**Simple and informative scalar languages are monotone**

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Monotonicity is an abstract property of meaning that has been attested in several semantic domains, including adjectives, quantifiers and modals. The meaning of a signal is upward/downward monotone if the signal refers to all upper/lower bounds of each of its referents, according to a certain underlying ordering. It has been shown that monotonicity arises via artificial iterated learning with pragmatic agents biased towards simplicity and expressiveness [2]. Monotone concepts have been also demonstrated to be easier to learn by humans [3] and neural networks [6].

We explain monotonicity in terms of a domain-general optimization principle seeking to reduce communicative and cognitive costs associated with a language [5]. Possible meanings of a signal are taken to be subsets of $n$ values arranged on a discrete ordered scale. Each possible meaning is thus represented by a binary vector of length $n$. A meaning $a_1a_2\ldots a_n$ is upward (downward) monotone iff, for each value $i$, $a_i = 1$ implies $a_j = 1$, for all $i < j \leq n$ ($1 \leq j < i$). The cognitive complexity of meaning is modeled by change complexity [1]. The complexity of a language consisting of $k$ signals is the average complexity of a signal in the language. The communicative cost of a language is the probability that the language confuses two random values from the scale (e.g., 1111 confuses everything, 1100 confuses $1, 2$ and $3, 4$; this can be extended to languages with many signals). A scalar language is monotone if all its signals have monotone meanings.

Optimizing simplicity and informativeness depends on the relative value of these properties, which is controlled by the $\gamma$ parameter. For a wide range of $\gamma$ (including $\gamma = 0.5$, i.e. equal division between communication and cognition) optimal languages are monotone (Fig. 1). The results show that the tradeoff between simplicity and informativeness might be sufficient to explain monotonicity. Moreover, the generality of this argument suggests that monotonicity might arise at various timescales for which such optimization is viable. We backup this conclusion with initial simulations based on a recent model of meaning coordination [4].

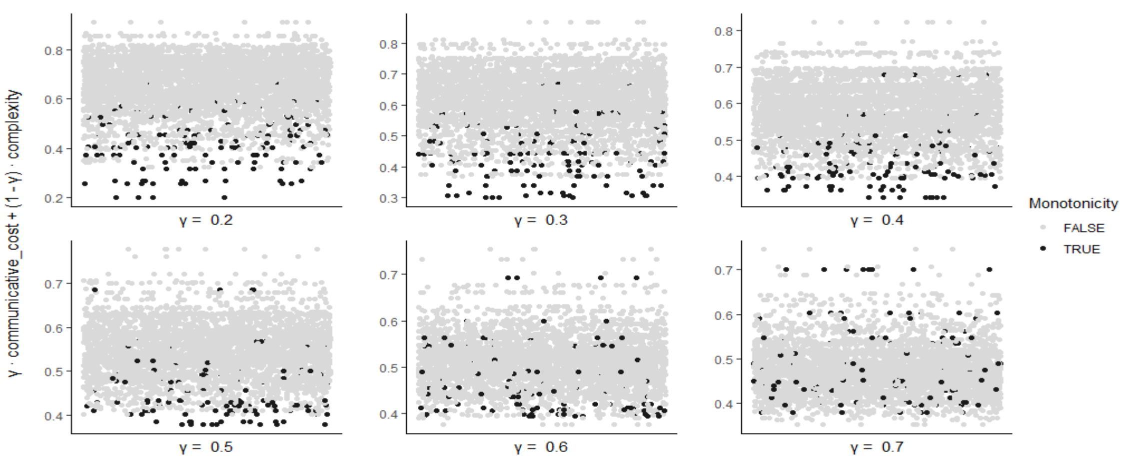


Figure 1: Costs of 2-term languages acting over a scale of length 6, for six values of $\gamma$.

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