MINIMAL PRESSURES LEADING TO DUALITY OF PATTERNING

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Hockett (1959) identified *duality of patterning* as a fundamental design feature of human language. Ladd (2012) re-analyses 'duality' as two levels of systematicity, one fully embedded within the other: a meaningless, *combinatorial* level, providing the building blocks for a meaningful, *compositional* level. Explanations for the emergence of combinatoriality include ease of production and reception (e.g. Roberts, Lewandowski, & Galantucci, 2015), robustness (Ay, Flack, & Krakauer, 2007), cultural adaptation to physical constraints (Zuidema & Boer, 2009), and learnability (Verhoef, Kirby, & Boer, 2014). Likewise, explanations for compositionality range from communicative function (e.g. De Beule, 2008) to cultural selection for expressivity and learnability (e.g. Kirby, Tamariz, Cornish, & Smith, 2015). Tria, Galantucci, and Loreto (2012) are the first to outline an integrated model of the emergence of duality, showing that distinct mechanisms of 'noise/recognition' and 'blending/repair' lead to the emergence of combinatorial and compositional structure respectively.

Our proposal is that both combinatoriality and compositionality are functional responses to maintain expressivity and learnability against noise. This depends on the level of analysis at which noise applies: signal-directed noise leads to combinatoriality, and noise which affects signal/meaning associations drives compositionality. Our approach contrasts with that of Tria et al.: we also investigate the emergence of the two levels of patterning, but we aim to show that they are driven by identical — not distinct — pressures. We employ a exemplar-based computational model of cultural learning subjected to twin pressures of expressivity and learnability. In common with Tria et al., utterances are modelled as strings drawn from a potentially infinite set of characters, subject to noise during transmission/storage. *Learnability* is modelled in terms of *compressibility*, a consequence of noisy pressures causing sub-strings across all exemplars to become more similar. *Expressivity* is an opposing force causing competition between similar sub-strings with a shared meaning. Besides these processes, agents are modelled simply as a set of exemplars associating full strings and complex meanings, with an exemplar memory of fixed size. We show that both combina-

torial *and* compositional structures act to maintain learnable, expressive systems against noise: similarly to Tria et al., we find that combinatoriality is modulated by signal-directed noise, which can be situated in both perception and cognition. Furthermore, compositionality also requires pressures for learnability and expressivity but, as with Kirby et al., whether systems become compositional or holistic depends on the presence of noise in the shape of an information bottleneck, which can be located in both transmission and memory. Given these results, we propose that combinatoriality emerges when noise puts the signal space under pressure to maintain learnability and expressivity: compositionality occurs when noise puts the signal/meaning association space under similar pressures. This helps dispel apparent conflicts between physical, perceptual and cognitive accounts of combinatoriality on the one hand, and acquisition vs. interaction-based accounts of compositionality on the other. However, this does not guarantee that duality of patterning will arise in any socially learnt communication system. Neither does either level of patterning predict the other: we suggest that duality is a response to noise at two levels of analysis.

References

Ay, N., Flack, J., & Krakauer, D. C. (2007). Robustness and complexity co-constructed in multimodal signalling networks. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, *362*(1479), 441–7.

De Beule, J. (2008). the Emergence of Compositionality, Hierarchy and Recursion in Peer-To-Peer Interactions. *The Evolution of Language - Proceedings of the 7th International Conference (EVOLANG7)*, 75–82.

Hockett, C. F. (1959). Animal 'languages' and human language. *Human Biology*, *31*(1), 32–39.

Kirby, S., Tamariz, M., Cornish, H., & Smith, K. (2015). Compression and communication in the cultural evolution of linguistic structure. *Cognition*, *141*, 87–102.

Ladd, D. R. (2012). What is duality of patterning, anyway? *Language and Cognition*, *4*(04), 261–273.

Roberts, G., Lewandowski, J., & Galantucci, B. (2015). How communication changes when we cannot mime the world: Experimental evidence for the effect of iconicity on combinatoriality. *Cognition*, *141*, 52–66.

Tria, F., Galantucci, B., & Loreto, V. (2012). Naming a structured world: a cultural route to duality of patterning. *PloS one*, *7*(6), e37744.

Verhoef, T., Kirby, S., & Boer, B. de. (2014). Emergence of combinatorial structure and economy through iterated learning with continuous acoustic signals. *Journal of Phonetics*, *43*, 57–68.

Zuidema, W., & Boer, B. de. (2009). The evolution of combinatorial phonology. *Journal of Phonetics*, *37*(2), 125–144.