A FITNESS FUNCTION FOR GRAMMATICALIZATION

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There is a strong theoretical tradition approaching grammaticalization in terms of frequency of use (Bybee, 2003; Haspelmath, 2019), which has been mirrored in psycholinguistic accounts in terms of productivity and reuse (Hawkins, 2004; O'Donnell, 2015). In both accounts, the frequency of linguistic units reflects communicative need (Anderson & Schooler, 1991), and languages are pressured to *compress*, or reduce the complexity of, highly needed forms to aid language processing. The rampant ambiguity in languages at all levels of processing suggests this compression is lossy. Therefore, optimal communication systems should trade-off compression and communicative robustness. This trade-off is formalized by the information bottleneck method (Tishby et al., 2000) using Shannon information, or alternatively from an algorithmic information theory perspective as the Kolmogorov structure function (Kolmogorov, 1974). We argue that the grammatical systems found in the world's languages demonstrate this trade-off. We propose a hybrid algorithmic-Shannon information-theoretic approach as a fitness function for grammaticalization–i.e. a function that identifies which linguistic innovations are likely to persist. Here we present a synchronic evaluation of the model that opens up the possibility of future diachronic work.

Grammatical features can be separated into morpho-semantic features (e.g. tense, aspect) that provide new semantic information, and morpho-syntactic features (e.g. gender, case) that involve a dependency (Kibort & Corbett, 2008). We focus on morpho-syntactic features and propose that their function is to communicate information about semantic dependencies and semantic roles. We therefore predict that communicative precision is impaired when a language is stripped of one of its morpho-syntactic features. Taking grammatical case as an example, we test this prediction by training communication models with and without case and comparing the expected information loss between a speaker and a hearer attempting to reconstruct semantic dependencies. Based on data from the Universal Dependency treebank, we find that removing case increases information loss for 12 out of 13 languages tested. Preliminary results stripping gender from Spanish are also in line with the hypothesis. As a preliminary check that information loss does not always decrease when any possible feature is added, we augmented English

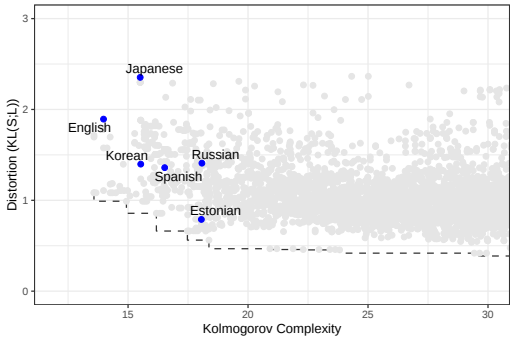

Figure 1. Using MCMC methods, we simulated possible languages (light gray dots) that could adopt different word orderings and make use of different grammatical features. The dotted line reflects the observed optimal trade-off frontier. Natural languages are shown as blue dots.

with a concreteness feature taken from Brysbaert et al. (2014) and find the effect in the opposite direction. Taken together, our results suggest that grammatical features may result from a selective pressure towards communicative robustness.

To further test our hypothesis, we probe whether the word order strategies and grammatical features of natural languages achieve a near-optimal trade-off between communicative robustness and algorithmic efficiency. Noting the isomorphism between Abstract Meaning Representation graphs and dependency parses, we constructed a generative model of "languages"—i.e., functions that encode a meaning graph into a linear string. For our analysis, we focused only on transmitting information about dependencies between verbs, arguments and adjuncts and their semantic roles—i.e., where there is considerable variation in morphology across extant languages (Nichols, 1986). Our analysis included grammatical number, gender and case, and semantic roles for agent, patient, location, beneficiary, instrument, duration and manner. We allowed our model to innovate by changing word orderings and expressing grammatical features either implicitly/derivationally in words, via inflection or via lexicalization. We find that natural languages lie relatively near the optimal trade-off between algorithmic complexity and communicative robustness (Figure 1). These languages, however, are not strictly optimal with respect to our framework, and Japanese in particular deserves further investigation.

Our framework suggests how grammatical features allow languages to navigate a tradeoff between communicative robustness and psychological complexity, and therefore motivates future work on the emergence of grammatical features through time. The framework can be linked with ideal learner models of language and Bayesian agent-based models, which make predictions about the dynamics of language change, development and evolution. Future work can test these predictions experimentally using iterated learning and artificial language learning tasks.

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