-category agreement** motivates the homogeneity of vowel and consonant place features and the use of a syntagmatic AGREE constraint (Bakovic 2000).
- **General dominance** of root nodes over individual place features is encoded in the model, and cross-category agreement (and faithfulness) constraints crucially make reference to this relation.

Definitions

Naturalness of Assimilation (NoA) is the idea that the rule or constraint causing an assimilation process refers to a *single* feature:

- X → [αF] / _ [αF] *cf.* X → [αF] / _ [βG]
- *[αF][−αF] *cf.* *[αF][βG]

Cross-category agreement or assimilation is the interaction of consonant place features with vowel place features.

Background and Data

- Padgett 2011 a.o.: the extent to which vowels can cause change in consonantal place of articulation is limited to palatalization.

Table 1: Cross-category typology of Padgett 2011

	Within-category	Cross-category
V-to-C	✓/e/ → [u] / _ w (Kabardian)	✓/k/ → [u] / p, m_ (Mapila Malayalam)
C-to-V	✓/t͡ʃ/ → [t͡ʃ] / _ i, e (Russian)	✓/k/ → [t͡ʃ] / _ i (Slovak) ✗/k/ → [p] / _ u (Unattested?)

- In Vietnamese, back, round vowels cause velar coda consonants (stops and nasals) to become labial-velar double articulations, in addition to front vowels causing palatalization. (Kirby 2011, Phạm 2006, Thompson 1965)

Table 2: Rhyme restrictions in Vietnamese (summarized from Kang et al. 2016)

V↓ C→	Palatal	Velar	Labial-Velar
Front	[sec] 'slanting'	*[ek]	*[ek͡p]
Central	*[ac]	[sak] 'corpse'	*[ak͡p]
Back	*[oc]	*[ok]	[sok͡p] 'shock'

- Vietnamese fills the empirical gap of a non-palatalization consonant-to-vowel cross-category assimilation process.

Representation

- Geometry for representations explicitly includes **transitive** association relation A_T (assumed to be dominance).

Figure 1: Model of representation for [ok͡p]

- Consonants and vowels share the core set of place features [labial], [coronal], and [dorsal] (following Clements & Hume 1995).
- Grammar here does not make crucial reference to tier structure, so it is not encoded.

Grammar

1. Cross-category AGREE$_X$[LAB]:
   (a) $(\forall x, y)[\delta(x, y) \wedge \texttt{isLab}(x) \leftrightarrow \texttt{isLab}(y)]$
   (b) $\texttt{isLab}(x) \equiv (\exists y)[\texttt{Root}(x) \wedge \texttt{lab}(y) \wedge A_T(x, y)$
   "For all root nodes x, y in a some domain δ, x generally dominates [labial] iff y generally dominates [labial]."
2. No Rounding (*Cʷ) :
   $(\neg\exists w, x, y, z)[\texttt{Root}(w) \wedge \texttt{C-pl}(x) \wedge \texttt{V-pl}(y) \wedge \texttt{lab}(z) \wedge A_T(w, x) \wedge A_T(w, y) \wedge A_T(y, z)$

Table 3: Cross-category agreement in Vietnamese

	/ok/	AGREE$_X$[LAB]	*Cʷ	IDENT[DORS]	*COMPLEX
a.	okp				*
b.	ok	* W			L
c.	okʷ		* W		L
d.	op			* W	L

- The back, round vowel contains labial and dorsal V-place features, which totally agree with the C-place features of the double-articulation k͡p.
- Palatalization works in a parallel fashion: an input such as /ek/ is realized as [ec], where [c] is phonologically dorsal and coronal C-place: there is cross-category coronal assimilation, while the dorsal C-place of the input is preserved (see Danis 2017 for a full analysis/discussion).
- Class behavior of place: Feature Class Theory (Padgett 2002) or constraint summation (Danis 2017)

Discussion

- Models where phonetic rounding is expressed via [+round] (e.g. Halle et al. 2000, Ni Chiosáin & Padgett 1993, a.o.) cannot straightforwardly capture interaction with non-round labials while obeying NoA, as in Vietnamese.
- Halle et al. 2000's critique of C&H: actually modeling cross-category interactions is cumbersome (though see e.g. Selkirk 1988 and Urek 2016).

Figure 2: Vietnamese under the C&H model requires either transplanar spreading (a.) or a derivational process of spreading (bi.) and promotion (bii.) for cross-category assimilation

Cross-category faithfulness interactions also occur, and can be modeled with a parallel IDENT$_X$ constraint:

- Mumuye [mzm]: k͡p ~ kʷ alternation (Shimizu 1983)

Table 4: Cross-category faithfulness in Mumuye

	/k͡p/	*COMPLEX	IDENT$_X$	*Cʲ	IDENT$_\alpha$	*Cʷ
a.	kʷ				*	*
b.	k͡p	* W			L	L
c.	k		* W		*	L
d.	p		* W		*	L
e.	pʲ			* W	*	L

Conclusion

- The general domination model plus cross-category AGREE$_x$/ IDENT$_x$ straightforwardly captures both cross-category agreement and faithfulness processes while obeying Naturalness of Assimilation, supporting a model of unified place features.

References and Acknowledgements

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Bakovic, Eric. 2000. *Harmony, Dominance and Control*. Rutgers University dissertation.Clements, G. N. & Elizabeth V. Hume. 1995. The Internal Organisation of Speech Sounds. In John Goldsmith, Jason Riggle & Alan C. L. Yu (eds.), *The Handbook of Phonological Theory*. Blackwell Publishing.Danis, Nick. 2017. *Complex Place and Place Identity*. Rutgers University dissertation.Halle, Morris, Bert Vaux & Andrew Wolfe. 2000. On Feature Spreading and the Representation of Place of Articulation. *Linguistic Inquiry* 31. 387–444.Kirby, James. 2011. Vietnamese (Hanoi Vietnamese). *Journal of the International Phonetic Association* 41(3). 381–92.Ni Chiosáin, Máire & Jaye Padgett. 1993. Inherent VPlace. Report LRC-93-09, Linguistics Research Center, University of California, Santa Cruz.Padgett, Jaye. 2002. Feature Classes in Phonology. *Language* 78. 81–110.Padgett, Jaye. 2011. Consonant-Vowel Place Feature Interactions. In Marc van Oostendorp, Colin J. Ewen, Elizabeth Hume & Keren Rice (eds.), *The Blackwell Companion to Phonology*, vol. 3, 1761–1786. Wiley-Blackwell.Pham, Andrea Hóa. 2006. Vietnamese Rhyme. *Southeast Journal of Linguistics* 25(2). 107–141.Selkirk, Elisabeth. 1988. Dependency, Place and the Notion 'Tier'. UMass Amherst.Thompson, Laurence C. 1965. *A Vietnamese Reference Grammar*. Honolulu, HI: University of Hawai'i Urek, Olga. 2016. Consonant-vowel interactions in Modern Standard Latvian: a representational and constraint-based account. *Glossa: a journal of general linguistics* 1(1).

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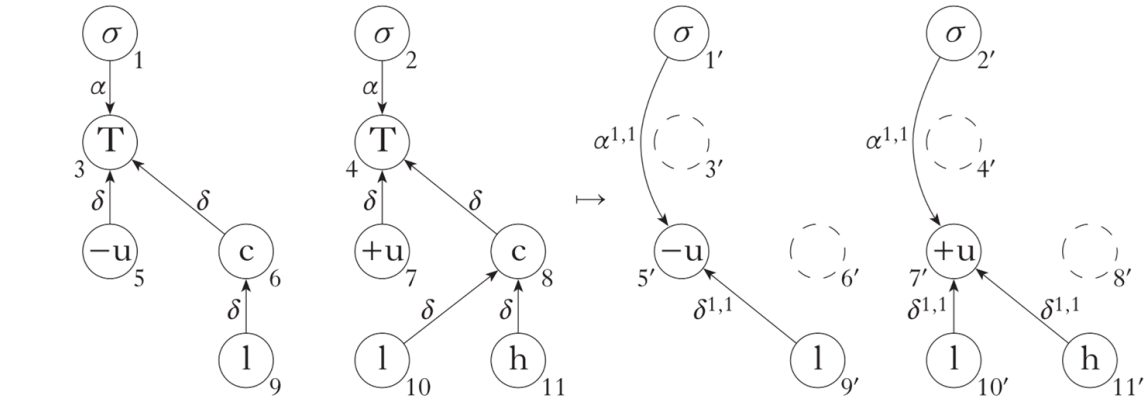
Oakden (2021)

tone	Yip (1989)	Bao (1990)
low level L	σ −u l	σ T −u c l
high level H	σ +u h	σ T +u c h
mid level M	σ σ −u *or* +u h l	σ σ T T −u c *or* +u c h l
high falling HM	σ +u h l	σ T +u c h l

tone	Yip (1989)	Bao (1990)
high rising MH	σ +u l h	σ T +u c l h
low falling ML	σ −u h l	σ T −u c h l
low rising LM	σ −u l h	σ T −u c l h

Table I
Level and contour tonal contrasts in Yip (1989) and Bao (1990).

(38) *separated* *bundled*



- Oakden (2021) provides a non-size-preserving QF transduction (above) between two theories of tone sandhi (left), arguing for notational equivalence
- **is this transduction also natural class preserving?**

Oakden (2021)

- yes
- because Python

[8]:

```
yip = {
    'L' : {('s','-u'), ('-u','l')},
    'H' : {('s','+u'), ('+u','h')},
    'M1' : {('s','-u'), ('-u','h')},
    'M2' : {('s','+u'), ('+u','l')},
    'HM' : {('s','+u'), ('+u','h'), ('+u','l')},
    'MH' : {('s','+u'), ('+u','l'), ('+u','h')},
    'ML' : {('s','-u'), ('-u','l'), ('-u','h')},
    'LM' : {('s','-u'), ('-u','l'), ('-u','h')}
}

bao = {
    'L' : {('s','T'), ('T','-u'), ('T','c'), ('c','l')},
    'H' : {('s','T'), ('T','+u'), ('T','c'), ('c','h')},
    'M1' : {('s','T'), ('T','-u'), ('T','c'), ('c','h')},
    'M2' : {('s','T'), ('T','+u'), ('T','c'), ('c','l')},
    'HM' : {('s','T'), ('T','+u'), ('T','c'), ('c','h'), ('c','l')},
    'MH' : {('s','T'), ('T','+u'), ('T','c'), ('c','h'), ('c','l')},
    'ML' : {('s','T'), ('T','-u'), ('T','c'), ('c','h'), ('c','l')},
    'LM' : {('s','T'), ('T','-u'), ('T','c'), ('c','h'), ('c','l')},
}

compare_theories(yip, bao)
```

```
Natural classes unique to theory 1:
Natural classes unique to theory 2:
Natural classes in common:
('LM', 'M1', 'ML')
('LM', 'ML')
('HM', 'M2', 'MH')
('H', 'HM', 'M2', 'MH')
('L', 'LM', 'M1', 'ML')
('H', 'HM', 'LM', 'M1', 'MH', 'ML')
('H', 'HM', 'L', 'LM', 'M1', 'M2', 'MH', 'ML')
('HM', 'L', 'LM', 'M2', 'MH', 'ML')
('H', 'HM', 'MH')
('L', 'LM', 'ML')
('HM', 'MH')
('HM', 'LM', 'MH', 'ML')
```

code available at https://www.nickdanis.com/research/representations

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summary

- the use of features/subsegmental structure sorts segments into natural classes based on shared structure
- while transductions can translate from model A to model B, the predicted natural classes present in the system as a whole may still differ in a linguistically significant way
- the definition of natural class preserving transductions is a start to identify comparisons of theories which still involve differing linguistic predictions

going forward

- the definition of *natural class preserving* is based on the representation themselves—can this property be identified by investigating the transduction rules alone?
- how else can transductions themselves be compared and evaluated from a linguistic standpoint?
- how strongly should our metatheoretical assumptions and expectations about linguistic processes be formalized?

thank you

🗺 ⟷ 🌎

& thank you Adam Jardine (for helping with the transductions like 3 years ago)
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