Some implications for representing gradual oppositions directly

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NECPHON

November 7, 2015

This talk

1. We provide a representational solution to phonological changes along scales (gradual oppositions).
2. The example we analyze is Danish vowel lowering
3. The representational solution is essentially Schane's 1984 analysis, but it gets new life within a general analytical computational framework (logic over relational structures)

Representations matter

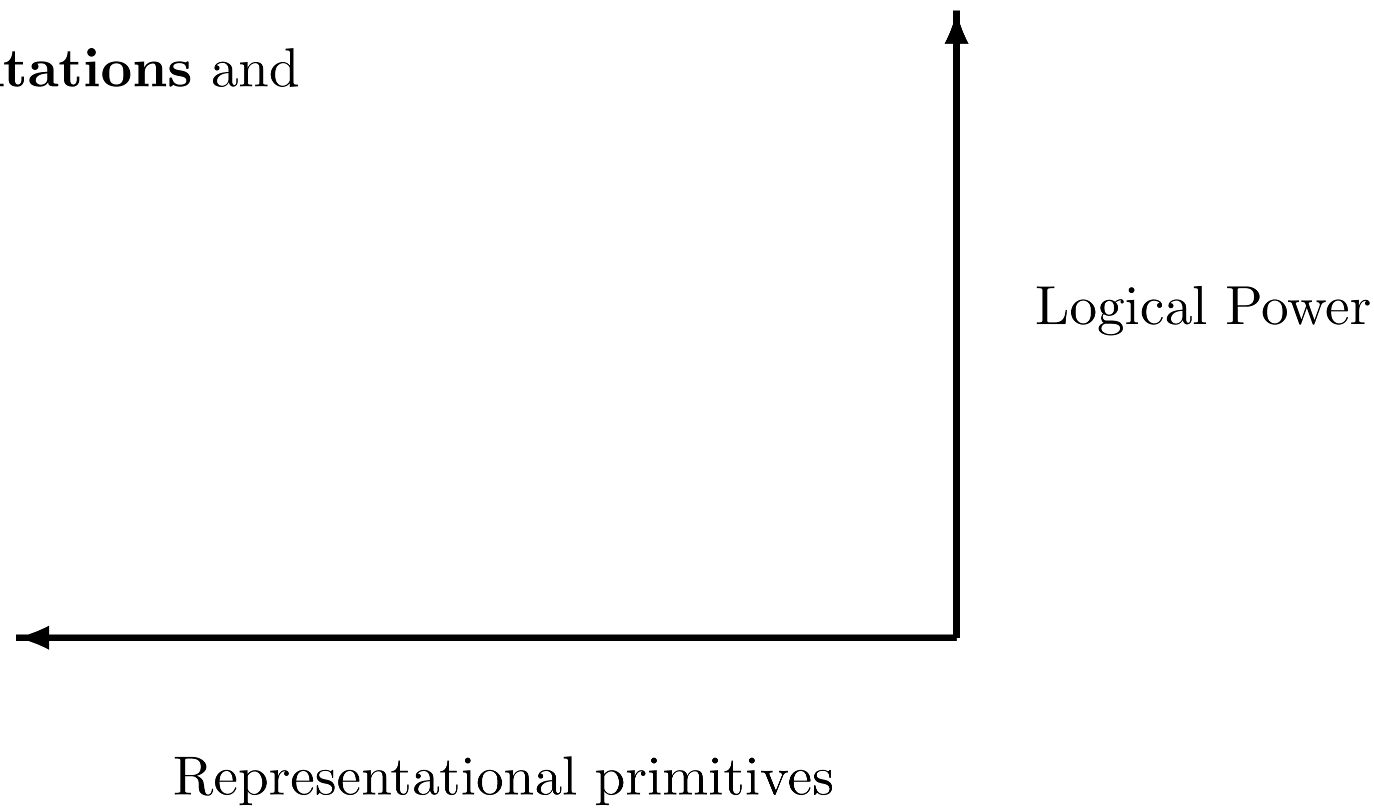
Many phonological generalizations invoke representations.

1. Kastner and Adriaans (today); Jardine (today); Futrell et al. (today)
2. Pater's (1999) solution to 'counterbleeding' in Indonesian as fusion relied on output representations which explicitly refer to input correspondents.
3. Tonal phenomenon is commonly understood in terms of autosegmental representations (Leben, Goldsmith, Hyman, Odden, Marlo, inter alia).
4. Tesar (2014) observes that what is output-driven and what is not depends on a theory of similarity and disparity among *representations*.

Factoring complexity

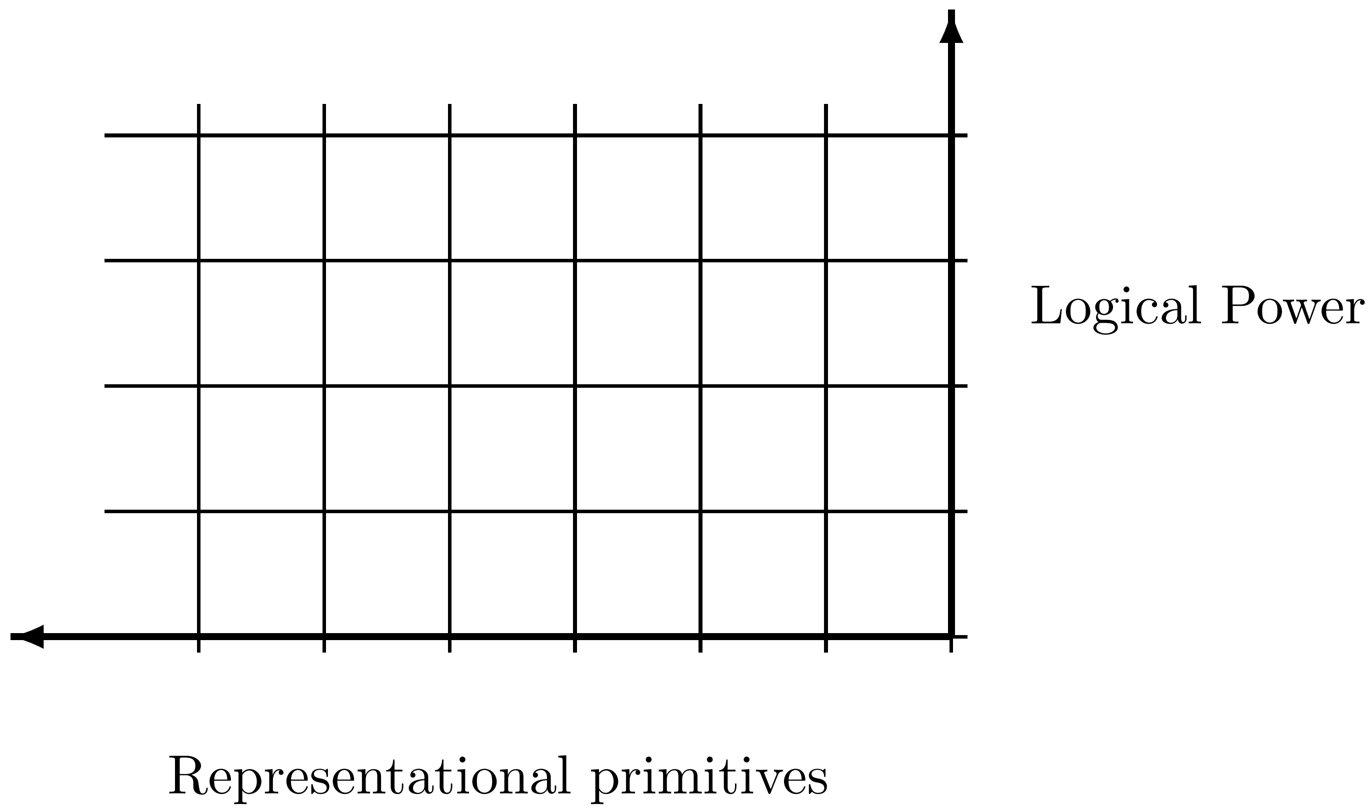
Phonological constraints and maps can be factored along two computational dimensions:

1. **representations** and
2. **power**.

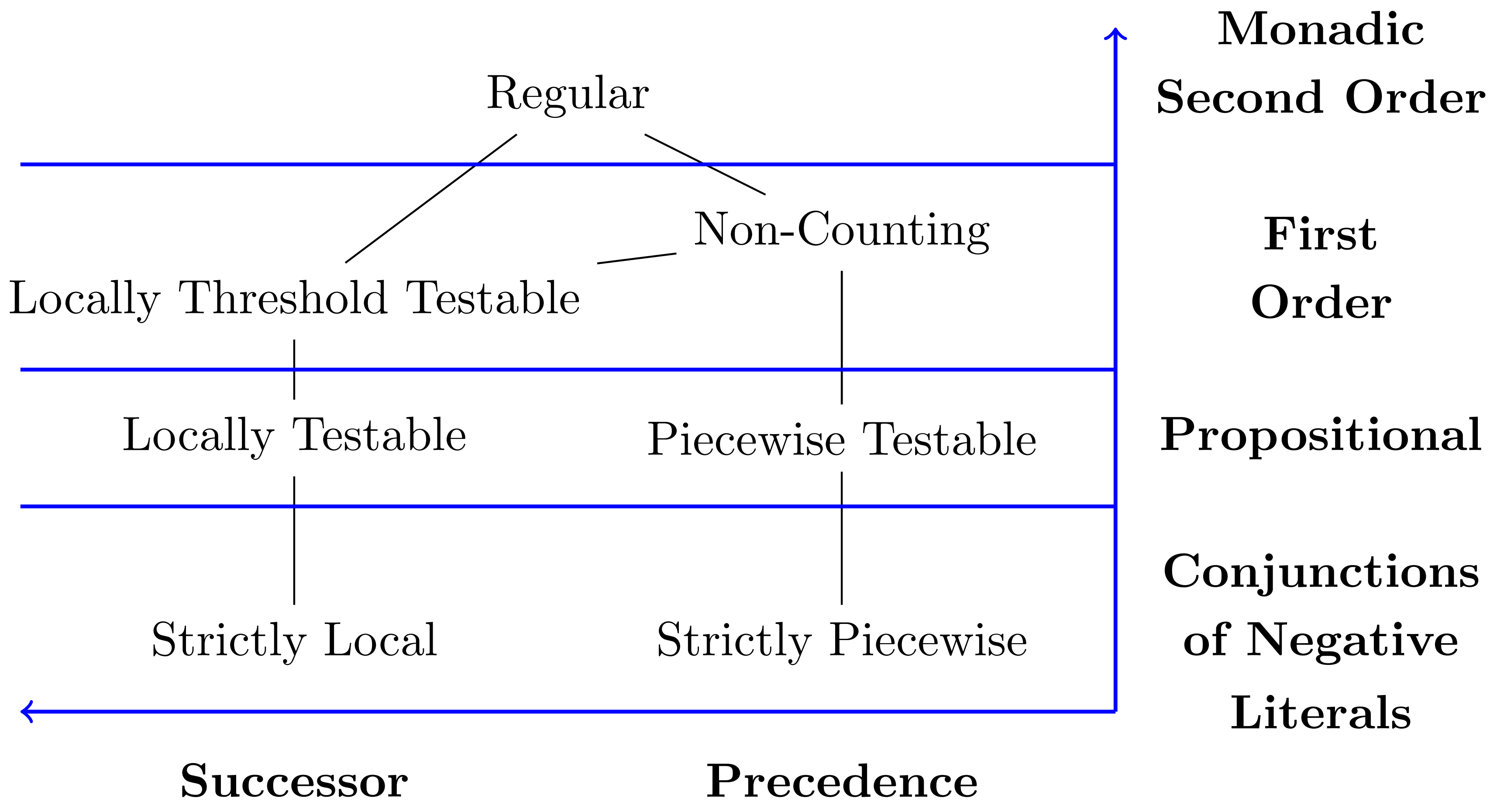


Channeling Humboldt

This factorization provides an ontology of types—*an encyclopedia of categories*— with which phonological phenomenon—*the encyclopedia of types*—can be identified.

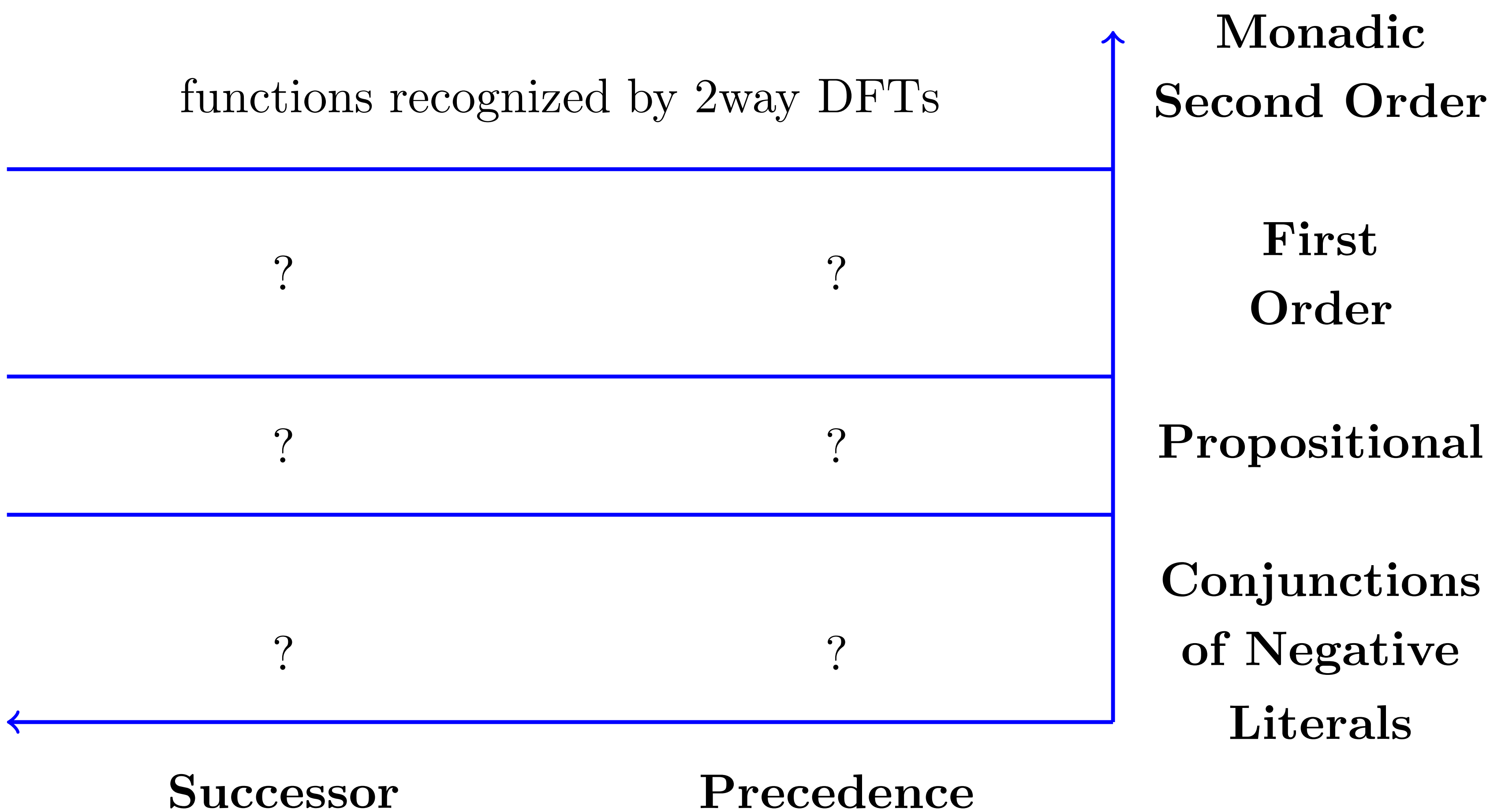


Logical Characterizations of Subregular Stringsets



(McNaughton and Papert 1971, Heinz 2010, Rogers and Pullum 2011, Rogers et al. 2013)

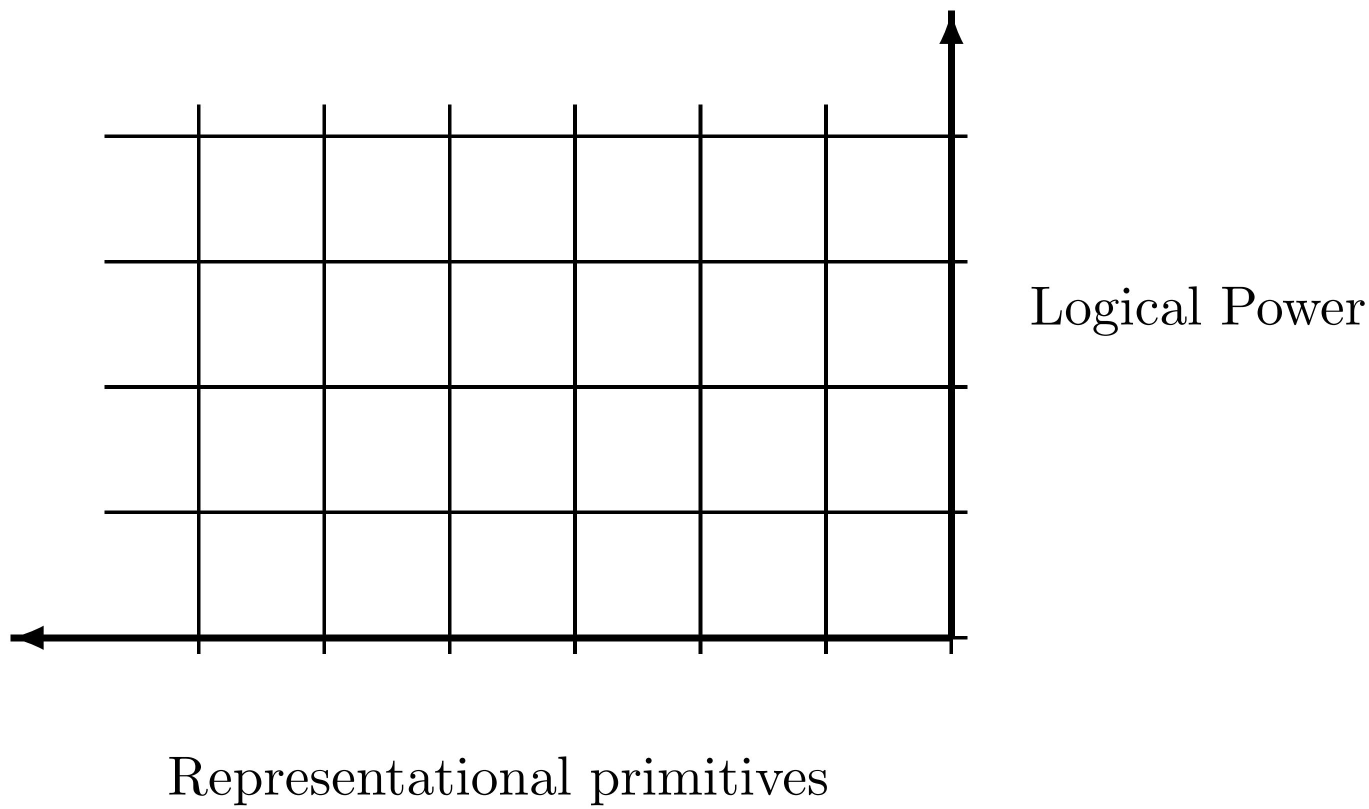
Logical Characterizations of Subregular *Functions*



 (Courcelle and Engelfriedt 2001, 2011)

Channeling de Lacy (2011)

This factorization also provides many Constraint Definition Languages (de Lacy 2011) as well as languages for defining maps.



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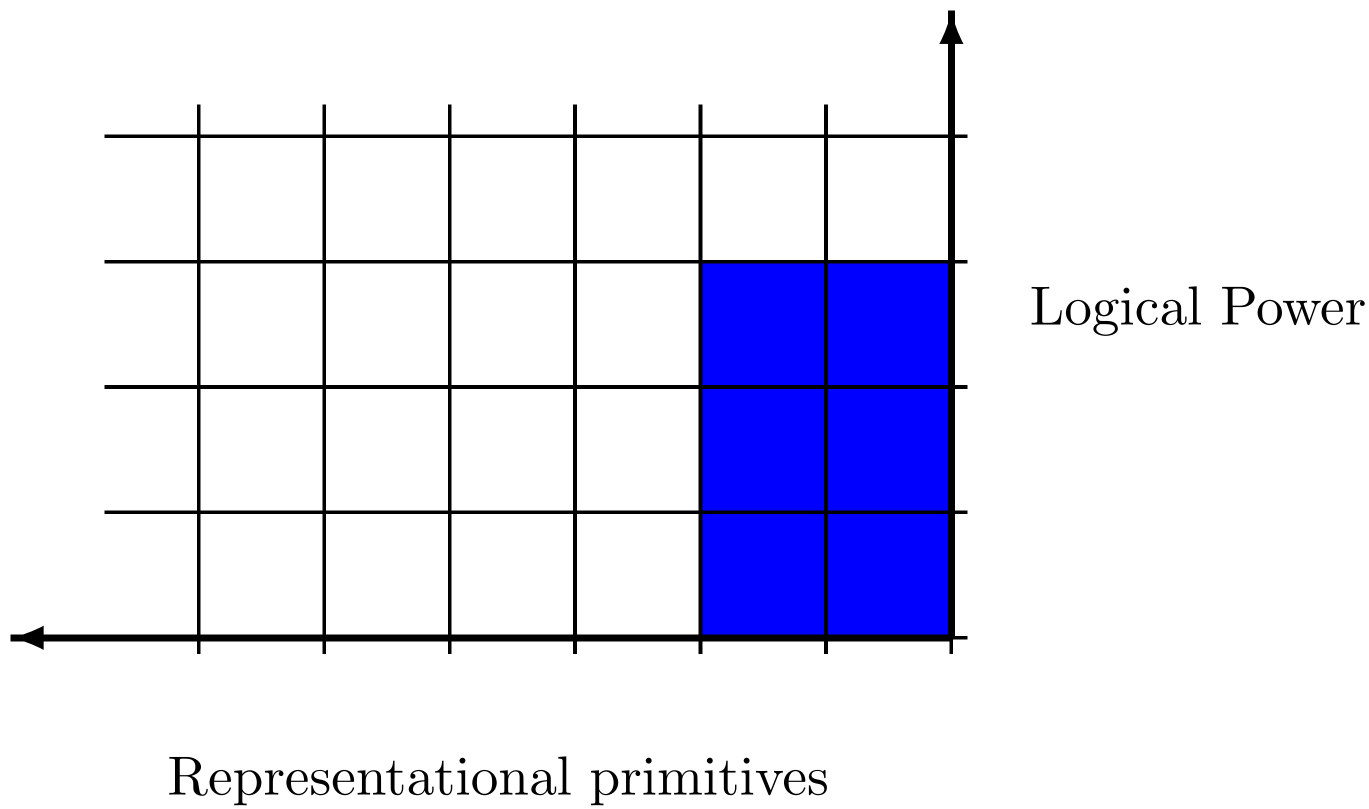

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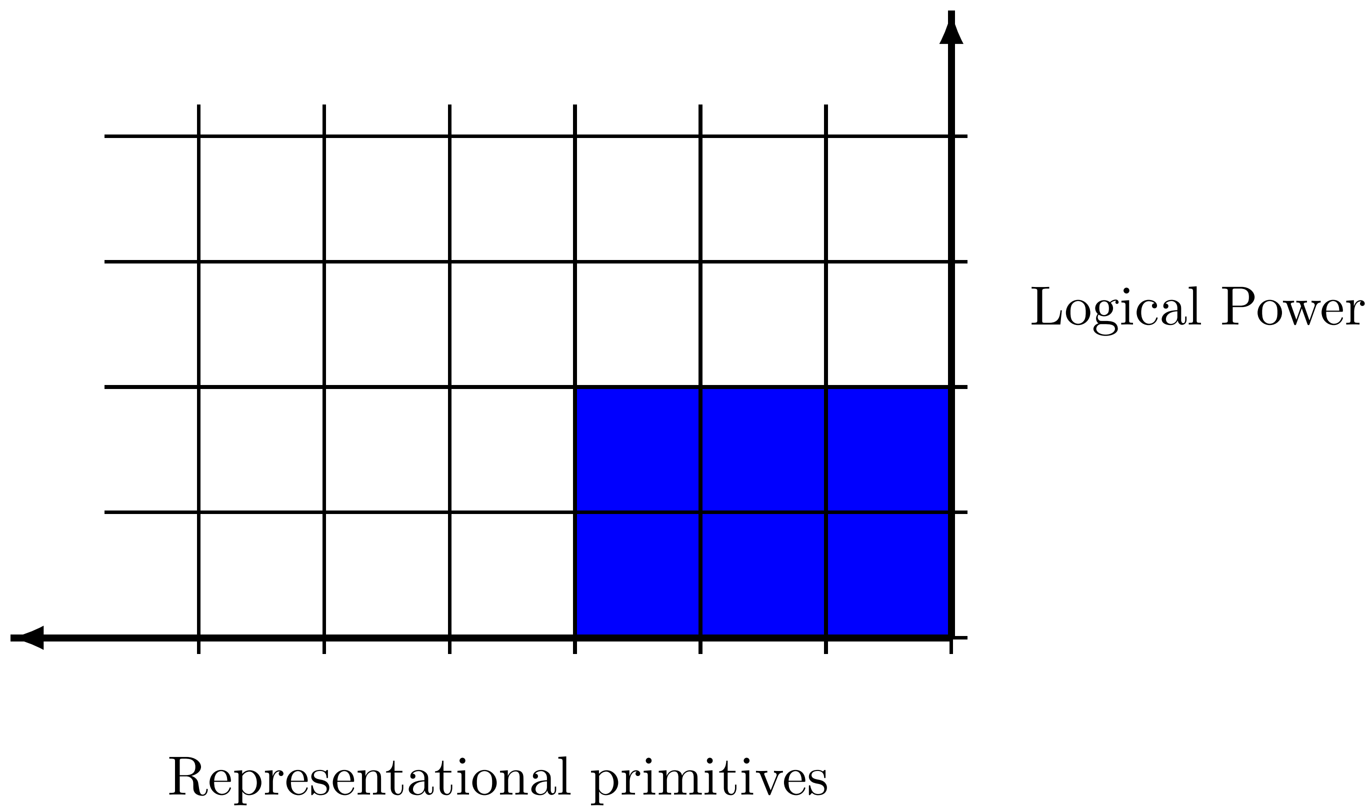
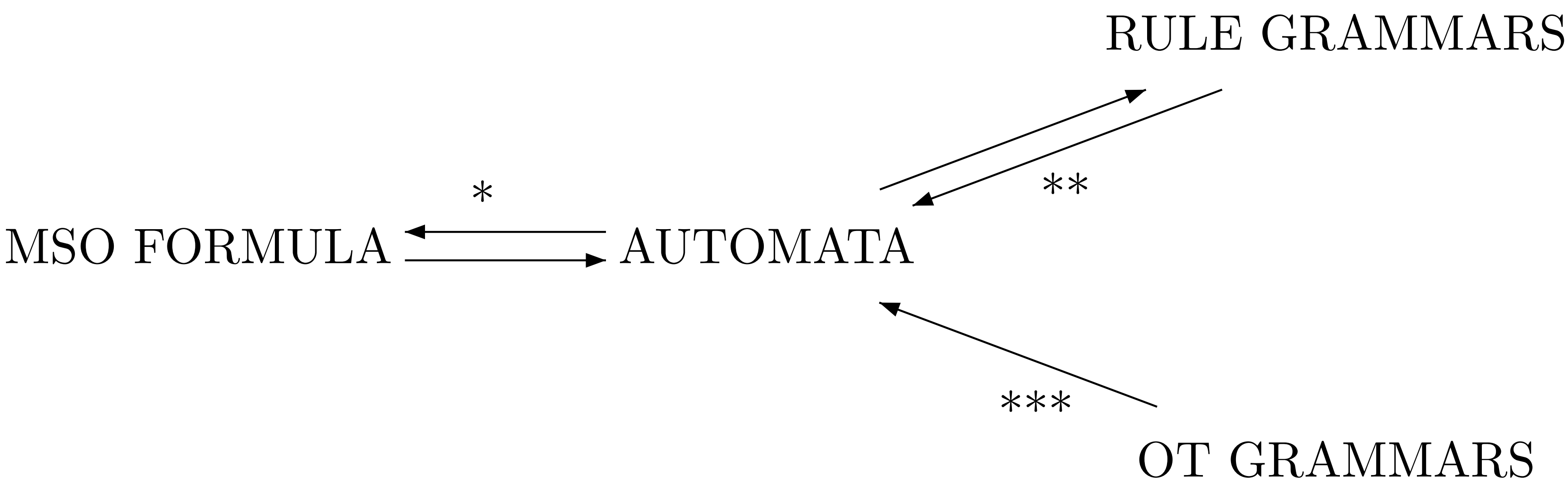


Why logical formula?

1. They are a high-level language.
   (a) They are very expressive.
   (b) They are precise.
   (c) They are easy to learn with only a little practice.
2. Linguists can use (and systematically explore) different representational primitives like features, syllables, etc (Potts and Pullum 2002, Graf 2010).
3. They can be translated **to and from** finite-state automata (Büchi 1960).

Finite-state automata are a low-level language

Automata can serve as a *lingua franca* because different grammars can be translated into them and then equivalence can be checked.



*Büchi 1960.

**Johnson 1972, Kaplan and Kay 1994, Beesley and Karttunen 2003.

***Under certain conditions (Frank and Satta 1998, Kartunnen 1998, Gerdemann and van Noord 2000, Riggle 2004, Gerdemann and Hulden 2012)

Doing Phonology

“A good descriptive generalization will foreshadow the analysis. An excellent descriptive generalization will make the analysis seem almost inevitable.”

(McCarthy 2003, p. 34)

Schane's Mirror Principle

- "If one believes that a process or change happens in a certain way, then the notation should not just describe that event but should *reflect* as closely as possible its manner of occurrence." [emphasis added]

- "Rule (ia) requires independent, unrelated features; (ib) does not."

$$(\text{i})\ \text{a. } C \rightarrow [+\text{sharp}] / \_\_ \begin{bmatrix} \text{V} \\ +\text{high} \\ -\text{back} \end{bmatrix} \quad \text{b. } C \rightarrow \begin{bmatrix} +\text{high} \\ -\text{back} \end{bmatrix} / \_\_ \begin{bmatrix} \text{V} \\ +\text{high} \\ -\text{back} \end{bmatrix}$$

- "For this particular example, the notation of generative phonology *mirrors* the nature of the process, and I believe it is fair to say that generative phonology has considered *mirroring* to be one of the goals of its notation." [emphasis added]

(Schane 1984, pp. 129-130)

Unrounded front vowels in Danish...

Danish Vowels (Lundskaer 2011)

Front		Back	
Unrounded	Rounded	Unrounded	Rounded
i	y		u
e	ø		o
ɛ	œ		å
æ		ɑ	ɔ

...lower adjacent to /r/.

Standard Rule-based Counterfeeding Analysis

Vowel	Height Features
i	[+high, −low, +tense]
e	[−high, −low, +tense]
ɛ	[−high, −low, −tense]
æ	[−high, +low]

1. $\varepsilon \rightarrow$ [+low]/______ r (ɛ → æ)
2. e $\rightarrow$ [−tense]/______ r (e → ɛ)
3. i $\rightarrow$ [−high]/______ r (i → e)

This analysis violates Schane's mirror principle.

Possible OT Analysis

Conjoined faithfulness

1. *ir >> ID(HIGH), *er >> ID(TENSE), *ɛr >> ID(LOW)
2. undominated ID(HIGH) && ID(LOW), ID(HIGH) && ID(TENSE)

Harmonic Serial Analysis

1. FAITH-UO (Hauser et al. 2014)

These analyses also violate Schane's mirror principle.

The curse of binary features

Certain generalizations are difficult to state in terms of binary features.

1. Movement along a scale.
2. Place assimilation.

Phonemic Oppositions (Trubetzkoy 1939)

Privative: Presence versus absence of property (like voicing, aspiration)

Gradual: Difference along a scale (like vowel height)

Equipollent: Neither of the above (like place)

Binary features are good for privative oppositions, maybe not so good for the others.

(Jakobsen, Clements, inter alia)

Height as a scale

Vowel	Features
i	1st degree of aperture
e	2nd degree of aperture
ɛ	3rd degree of aperture
æ	4th degree of aperture

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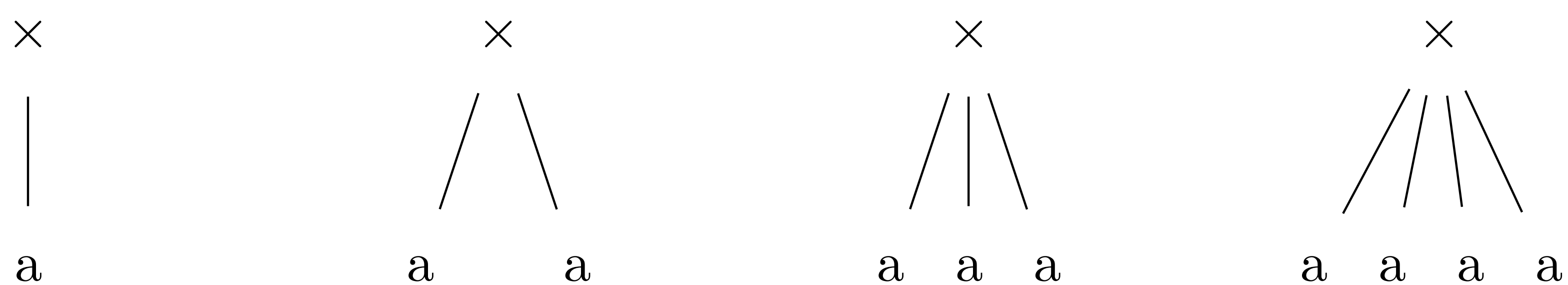
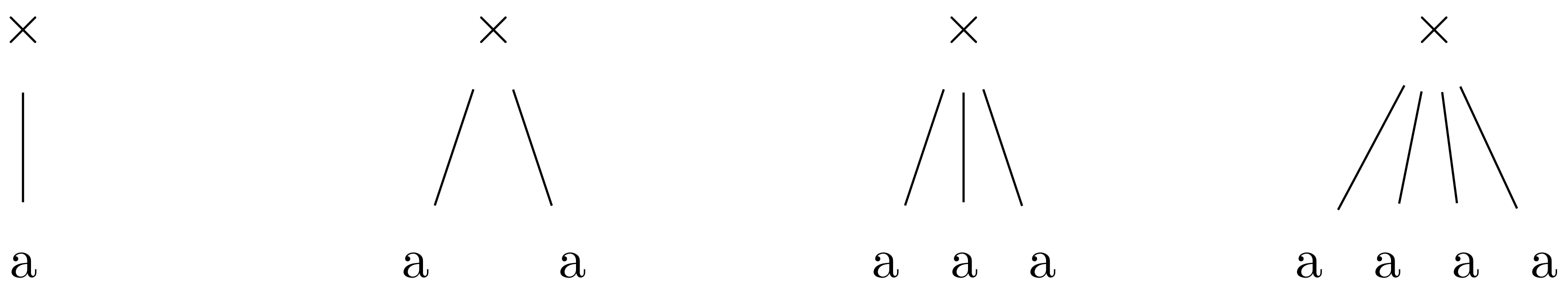
Schane's (1984) 'aperture particles'



Schane's (1984) 'aperture particles'



This representation makes the solution inevitable.

- Danish lowering is the addition of one aperture particle.

Formalizations

1. **Rule-based grammars**

   $$[+\text{front}, +\text{vocalic}, n \text{ aperture}] \longrightarrow [n+1 \text{ aperture}] \;/\; \underline{\quad}\, \text{r}$$

   But how is this rule interpreted?
   (Johnson 1972, Kaplan and Kay 1994, Chandlee 2014)

2. **Sketch of OT analysis**

   - Let [r] have one aperture particle.
   - Have a markedness constraint against it.
   - The most faithful solution is for this aperture particle to reassociate to an adjacent front vowel (if present).
     How are the constraints to be defined?
     (de Lacy 2011)

3. **Logical formulae** (next slides)

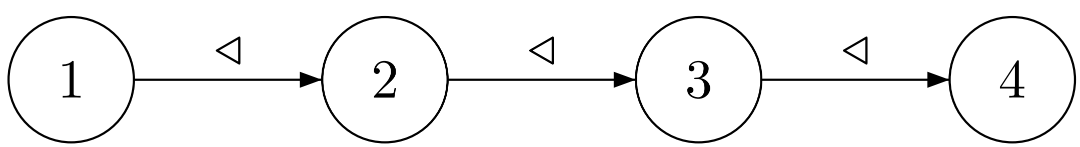
Transductions over relational structures

1. Relational structures contain a domain and a set of relational primitives $\langle \mathcal{D}, \mathcal{R}_1, \mathcal{R}_2, \ldots \mathcal{R}_n \rangle$.
2. Relational structures have been used to model strings, trees, and graphs.
3. Transductions over them can be defined with MSO logic (Engelfriedt and Courcelle 2011).

Represenational primitives

1. Words are sequences of timing nodes, which we enumerate for convenience.

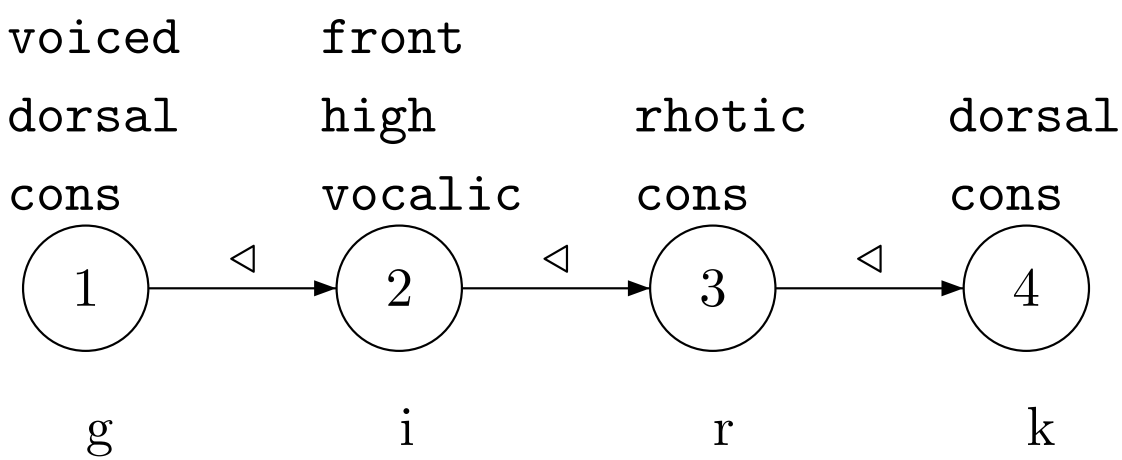
2. The '$\triangleleft$' indicates the successor relation. So $1 \triangleleft 2$ is `true` but $1 \triangleleft 4$ is `false`.



Represenational primitives

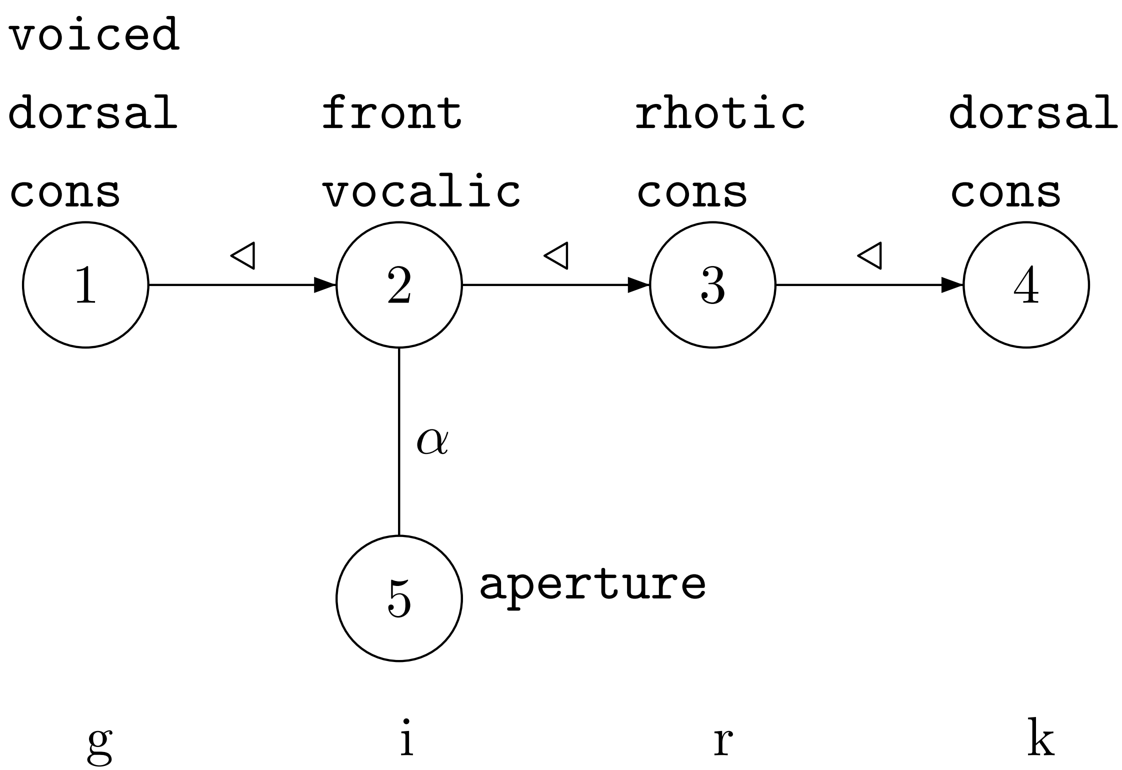
1. The 'binary feature bundle' representation can be modeled with each feature as unary predicates (so sets of nodes).

2. Negation can be used to refer to absence of a property. So we have `voiced`(1)=`true` and ¬`voiced`(4)=`true`.



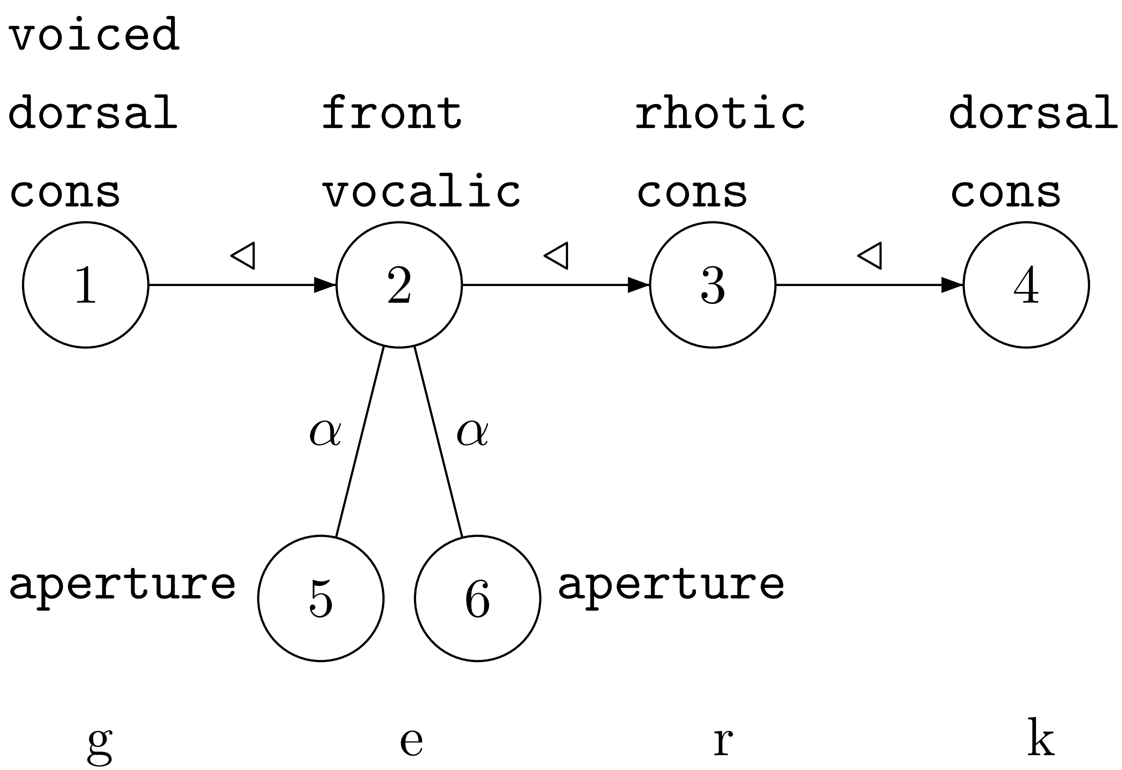
Represenational primitives

- The same word with aperture particles.



Represenational primitives

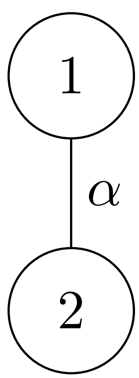
- The word *gerk* with aperture particles.

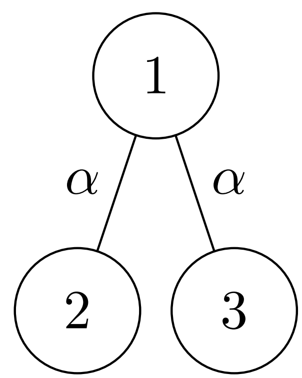


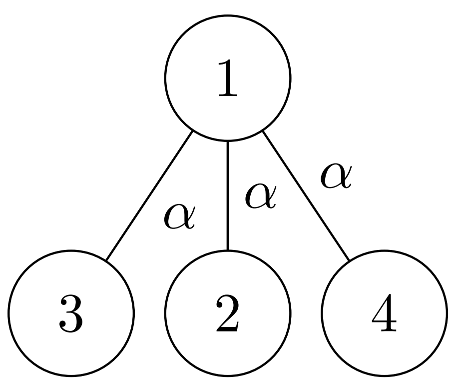
Danish front vowels

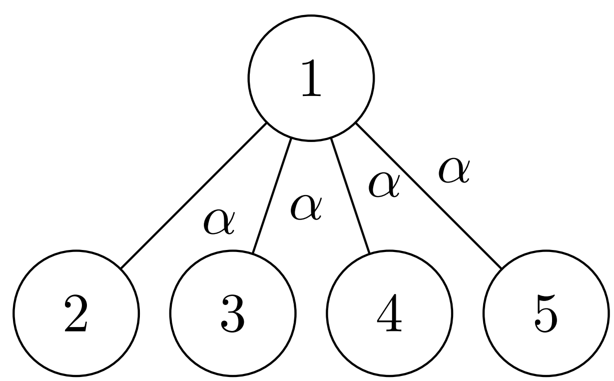
For all relational structures shown here,

- node 1 satisfies these predicates: `vocalic`, `front`
- nodes 2 through 5 satisfy this predicate: `aperture`



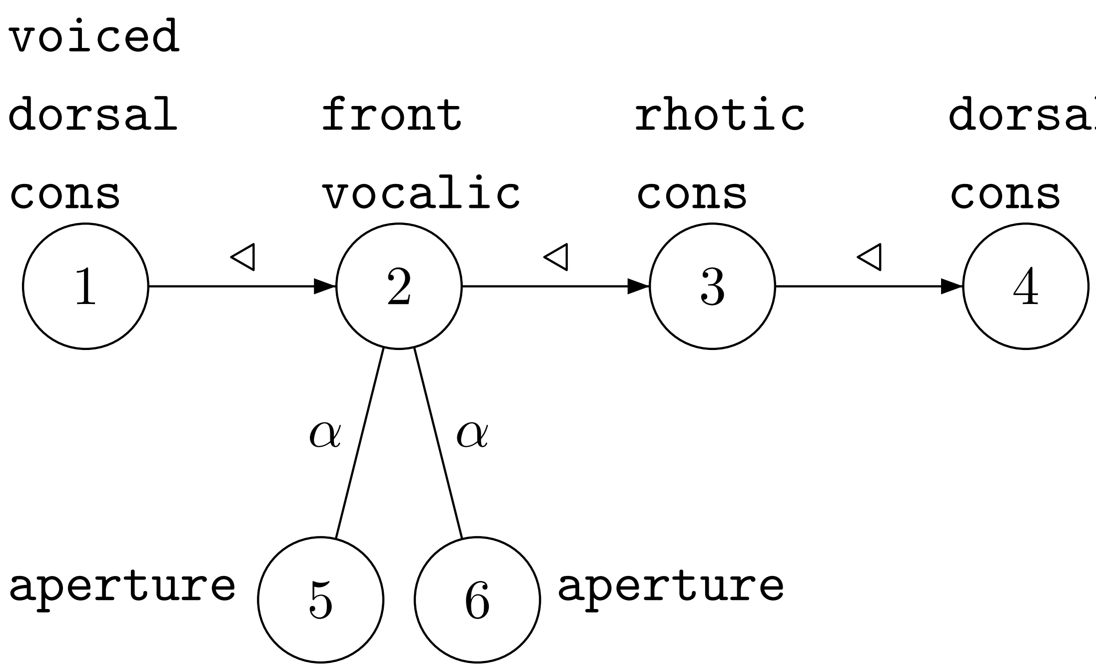




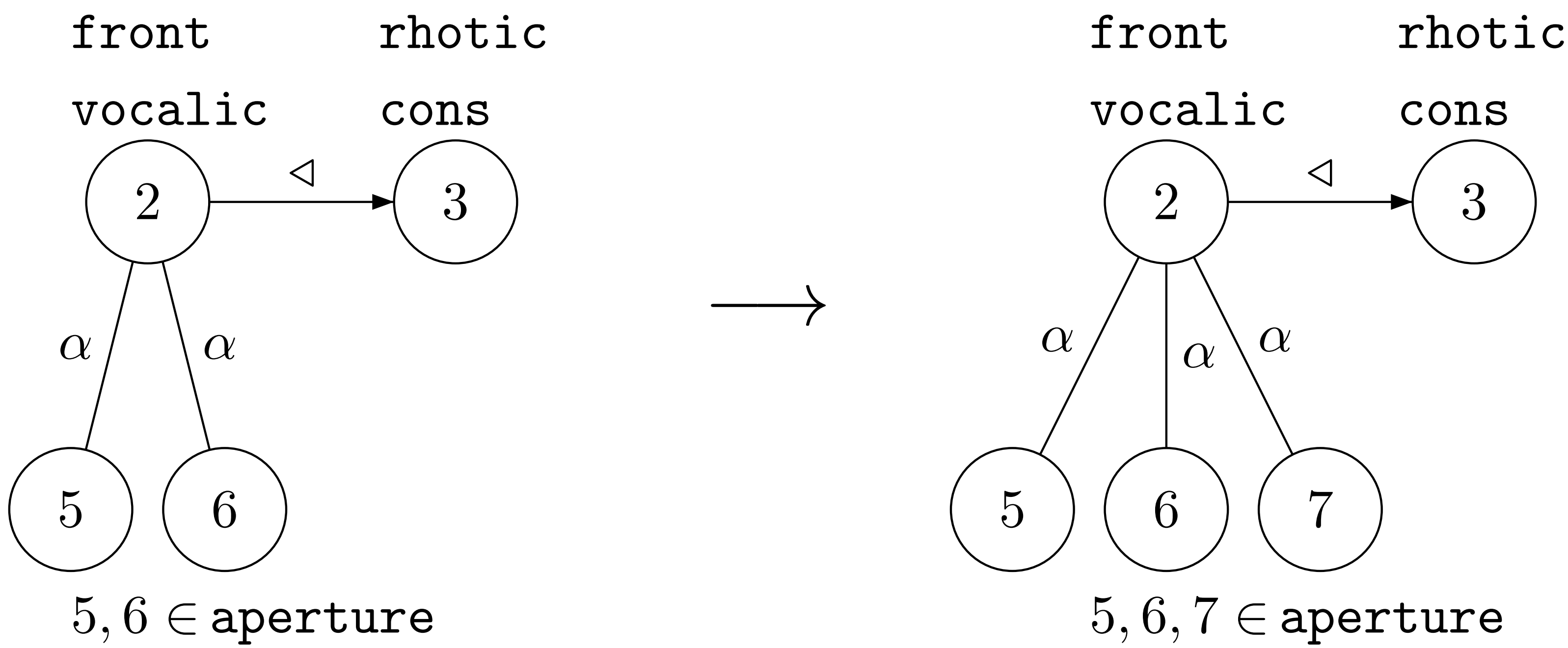


Concatenation (Jardine and Heinz 2015, MoL)

- These (complex) structures become ‘primitive units’ that can be concatenated using a graph-theoretic notion of concatenation.
- This allows the formation of word structures like *gerk* which keep properties of both graphs and strings.



Specifying the transformation

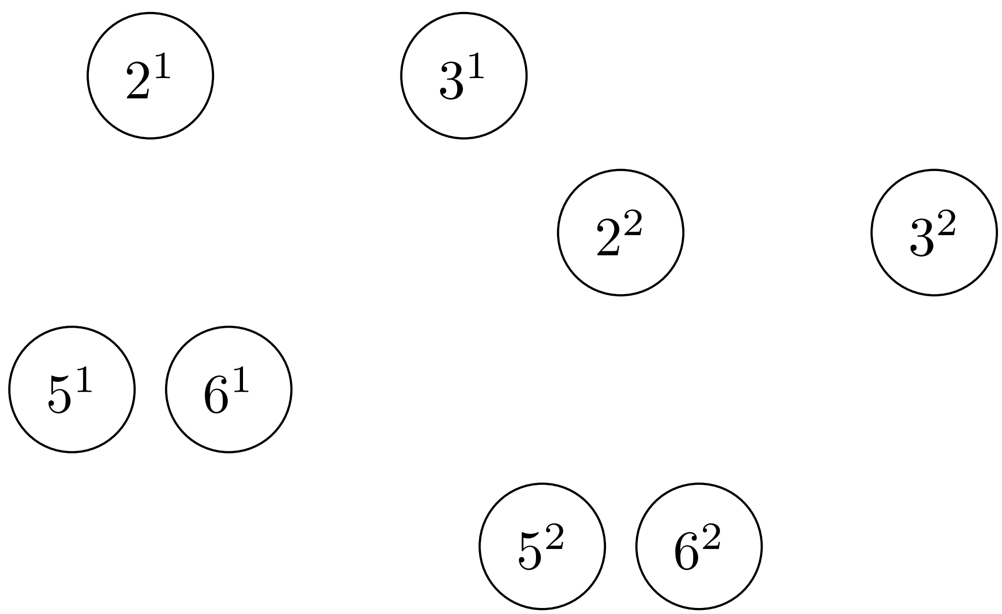


(er → ɛr)

(Courcelle and Engelfriedt 2001, 2011)

Ingredient #1: The Copy Set

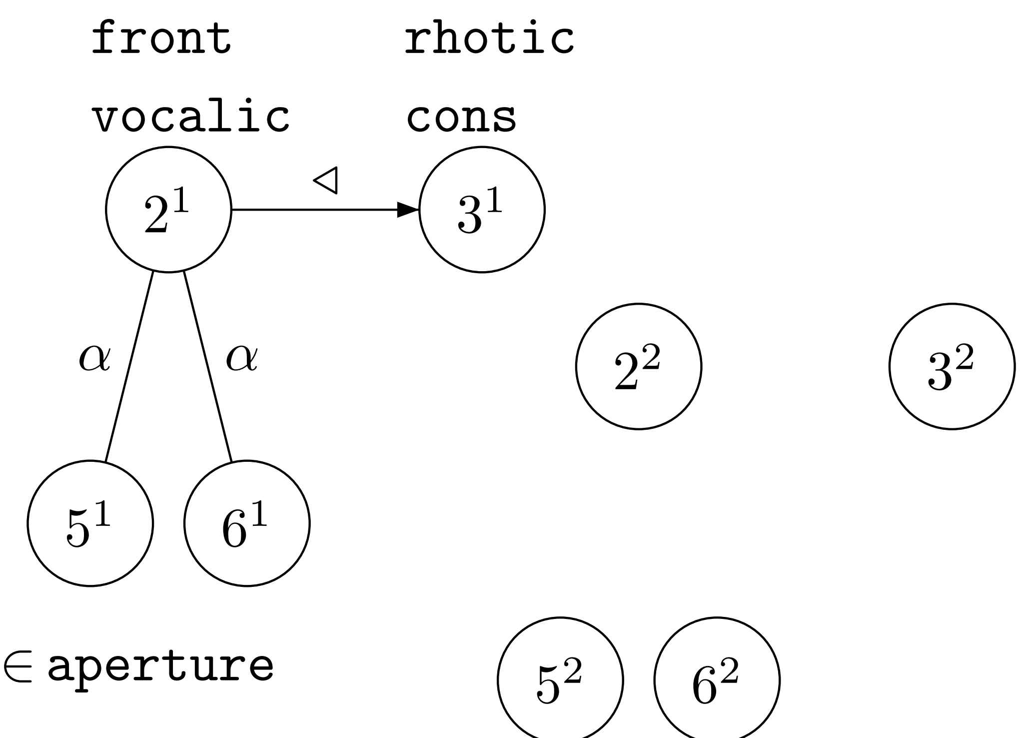
- The copyset specifies how many times larger the output structure can be than the input structure.
- Here the output graph will be larger than the input but graph never two times larger.
- So the copy set $C = \{1, 2\}$.



Ingredient #2: Faithfulness

- Formulae specify which nodes stand in which relations.

$$\varphi^1_{\texttt{vocalic}}(x) \stackrel{\text{def}}{=} \texttt{vocalic}(x) \qquad \varphi^1_{\texttt{aperture}}(x) \stackrel{\text{def}}{=} \texttt{aperture}(x)$$
$$\varphi^1_{\texttt{front}}(x) \stackrel{\text{def}}{=} \texttt{front}(x) \qquad \varphi^{1,1}_{\lhd}(x,y) \stackrel{\text{def}}{=} x \lhd y$$
$$\varphi^1_{\texttt{rhotic}}(x) \stackrel{\text{def}}{=} \texttt{rhotic}(x) \qquad \varphi^{1,1}_{\alpha}(x,y) \stackrel{\text{def}}{=} x\,\alpha\,y$$

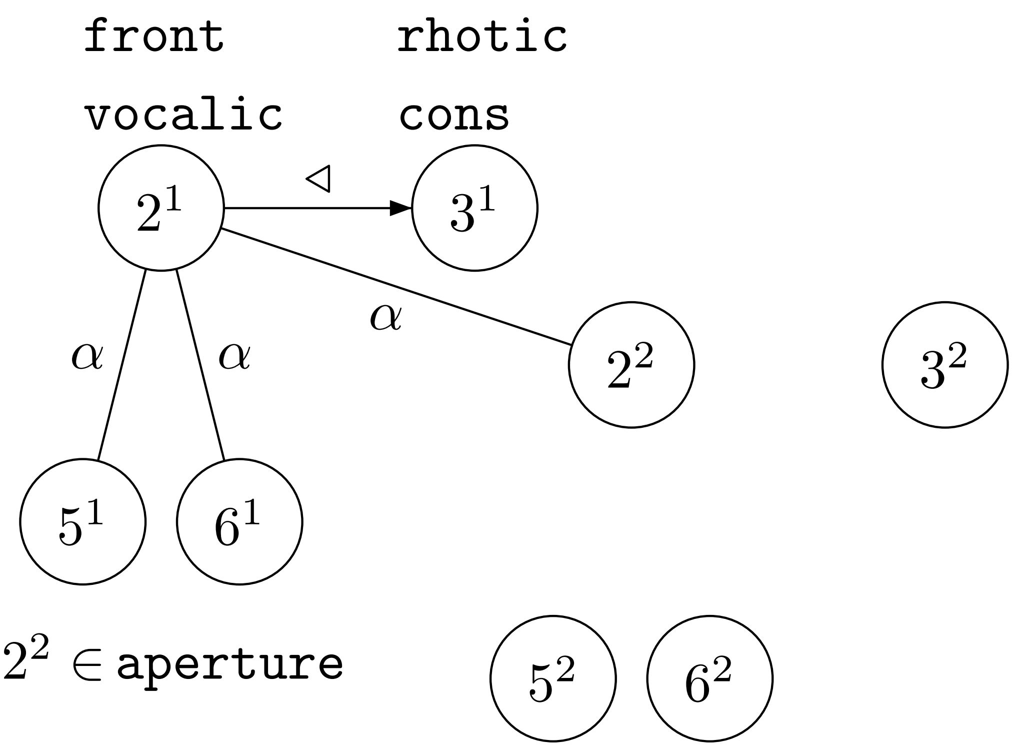


$5^1, 6^1 \in \texttt{aperture}$

Ingredient #3: The change

- Formulae specify which nodes stand in which relations.

$$\varphi^2_{\texttt{aperture}}(x) \overset{\text{def}}{=} \texttt{vocalic}(x) \wedge \texttt{front}(x) \wedge \exists y[\texttt{rhotic}(y) \wedge x \triangleleft y)]$$
$$\varphi^{1,2}_{\alpha}(x,y) \overset{\text{def}}{=} (x = y) \wedge \varphi^2_{\texttt{aperture}}(x)$$

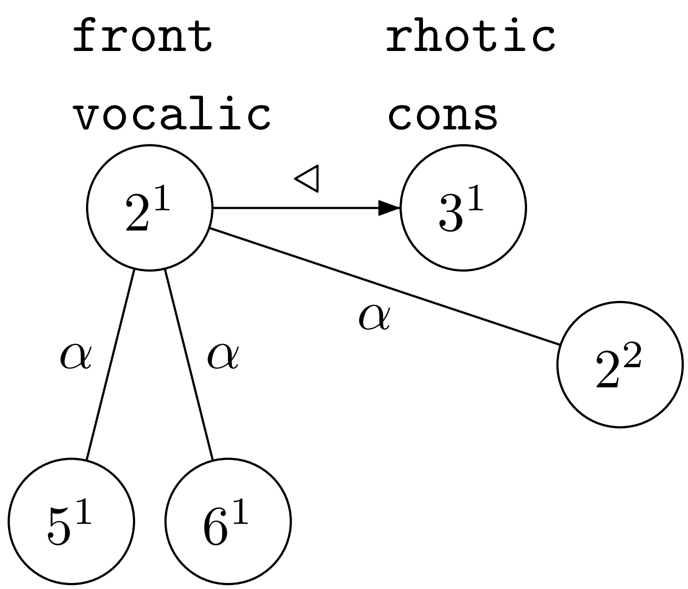


$5^1, 6^1, 2^2 \in \texttt{aperture}$

Ingredient #4: Clean up

- Formulae specify which nodes stand in which relations.

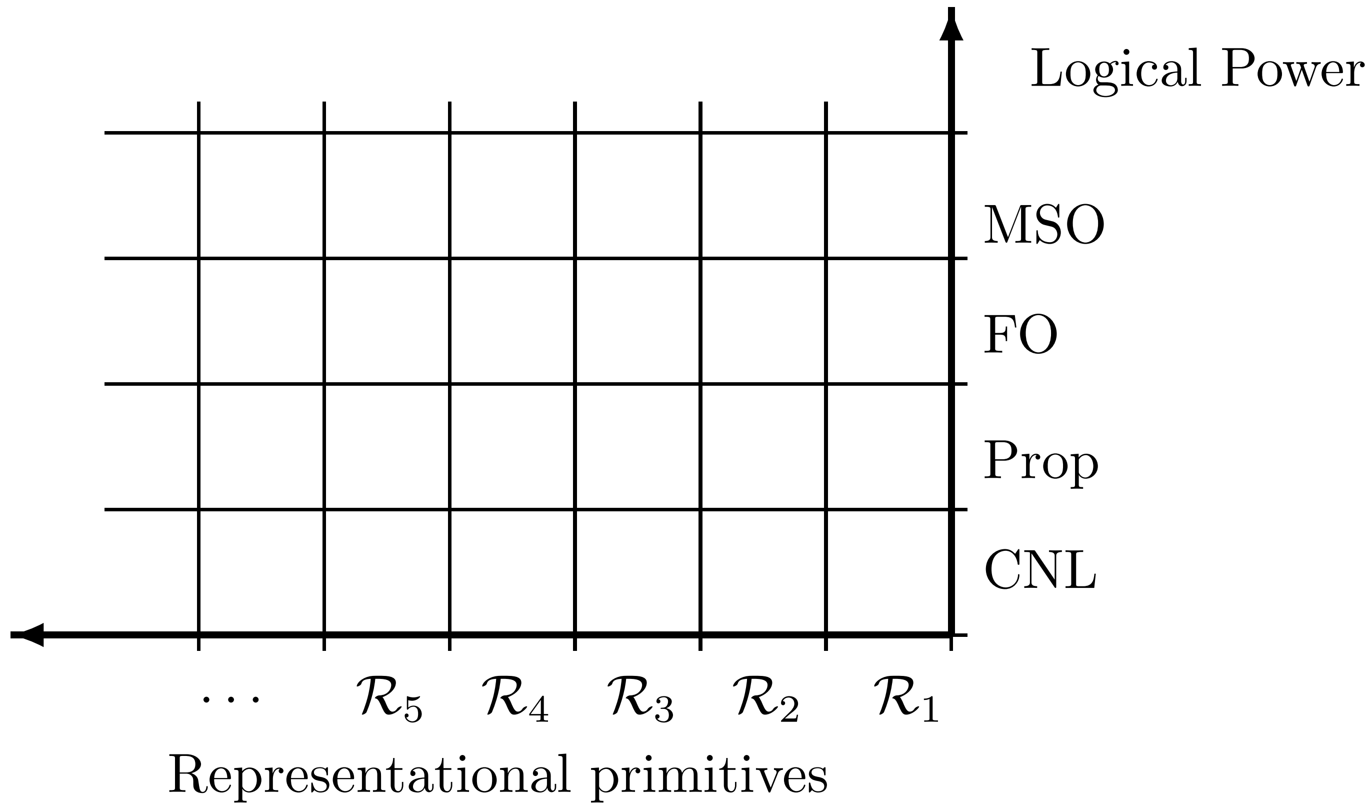
$$\varphi^{2,2}_{\triangleleft}(x,y) \overset{\text{def}}{=} \varphi^{2,2}_{\alpha}(x,y) \overset{\text{def}}{=}$$
$$\varphi^{2,2}_{\triangleleft}(x,y) \overset{\text{def}}{=} \varphi^{2}_{\texttt{vocalic}}(x) \overset{\text{def}}{=} \varphi^{2}_{\texttt{rhotic}}(x) \overset{\text{def}}{=} \texttt{false}$$



$5^1, 6^1, 2^2 \in \texttt{aperture}$

Future work: Comparing analyses

Logic and relational structures lets us compare binary features to alternatives in a single analytical framework.



Conclusion

1. Different representational schemes and different levels of logical power can be studied within a single analytical framework to determine the computational nature of phonological patterns.

2. This was illustrated here by reviving Schane's 1984 idea that generalizations involving gradual oppositions are better *reflected* if degree of aperture is represented directly.

3. Some putative cases of opacity may not be if certain representations are adopted (Recall Pater 1999 and Tesar 2014).

4. Future work can seek to place Schane's mirror principle on a firm computational ground.

Acknowledgments

Thanks to Jim Rogers, Rémi Eyraud, Bill Idsardi, and the members of the Spring 2015 computational phonology seminar.

Maranungku places primary stress on the first syllable and secondary stress on subsequent alternating syllables (Halle and Verganud 1987).

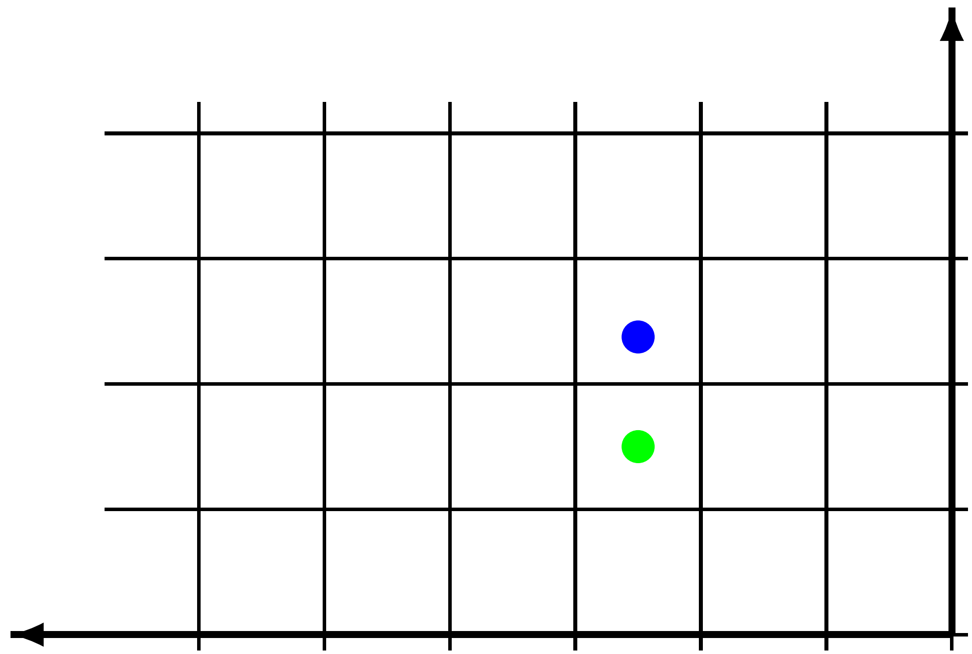
$$\acute{\sigma}\sigma \quad \acute{\sigma}\sigma\grave{\sigma} \quad \acute{\sigma}\sigma\grave{\sigma}\sigma \quad \acute{\sigma}\sigma\grave{\sigma}\sigma\grave{\sigma} \quad \acute{\sigma}\sigma\grave{\sigma}\sigma\grave{\sigma}\sigma \quad \acute{\sigma}\sigma\grave{\sigma}\sigma\grave{\sigma}\sigma\grave{\sigma}$$

$$\begin{aligned}
\texttt{first}(x) &\stackrel{\text{def}}{=} \neg(\exists y)[y \succ x] \\
\texttt{stress}(x) &\stackrel{\text{def}}{=} \acute{\sigma}(x) \vee \grave{\sigma}(x) \\
\rtimes\acute{\sigma} &\stackrel{\text{def}}{=} (\exists x)[\texttt{first}(x) \wedge \acute{\sigma}(x)] \\
\texttt{x}\acute{\sigma} &\stackrel{\text{def}}{=} (\exists x)[\acute{\sigma}(x) \wedge \neg\texttt{first}(x)] \\
\texttt{lapse} &\stackrel{\text{def}}{=} (\exists x, y)[x \succ y \wedge \sigma(x) \wedge \sigma(y)] \\
\texttt{clash} &\stackrel{\text{def}}{=} (\exists x, y)[x \succ y \wedge \texttt{stress}(x) \wedge \texttt{stress}(y)]
\end{aligned}$$

$$\texttt{Maranungku} \stackrel{\text{def}}{=} \rtimes\acute{\sigma} \wedge \neg\texttt{x}\acute{\sigma} \wedge \neg\texttt{lapse} \wedge \neg\texttt{clash}$$

Channeling Humboldt

This factorization provides an ontology of types—*an encyclopedia of categories*— with which phonological phenomenon—*the encyclopedia of types*—can be identified.



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