Energy and Phonology

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How do contrastive units combine into segments?

- Why is this important? E.g. The notion of natural class of segments is based on some answer to it.
- Contrastive units combine in two ways to form a segment:
  1. Sequentially, where contrastive units have linearity of order. So we need a technology to describe e.g. pre-nasalized vs. post-nasalized stops.
  2. Simultaneously, where several contrastive units occupy the same duration of time. So we need a technology to describe e.g. voiced fricatives, nasalized vowels.
- This talk will be about 2 only, but 1 and 2 necessarily interact.
- Argument to be presented: The logic of simultaneous contrastive units is the logic of aerodynamic energy transmission in the vocal tract.
- The presentation is *not* about the phonetic implementation of a cognitive phonological representational logic. Rather the argument is that energy transmission has a logical structure, and that the cognitive phonological representational logic of contrastive units into a segment is nothing but that energy-based logic.

Sonority Scale

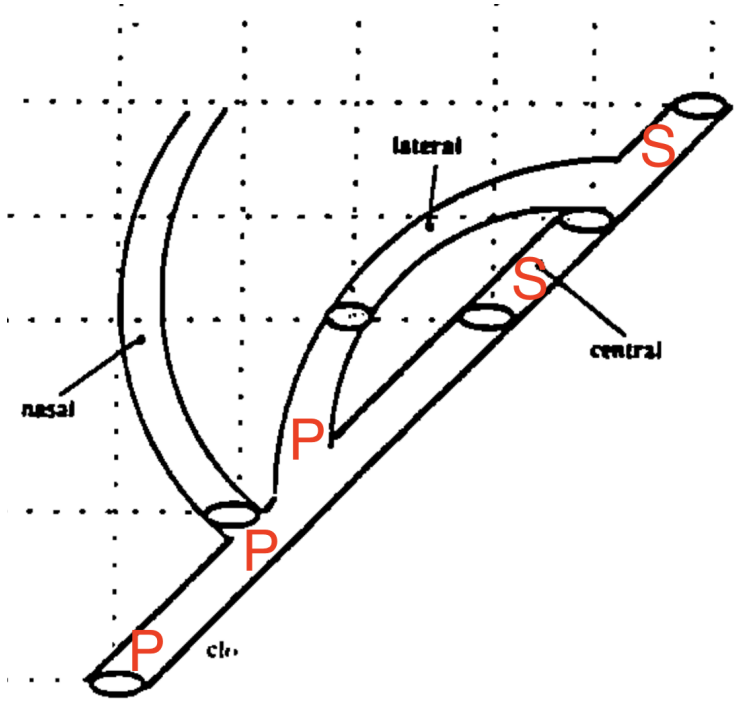
- The question *How do contrastive units combine into segments?* will be pursued here through the well-studied concept of a *sonority scale*.
- Vowels > Nasals > Laterals > Glides > Fricatives > Voiced Stops > Voiceless Stops
- Why is the scale ordered in this way? Usual Answers:
  - A universal fact of phonology implemented in a harmonic scale of constraints
  - Acoustic scale of Energy
- I do not consider these as competing hypotheses. There is a combinatoric energetic logic whose end result is an acoustic scale, and that combinatoric logic could be given as a universal scale of constraints.

Aerodynamic Energy Transmission: Series and Parallel Circuits

- Fluids can flow in a confined region such as a tube.
- The smaller the diameter of the tube, the less flow (Daniel Bernoulli).
- When tubes are arranged in a network of narrow and wide tubes, there is a complex flow, but it is completely predictable from the laws of conservation of energy (and entropy) flow.
- If two tubes are arranged one after the other, in series, the overall flow is that of the narrower one, since that's the bottleneck.
- If one tube feeds into two parallel tubes, the overall flow is that of the wider one, since the flow will bypass the bottleneck by passing through the wider tube.
- TO ADD: MOVIE SHOWING PARALLEL AND SERIES TUBE FLOWS

Browman and Goldstein (1989) Tube Geometry

The vocal tract is an aerodynamic flow network of tubes connected in series and parallel. Constrictions in particular Locations (Contrastive Places) and of particular Degrees (Contrastive Places) channel the flow in a complex fashion. predictable from conservation laws. These laws sanction the *hierarchical* simplification of complex tubes into simpler tubes, using series/parallel rules.



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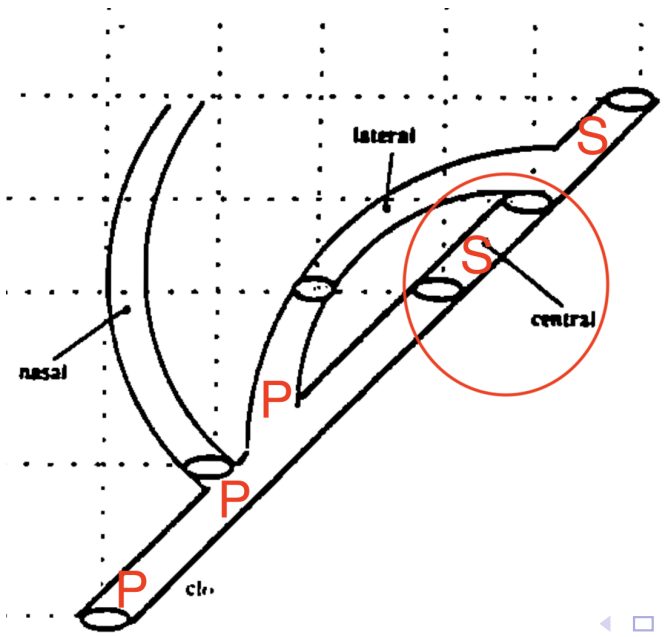

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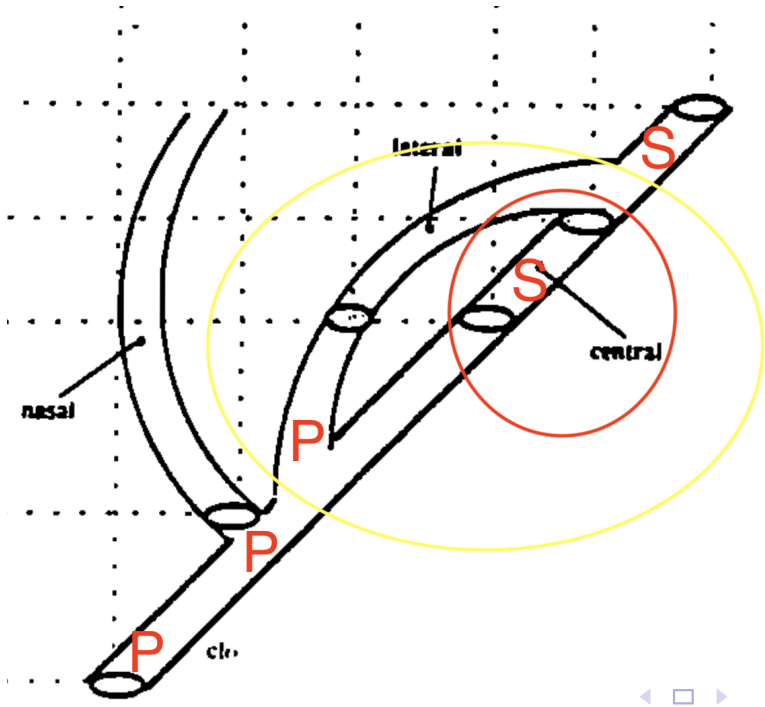

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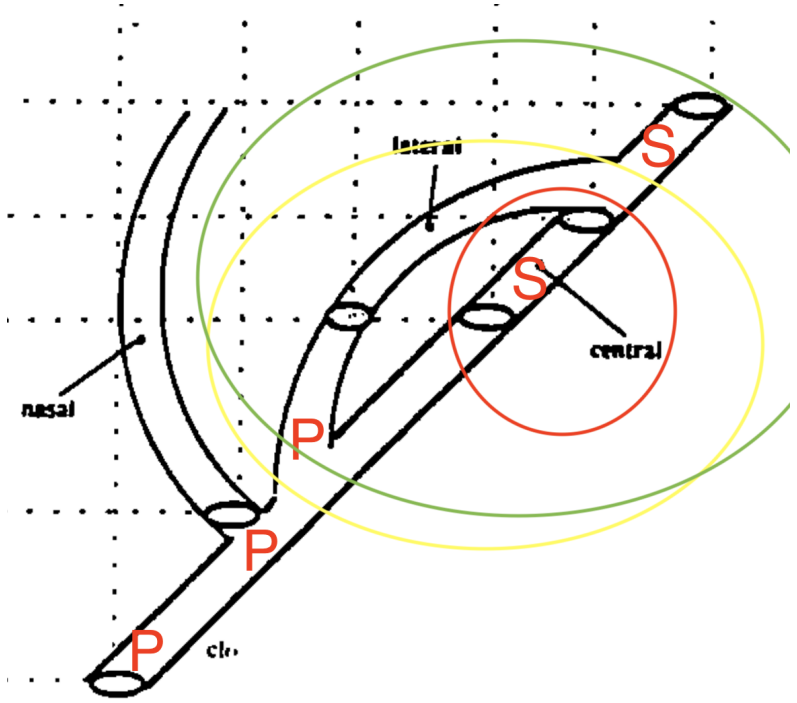

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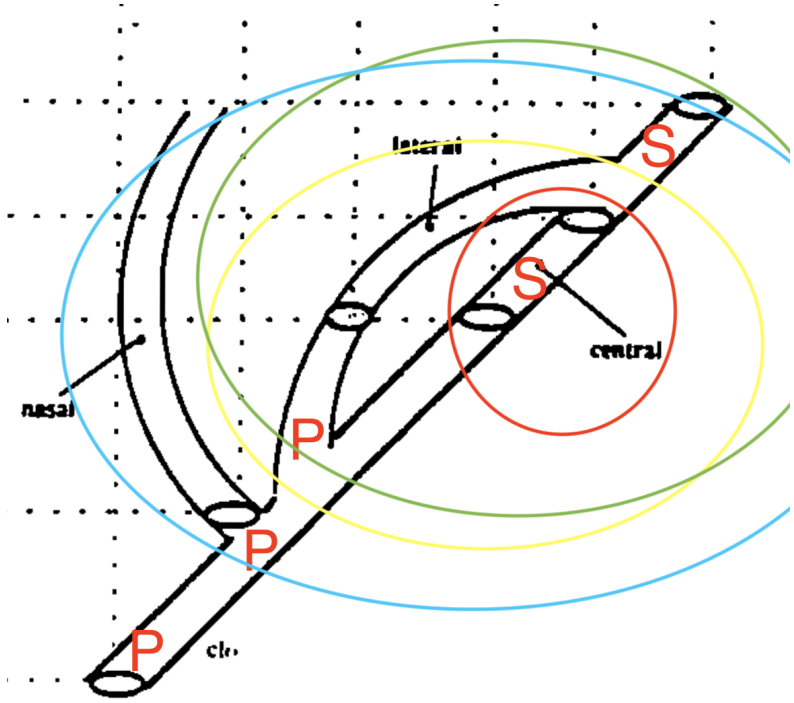

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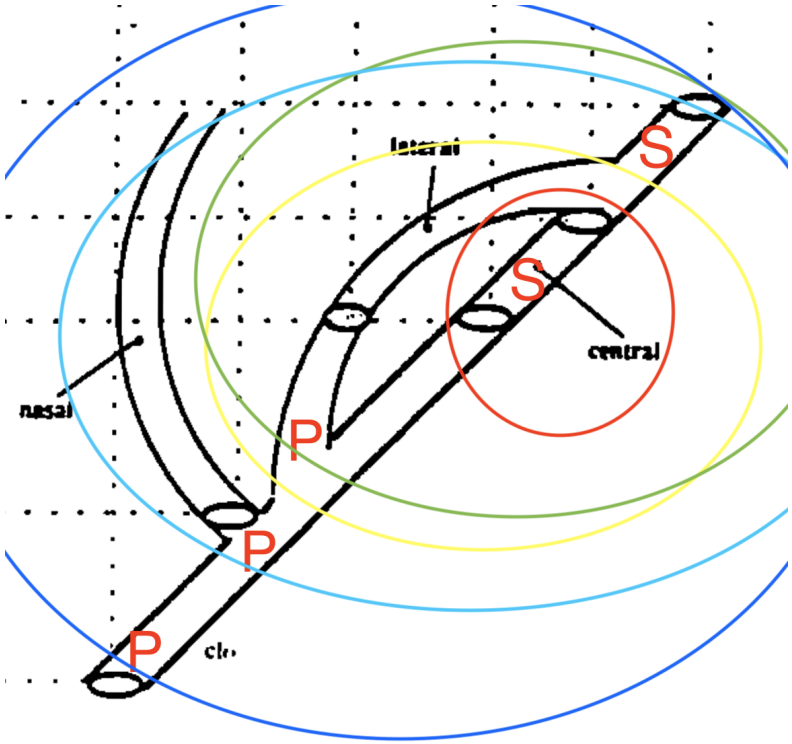


Browman and Goldstein (1989) Tube Geometry

Browman and Goldstein (1989) defined segmental natural classes based on the level at which different segments are alike, allowing them to belong to the same natural class.

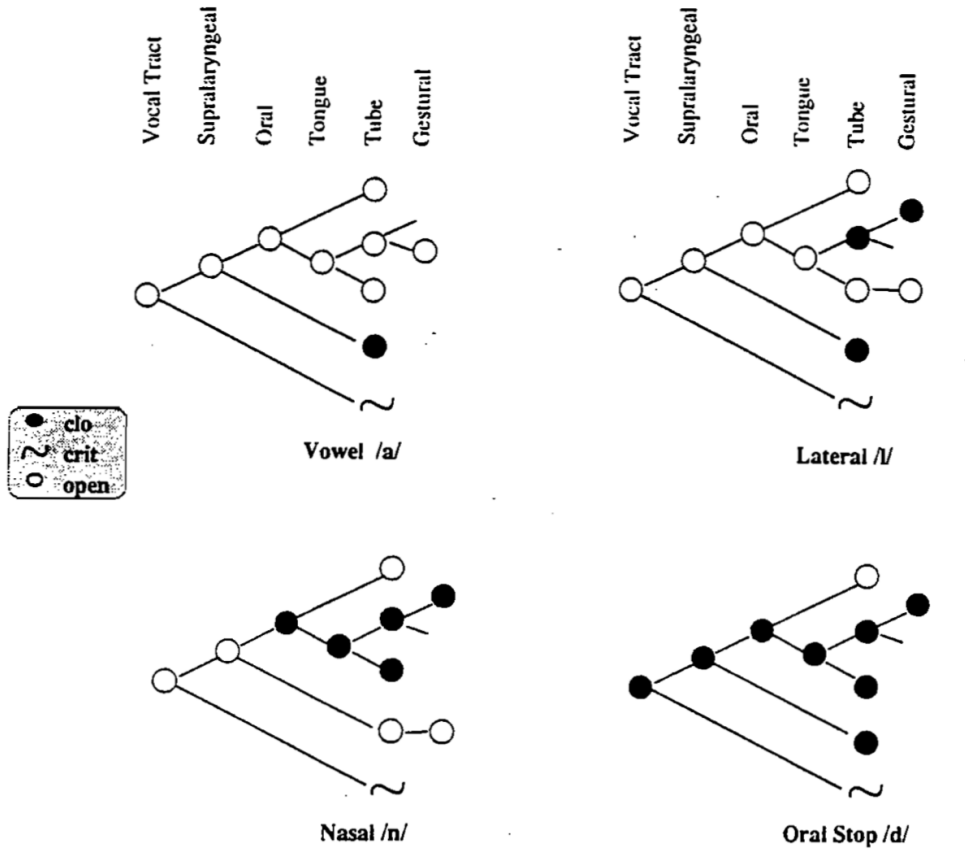
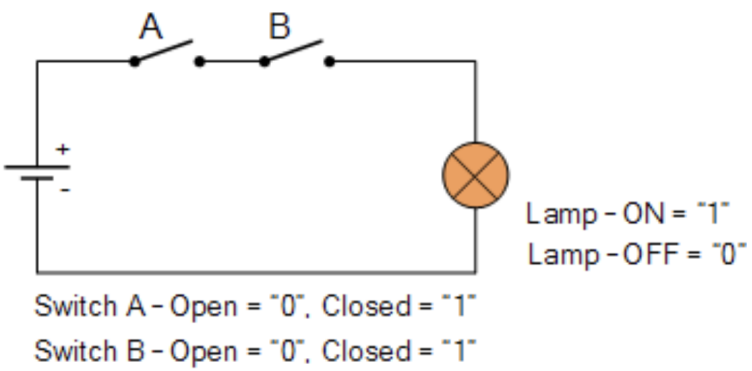
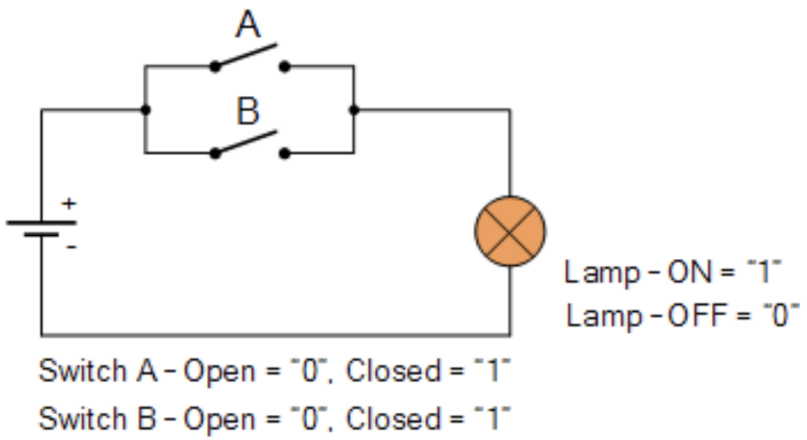


Figure 14
CD hierarchies for vowel, lateral, nasal and oral stop.

Logical Structure of Energy Transmission

- Boole, C.S. Peirce, and Shannon realized that Series/Parallel energy conservation rules (consequences of Kirchhoff's topological laws) are equivalent to a propositional logic.
- Series Connection of tubes p and q $\longrightarrow$ to p AND q.
- Parallel Connection of tubes p and q $\longrightarrow$ to p OR q.
- High Flow through a wide tube corresponds to 1.
- Low Flow through a narrow tube corresponds to 0.





https://www.electronics-tutorials.ws/boolean/bool_1.html

The Sonority Scale is the result of the Logical Structure of Energy Transmission

Seg	VT = Lr OR Sup	Lr	Sup = Ns OR Or	Ns	Or
t		0		0	0
d		1		0	0
n		1		1	0
a		1		0	1

So at the Oral Level, /a/ has higher energy than /t/, /d/, /n/.

The Sonority Scale is the result of the Logical Structure of Energy Transmission

Seg	VT = Lr OR Sup	Lr	Sup = Ns OR Or	Ns	Or
t		0	0	0	0
d		1	0	0	0
n		1	1	1	0
a		1	1	0	1

At the Supralaryngeal Level, /n/ has higher energy than /t/ and /d/.

The Sonority Scale is the result of the Logical Structure of Energy Transmission

Seg	VT = Lr OR Sup	Lr	Sup = Ns OR Or	Ns	Or
t	0	0	0	0	0
d	1	1	0	0	0
n	1	1	1	1	0
a	1	1	1	0	1

At the Vocal Tract Level, /d/ has higher energy than /t/.

The Sonority Scale is the result of the Logical Structure of Energy Transmission

Seg	VT = Lr OR Sup	Lr	Sup = Ns OR Or	Ns	Or
t	0	0	0	0	0
d	1	1	0	0	0
n	1	1	1	1	0
a	1	1	1	0	1

The Sonority Scale, which is fundamental to syllabification and phonotactics, crucial parts of phonology, has a logical structure due to energy flow.

Some comments

- It may seem that what has been proposed is a standalone theory having little to do with the current theory of computation, OT.
- In fact, the physical conservation principles inherent in Series/Parallel logic is equivalent to an optimizational version discovered in the 19th century named the Dirichlet Principle.
- According to this Principle, the observed complex flows in a network are ones that minimize a scalar function (the square of the Gradient of the Flow).
- Therefore it is possible to construct a harmony function that is the negative of this function, and incorporate this logical theory of representation into the usual computational infrastructure offered by OT ☺
- Well-known cross-linguistic differences in the phonological interpretation of sonority in languages like Amazigh vs. Spanish, let's say, are still treatable within how syllabification constraints are ranked.