Various hypotheses have been formulated regarding the factors molding segment inventories, among which enhancement of distinctive features (Stevens et al., 1986) and feature or contrast hierarchy (Stevens, 1989).

The factor upon which we will elaborate is feature economy (de Groot, 1931; Martinet, 1955). Clements (2003) suggested that the tendency toward a maximal feature combination can be found in the world's inventories. He thus proposed a formula for quantifying feature economy:

$$E = S/F \tag{1}$$

where E the economy index, S the number of sounds found in a given system and F the number of features used by the system to distinguish its sounds.

Hall (2007) reviewed Clements's concept of economy and broke it down into two new concepts: feature exploitation and frugality. The feature exploitation index corresponds to the extent to which a system approaches 'the ideal of getting as many segments as possible out of its features' (p.176) and is equal to $\frac{S}{2^F}$, with 2^F standing for the maximal combinations of F features. The feature frugality index, on the other hand, focuses on the extent to which the inventory approaches 'the ideal of using no more features than mathematically necessary to specify its segments' (p.176) and is equal to $\frac{log_2 S}{F}$. After calculating the three indices for the Hawaian, French and Nepali consonant systems, he suggested that frugality is the closest to E.

Mackie and Mielke (2007) indicated that E is sensitive to inventory size and favors larger inventories inasmuch as 'the value of E will increase because the chance of sharing features increases'. By estimating values for the three indices for 499 natural language inventories analyzed with Chomsky and Halle's (1968) feature system and comparing them to randomly generated systems, they concluded that 'Feature Economy *is* a property of natural languages' and agreed with Hall that frugality is closer to E than exploitation is. Contrary to E, frugality and exploitation seem to favor smaller inventories.

Albeit the intuitiveness of the three aforementioned concepts of economy, their estimation is based on false assumptions on the phonetic plausibility of certain featural combinations, leading to the overestimation of the number of possible associations and the penalization of those systems implementing less prolific features ([±anterior], [±anterior], [±lateral], [±sonorant]).

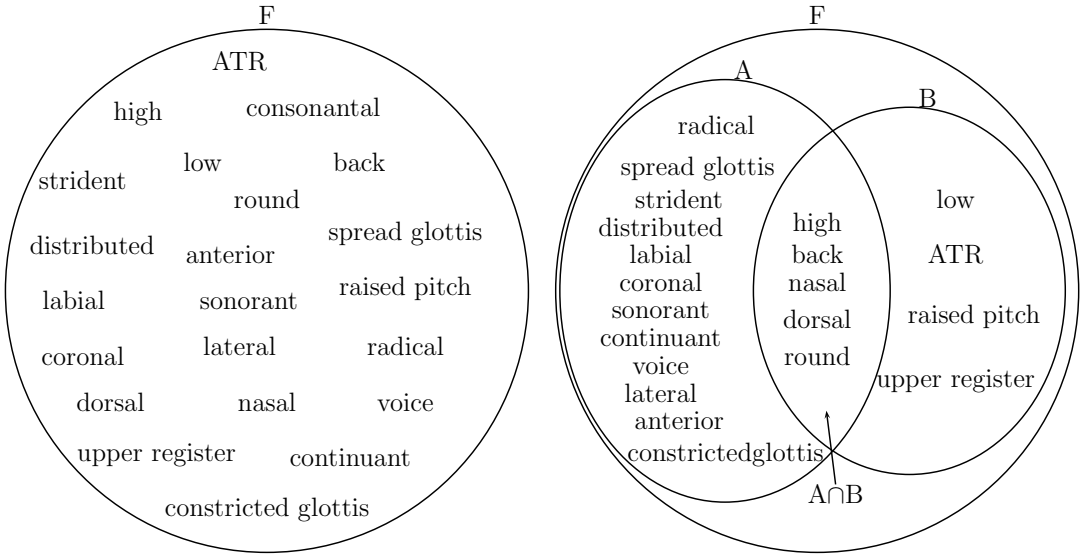
In order to remedy this problem, we have broken down features (Flynn, 2006) into sets and have attempted to identify most of the 'illegal' feature combinations. Three subsets were proposed: oral and guttural place of articulation, and manner of articulation.

Let set F contain all features (Figure 1(a)), with $|F| = 22$. By using [±consonantal], we then break down F into subsets (Figure 1(b)), one for [-consonantal] and one for [+consonantal] features. This results in sets A and B, for consonantal and vowel features respectively. $A \cap B$ contains features common to consonants and vowels.

We will use Modern Greek (Setatos, 1974) as example to showcase our methodology on account of its relative richness in contrasts and our familiarity with it. After conducting a featural analysis using all [+consonantal] features (Figure 1(b)), we construct a new subset of A, A' (not to be confused with the complement of A), that contains only those [+consonantal] features necessary for contrasting the consonants.

As it was explained earlier, not all feature combinations are possible. [±anterior] for example, is a specification of [+coronal] sounds and cannot be combined with [-coronal]. This reduces 2^F by 192 choices. All [+nasal] segments are by default [+sonorant], which reduces the maximal feature combinations even further. In order to estimate these 're-

Figure 1: Distinctive features within the Articulator Theory: (a) all features presented within a superset F; (b) subsets of F: A for [+consonantal], B for [-consonantal] and $A \cap B$ for features common to consonants and vowels.



ductions' and approach the most realistic value for maximal combinations, we have to group the nine features in order to facilitate the mapping of all possibilities.

Figure 2 does certainly not present all associations. Such a graph would be somewhat difficult to read. An aspect that is not presented here is the combination of [+labial +coronal] and [+labial +coronal +anterior] segments, which are produced with a double articulation — /p͡t/, /p͡ts/, /p͡ʧ/, among others. This omission is motivated by the rarity of this class of segments. Nonetheless, a comprehensive algorithm should include them in the estimation procedure.

The formula for estimating feature exploitation does not allow us to correct the 2^F component, so a new formula must be introduced:

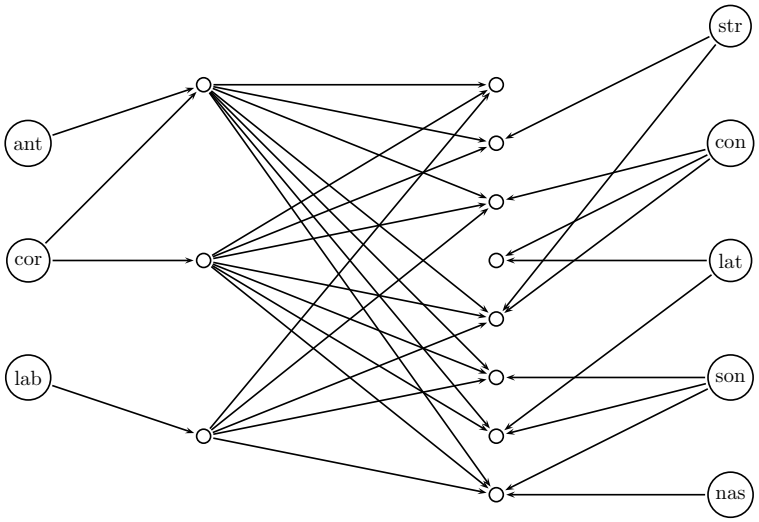
$$E = \frac{P}{|S_F|} \tag{2}$$

where E the economy index, P the number of phonemes in the system and $|S_F|$ the simplex of the implemented F features, after the 'illegal' lattices have been eliminated. F refers to — in this paper — to the A' subset.

By applying formula 2 on the inventory of Greek, we get $E = 19/38 = 0.5$, which is far from the values that the other three formulae yield.

The implications of feature economy estimation for cognitive modeling are multiple. A simulation using agents and based on features, instead of acoustic properties, would potentially help us shed more light on the mechanisms of language acquisition. In addition, it can constitute a tool for studying historical phonetics/linguistics. Phonological inventories are very often seen as static and as a finished work, and not as an entity in equilibrium. Economy, as it has been defined, is the tendency toward efficiency and away from redundancy. It is intriguing, therefore, to explore the shaping of an inventory over time and comprehend the motivation behind linguistic processes such as the addition or deletion of segments. In the same logic, a prediction on the future state of a modern language is within our reach.

Figure 2: Nineteen possible associations between the two sets of features. From left to right: 1. features for oral place of articulation; 2. the three legal combinations of these features; 3. the eight combinations for manner of articulation features; 4. the features for manner of articulation.



References

Chomsky, N. and Halle, M. (1968). *The sound pattern of English*. Harper & Row, New York.

Clements, G. (2003). Feature economy in sound systems. *Phonology*, 20(3):287–333.

de Groot, A. (1931). Phonologie und phonetik als funktionswissenschaften. *Travaux du Cercle Linguistique de Prague*, 4:116–147.

Flynn, D. (2006). Articulator theory. Manuscript.

Hall, D. C. (2007). *The Role and Representation of Contrast in Phonological Theory*. Phd thesis, Department of Linguistics, University of Toronto.

Mackie, S. and Mielke, J. (2007). Testing the limits of feature economy. Workshop 'Where do features come from?'. Paris.

Martinet, A. (1955). *Économie des changements phonétiques; traité de phonologie diachronique*. A. Francke, Berne.

Setatos, M. (1974). *Phonologia tis Koinis Neoellinikis [Phonology of Modern Greek]*. Papazisi, Athens.

Stevens, K., Keyser, S., and Kawasaki, H. (1986). Toward a phonetic and phonological theory of redundant features. In Perkell, J. and Klatt, D., editors, *Symposium on invariance and variability of speech processes*, pages 432–469. Lawrence Erlbaum, Hillsdale.

Stevens, K. N. & Keyser, S. J. (1989). Primary features and their enhancement in consonants. *Language*, 65:81–106.