

# Semantic typology and efficient communication

Charles Kemp<sup>\*1</sup>, Yang Xu<sup>2</sup>, and Terry Regier<sup>\*3</sup>

<sup>1</sup>Department of Psychology, Carnegie Mellon University, Pittsburgh, PA, USA, 15213

<sup>2</sup>Department of Computer Science, Cognitive Science Program, University of Toronto, Toronto, Ontario M5S 3G8, Canada

<sup>3</sup>Department of Linguistics, Cognitive Science Program, University of California, Berkeley, CA, USA, 94707; email: [terry.regier@berkeley.edu](mailto:terry.regier@berkeley.edu)

## Abstract

Cross-linguistic work on domains including kinship, color, folk biology, number, and spatial relations has documented the different ways in which languages carve up the world into named categories. Although word meanings vary widely across languages, unrelated languages often have words with similar or identical meanings, and many logically possible meanings are never observed. We review work suggesting that this pattern of constrained variation is explained in part by the need for words to support efficient communication. This work includes several recent studies that have formalized efficient communication in computational terms, and a larger set of studies, both classic and recent, that do not explicitly appeal to efficient communication but are nevertheless consistent with this notion. The efficient communication framework has implications for the relationship between language and culture and for theories of language change, and we draw out some of these connections.

*Keywords:* lexicon, word meaning, categorization, culture, cognitive anthropology, information theory

## 1 INTRODUCTION

The study of word meanings across languages has traditionally served as an arena for exploring the interplay of language, culture, and cognition, and as a bridge between linguistics and neighboring disciplines such as anthropology and psychology. Within linguistics, this area of study falls within semantic typology (Bach and Chao, 2009; Evans, 2011). Specifically, it is the semantic typology of the lexicon: the study of cross-language variation in the semantic categories labeled by single words (Boas, 1911; Sapir, 1929; Whorf, 1956; Witkowski and Brown, 1978; Wierzbicka, 1992; Koch, 2001; Brown, 2001; Boster, 2005; Koptjevskaja-Tamm et al., 2007; Malt and Majid, 2013; Majid, 2015).

Over the years word meanings have been investigated in semantic domains such as kinship (Murdock, 1949; Nerlove and Romney, 1967), color (Berlin and Kay, 1969; Kay and McDaniel, 1978), folk biology (Brown, 1984; Berlin, 1992), numeral systems (Greenberg, 1978; Comrie, 2013), and spatial relations (Talmy, 2000; Levinson and Meira, 2003; Majid et al., 2004). A natural and commonly-adopted approach is to focus on a particular semantic domain (but see Lucy, 2004), and to characterize that domain in terms

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<sup>\*</sup>These authors contributed equally to this article.



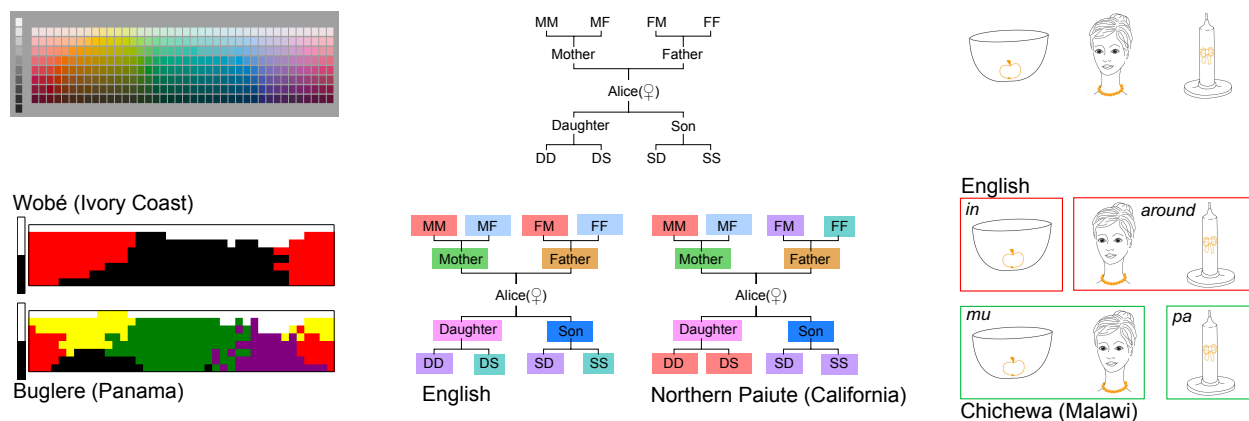


Figure 1: Variation in word meaning within the domains of color (left), kinship (middle) and spatial relations (right). The top row shows fine-grained meanings that correspond to colors and shades of lightness, kin types with respect to a female speaker, and spatial relations between figure objects (gold) and ground objects (grey). For each domain, the bottom row uses color-coded regions, sets or outlines to show how two languages group these fine-grained meanings into categories (color, Kay et al. (2009); kinship, Kroeber (1917), spatial relations, Carstensen (2011)). We ask why languages vary as they do in their category systems.

of a set of fine-grained meanings that are grouped into categories in different ways by different languages. This approach is illustrated in Figure 1 with respect to the semantic domains of color, kinship, and spatial relations. In this approach, given a body of cross-language semantic data, one may note which categorical groupings of fine-grained meanings tend to recur across languages, and which do not—and derive on that basis a set of generalizations governing cross-language semantic variation in that domain. Two prominent examples of this approach are Berlin and Kay’s (1969) study of color naming across languages, which yielded an implicational hierarchy summarizing what sorts of color naming systems were and were not attested in their data, and Haspelmath’s (1997) study of indefinite pronouns across languages, which yielded a semantic map of that domain, suggesting possible conceptual connections between the various fine-grained meanings (Croft, 2003). This general approach is attractive because it allows one to specify cross-linguistic semantic patterns in a way that highlights both what is universal and what is variable across languages.

A natural question is what general principles explain such semantic variation—ideally not just within a single domain, but also across different domains. Several such principles have been proposed, accounting for observed patterns of semantic variation in terms of: connectedness in a discrete semantic map (Jurafsky, 1996; van der Auwera and Plungian, 1998; Haspelmath, 1997, 2003; Cysouw et al., 2010), relative positions of fine-grained meanings in a continuous semantic space (Cysouw, 2001; Levinson and Meira, 2003; Croft and Poole, 2008; Majid et al., 2008; Gärdenfors, 2014), and universal semantic primitives combined in culture-specific ways (Wierzbicka, 1972, 1980, 1992). In this review, we focus on a specific principle with cross-domain scope: the need for *efficient communication*, an idea with roots in the functionalist tradition (e.g. von der Gabelentz, 1901; Haiman, 1985; Haspelmath, 1999; Hopper and Traugott, 2003; Croft, 2003). This principle holds that languages are under pressure to be simultaneously informative (so as to support effective communication) and simple (so as to minimize cognitive load). The research we survey argues that this principle—which has been invoked to explain aspects of linguistic form—also helps to explain why systems of word meanings vary across languages as they do. Like the other principles referenced above, the



principle of efficiency appears to operate in similar ways across very different semantic domains, including domains that have traditionally been characterized by a focus on semantic universals (e.g. color), and those traditionally characterized by a focus on culture-dependent variation (e.g. kinship, and the vexed question of words for snow). As we shall see, exploring this principle leads naturally to an approach that integrates psychological and cultural factors, and casts that integration in computational terms.

An efficient communication approach to semantic variation connects naturally with work on pragmatics, conceptual development, and language evolution (Frank, 2017). We will not be able to draw out all of these connections, but focus instead on a set of ideas directly rooted in the typological literature. We begin in the next section by providing a general theoretical framework for exploring efficient communication, and then review recent studies that have used this framework to explain cross-language variation in semantic category systems in several semantic domains. We next examine the interaction of cultural forces with systems of semantic categories, and the question of semantic change, both through the lens of efficiency. We close by considering a number of limitations of existing research along these lines, as well as ideas for extension.

## 2 THEORETICAL FRAMEWORK

Language is often viewed as a means of transmitting ideas from one mind to another. To serve this function well, language must be *informative*: it must convey the speaker’s intended message to the listener with reasonable accuracy. Ideally, language should also be *simple*: it should require only minimal cognitive resources. These two desiderata necessarily compete against each other. A highly informative communicative system would be very fine-grained, detailed, and explicit—and would as a result be complex, not simple. A very simple system, in contrast, would necessarily leave implicit or unspecified many aspects of the speaker’s intended meaning—and would therefore not be very informative. A system supports *efficient communication* to the extent that it achieves an optimal tradeoff between these two competing considerations.

A general preference for efficient communication—often formalized in information-theoretic terms—has been invoked to explain several aspects of language, including word frequency distributions (Zipf, 1949; Ferrer i Cancho and Solé, 2003), word lengths (Piantadosi et al., 2011), syllable duration (Aylett and Turk, 2004), syntactic structures and processing (Hawkins, 2004; Levy, 2008; Jaeger, 2010), pragmatic language understanding (Wilson and Sperber, 2004; Frank and Goodman, 2012), the acquisition of case marking (Fedzechkina et al., 2012), and compositional structure (Kirby et al., 2015). Of particular relevance to this review is Rosch’s (1999, p 190) suggestion that semantic categories tend to “provide maximum information with the least cognitive effort.” The research we review here formalizes this idea in information-theoretic terms, and tests it across languages, across domains, and to some extent across time. Broadly related proposals have also been formalized in terms of optimality theory (Jones, 2015).

Figure 2 illustrates these general principles in the specific domain of kinship. Here, the domain universe  $U$  of objects about which one might communicate includes kin types such as mother, father, and others. The speaker wishes to communicate about a specific kin type  $t \in U$  (here, her older brother), and she represents that object in her own mind as a probability distribution  $s$  (for speaker) over the universe, with mass only at  $t$ . The speaker then utters the word  $w$  (here, “brother”) to convey this mental representation to the listener. Upon hearing this word, the listener attempts to reconstruct the speaker’s intention given the word used by the speaker; this listener reconstruction is also represented as a probability distribution,  $l$  (for listener). In the present example, the listener can infer that the speaker has in mind either her older brother or her younger brother, but cannot distinguish between these two possible kin types. Thus, some information has been lost in this act of communication, and that information loss can be captured using a standard information-



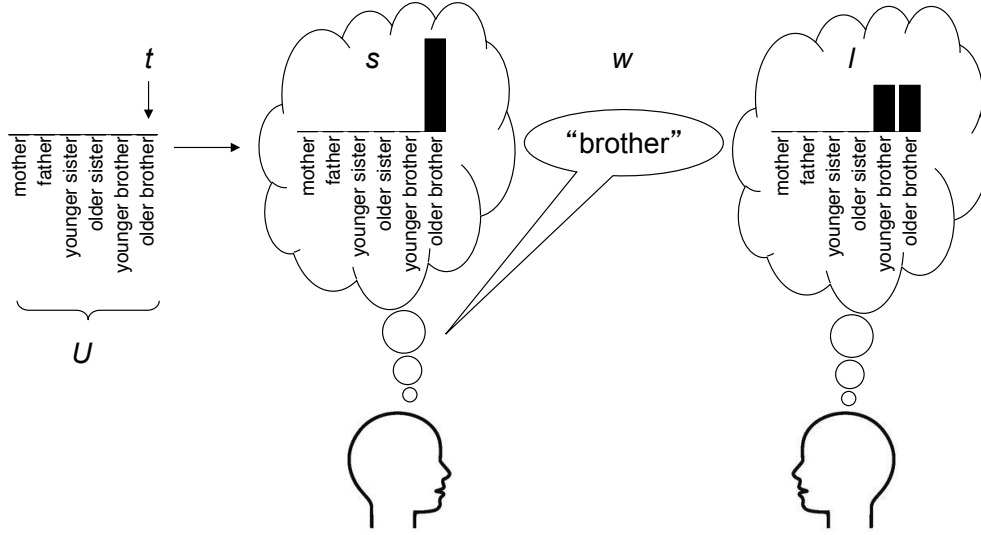


Figure 2: A communicative scenario. The speaker wishes to communicate about a specific kin type,  $t$  (older brother), represents it mentally as a distribution  $s$  (for speaker) over the universe  $U$  of all kin types, and expresses it using a word,  $w$  (here the English term “brother”). On the basis of this term, the listener attempts to mentally reconstruct the speaker’s intended meaning in a distribution  $l$  (for listener), but cannot tell whether the older or younger brother was intended; thus some information is lost in communication. Efficient communication involves minimizing such information loss while keeping language simple.

theoretic measure of the divergence between the speaker and listener distributions (Frank and Goodman, 2012; Kemp and Regier, 2012; Regier et al., 2015). We use the term  $e(t)$  to denote this information loss, or error, in communicating about a particular target object  $t$ . We similarly use the term  $n(t)$  to denote the *need probability* for object  $t$ , that is, the probability that the speaker will need to communicate about that object rather than any other in the domain. Given this, the overall expected information loss is:

$$E = \sum_{t \in U} n(t)e(t) \quad (1)$$

which is simply the average information loss across objects in the domain, weighted by need. This quantity gives us a measure of the *communicative cost* of using a given semantic system to communicate about this domain. We take a semantic system to be informative to the extent that it yields low communicative cost, and we wish to compare different semantic systems with respect to this measure. For example, a language that had a separate kin term for each kin type in the domain universe of Figure 2 would have lower communicative cost, and would therefore be more informative about this domain, than English. As noted above, however, such a system would also be less simple (more complex) than English: it would have more terms, with finer-grained meanings. We assess simplicity by the size of the mental representation of the lexicon for a given domain, and refer to this quantity as *cognitive cost*. An ideal measure of cognitive cost would be grounded in detailed knowledge of the relevant mental representations and processes, but in practice, simple measures such as minimum description length or the number of terms in a semantic system may be used as proxies.<sup>1</sup>

<sup>1</sup>This characterization differs from some others in the literature, in that we focus on the simplicity of a cognitive representation



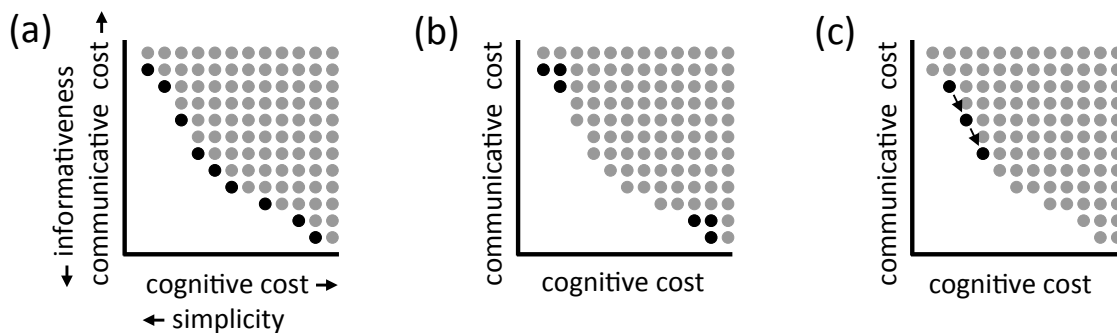


Figure 3: Tradeoff between communicative and cognitive costs. Each point is a semantic system; gray points are hypothetical systems that together designate the achievable region within this space, and black points are attested systems. (a) Attested systems are predicted to lie along or near the optimal frontier. (b) Systems from cultures for which this domain is important are predicted to be more informative and more complex (lower right cluster) than systems from cultures for which the domain is less important (upper left cluster). (c) As semantic systems change over time, they are predicted to follow the optimal frontier.

The tradeoff at the heart of efficient communication is illustrated in Figure 3. The two dimensions of each graph represent communicative cost and cognitive cost, and each point in the resulting two-dimensional space represents a semantic system. The ideal communicative system would be located at the origin: this represents perfectly informative (lossless) communication, with perfect simplicity (no cognitive cost). This situation amounts to mind-reading, and is of course impossible. However it is still useful conceptually, for it suggests that mind-reading is the ideal to which language aspires but can never actually reach. What then can language reach? The *achievable region* of possible semantic systems may be determined by creating a wide range of hypothetical systems out of semantic primitives for a given domain. Such hypothetical systems are shown as gray points in Figure 3. We then predict that attested semantic systems, shown as black dots in the figure, will tend to lie along or near the *optimal frontier* of this region: the curve defined by systems that are as informative as possible for their level of simplicity, and as simple as possible for their level of informativeness.

The core idea explored by the research we review is that the wide but constrained variation found in systems of word meanings across languages corresponds to variation along the optimal frontier (Figure 3a). We expect systems to lie either on the frontier, or in the parts of the achievable region that are near it, as this nearby area is highly if not quite optimally efficient. On this view, communicative and cognitive costs are universal forces that shape semantic systems in every language, but different languages may make different tradeoffs between the two dimensions, and may therefore lie in different regions along the optimal frontier. One factor that could drive such variation is the culture-specific importance of a particular semantic domain (Figure 3b). If a domain is important to a given culture, and elements in that domain are frequently referred to, then it would make sense to invest in some complexity for this domain in order to acquire increased informativeness—and it would make less sense to do so if the domain is not culturally important. The same framework also makes predictions about semantic change over time (Figure 3c). If languages adapt over time to shifting functional pressure for efficient communication, we would expect semantic change to be represented as motion along or near the optimal frontier, in one direction or another.

The framework that we have described here is extremely simple, and real-world communication departs

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(Chater and Vitányi, 2003), rather than simplicity of overt linguistic form (e.g. Piantadosi et al., 2011; Fedzechkina et al., 2012).



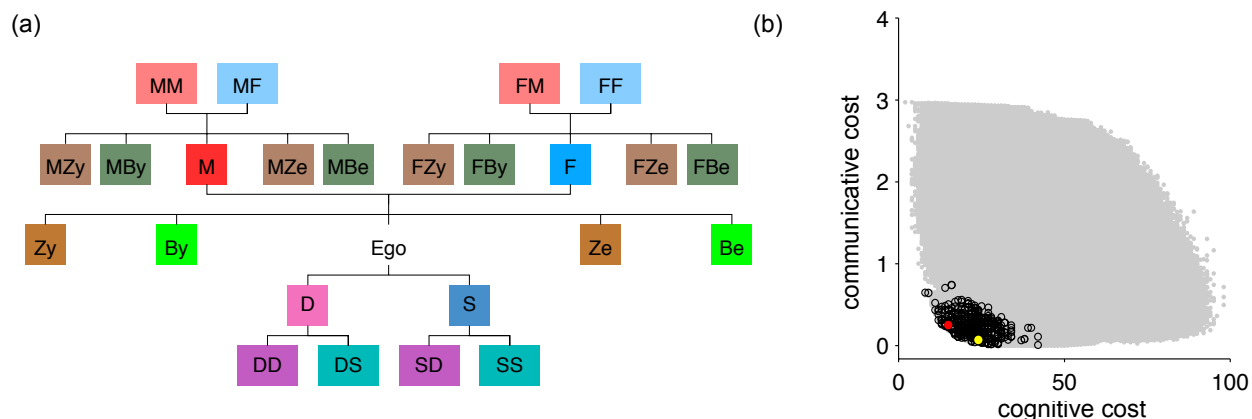


Figure 4: Kinship analysis. (a) Kin types arranged in a family tree (e.g. MF: mother’s father; FZe: father’s elder sister). Color codes show how these kin types are grouped into the kinship categories of English. Languages partition this tree into categories in a wide but constrained variety of ways. (b) Hypothetical kinship systems are shown as gray dots, and systems from the Murdock dataset are shown as black circles. English is shown as a red dot, and Northern Paiute as a yellow dot. Attested systems tend to lie near the optimal frontier. Adapted from Kemp and Regier (2012).

from it in a number of important respects. For example, speakers utter phrases and sentences rather than single words; semantic categories are sometimes used in ways that do not involve reference to single specific objects; context often supplies substantial information about the speaker’s intended meaning; and speakers may have goals such as establishing social status instead of conveying information to their hearer. In section 6 below we discuss how this framework might be extended to capture some of these factors, but we argue below that even this simple framework can account in a straightforward way for a substantial amount of data concerning cross-language semantic variation.

### 3 EFFICIENCY ANALYSES ACROSS SEMANTIC DOMAINS

Efficiency analyses along the lines sketched above have been conducted in several semantic domains, as we review below.

#### 3.1 Kinship

Cross-language variation in kin terminologies has traditionally been a focus of interest among anthropologists as well as linguists (Kroeber, 1917; Murdock, 1949, 1970; Nerlove and Romney, 1967; Kronenfeld, 1974; Valdés-Pérez and Pericliev, 1999; Greenberg, 2005; Read, 2007; Jones, 2010), and for this reason it is a natural domain in which to explore principles of efficiency—as foreshadowed in the previous section. Kemp and Regier (2012) conducted such an analysis, based on the set of kin types shown in Figure 4a, categorized according to a large set of languages from the dataset of Murdock (1970). These languages partition this family tree into kinship categories in a wide variety of ways. Each kinship system was represented as a kinship grammar, composed of primitives from the literature, such as  $\text{PARENT}(x, y)$  and  $\text{FEMALE}(x)$ . Need probability across kin types was estimated from corpus frequencies in English and German; this was a



choice of convenience, and we consider below how need probability distributions may vary across cultures and across time. The central results of this analysis are shown in Figure 4b. Each gray dot represents a hypothetical kinship system, constructed out of the same set of primitives used to represent attested systems, but arranged in many different ways. Each black circle represents the kinship system of a language in the Murdock dataset. The red dot represents English, and the yellow dot represents Northern Paiute, an indigenous language of northern California (Kroeber, 1917) that also appears in Figure 1. It can be seen that attested systems tend to fall along the optimal frontier of the achievable region of this space, efficiently trading off communicative cost and cognitive cost. These results are compatible with the idea that kinship systems are under pressure to support efficient communication, and that they navigate that pressure in a wide variety of language-specific ways. Follow-up analyses showed that this account captures known descriptive generalizations from the literature. For example, markedness constraints concerning the relative semantic breadth of various kinship categories (Greenberg, 1990, 2005) are explained by the distribution of need across the family tree, and a preference for categories defined by conjunction rather than disjunction of primitives (Nerlove and Romney, 1967; Kronenfeld, 1974; Greenberg, 1990) is explained by the greater informativeness of conjunctively defined categories.

### 3.2 Color

The domain of color provides a useful point of comparison and contrast with kinship. Like kin terminologies, color naming systems across languages have been of interest for many years (Berlin and Kay, 1969; Kay and McDaniel, 1978; Lucy, 1997; Jameson and D’Andrade, 1997; Kay and Regier, 2003; Lindsey and Brown, 2006, 2009). Color has moreover been a central testing-ground in the debate over linguistic relativity (Brown and Lenneberg, 1954; Kay and Kempton, 1984; Roberson et al., 2000, 2005; Winawer et al., 2007). At the same time, and importantly for our purposes, there are major representational differences between kinship and color. Kinship involves discrete kin types in a conceptually represented hierarchy—color, in contrast, is a perceptual domain and is represented in a continuous space. Despite these differences, recent work has suggested that semantic variation in color naming can be accounted for in terms of the same principles just reviewed for kinship (see also Jones, 2015).

Color naming has sometimes been seen as reflecting underlying perceptual structure in a fairly direct way (e.g. Berlin and Kay, 1969; Kay and McDaniel, 1978). More recent work, however, suggests that color naming is shaped not only by perceptual constraints (Boster, 1986) but also by the need to communicate informatively about color (Jameson and D’Andrade, 1997; Jameson, 2005; Steels and Belpaeme, 2005; Dowman, 2007; Komarova et al., 2007; Puglisi et al., 2008; Baronchelli et al., 2010). For example, Regier et al. (2015) conducted an efficiency analysis of color naming systems, assuming a standard model of perceptual color space and the measure of informativeness introduced above. Figure 5 shows the theoretically optimally informative color naming systems for  $n=3,4,5,6$  categories, on this analysis, compared with color naming systems from selected languages drawn from the World Color Survey (Kay et al., 2009). These theoretical optima capture qualitative aspects of the corresponding attested color naming systems, such as the rough location and shape of the various color categories. Not all color naming systems examined matched these globally optimal templates as closely, but most were found to be at least locally optimal, consistent with the hypothesis of adaptation to functional pressure for efficiency. The progression of optimal systems for increasing numbers of categories shown in Figure 5 qualitatively tracks, and provides an explanation for, early stages of the well-known implicational hierarchy of color naming systems advanced by Berlin and Kay (1969).



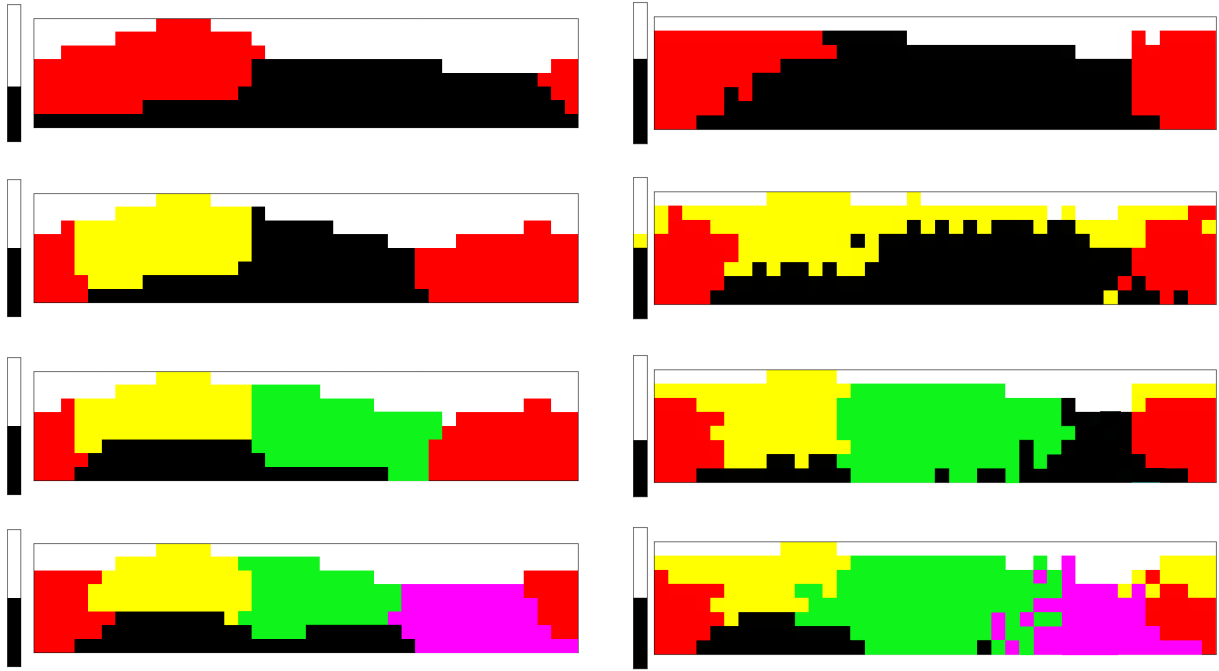


Figure 5: Theoretically optimally informative color naming systems (left) for  $n=3,4,5,6$  categories, compared with color naming systems (right, top to bottom) of Ejagam (Nigeria/Cameroon), Culina (Peru/Brazil), Iduna (Papua New Guinea), and Buglere (Panama). Each false-colored blob denotes the extension of a color term. All systems are plotted against the color naming grid in the top left panel of Figure 1. Adapted from Regier et al. (2015).

### 3.3 Other domains

The same principles of efficiency have also been applied to other semantic domains. As in the work reviewed above, the work we review here assumes a universal conceptual space for each domain; to what extent this is a valid assumption across domains is a separate and important question in its own right (Sapir, 1929; Whorf, 1956). Khetarpal et al. (2013) considered the domain of topological *spatial relations* (Bowerman and Pederson, 1992, 1993; Bowerman, 1996)—categorized in English by such spatial terms as “in”, “on”, “around”, and the like—and conducted an efficiency analysis of cross-language data in this domain drawn from independent sources (Levinson and Meira, 2003; Michael et al., 2013; Neveu, 2013). Although the languages they considered differed substantially in their structurings of space (Talmy, 2000), each language’s spatial category system was found to be highly informative relative to a large set of comparable hypothetical systems of the same complexity. Xu and Regier (2014) conducted a similar analysis of *numeral systems* across languages (Greenberg, 1978; Comrie, 2013), based on numeral grammars grounded in primitives of both approximate (Gordon, 2004; Pica et al., 2004; Dehaene, 2011) and exact numerosity. This analysis found that numeral systems of qualitatively different sorts tend to lie along the optimal frontier. The same analysis also supported a view of recursion in numeral systems as a cognitive tool (Frank et al., 2008) that enables very high informativeness at the cost of only modest cognitive complexity. Finally, Xu et al. (2016) considered names for *artifacts*, specifically household containers such as bottles, jars, etc., in English, Spanish, and Chinese (Malt et al., 1999). They found that the semantic systems of these three languages in this domain,



although different, were all highly informative when compared with a large set of hypothetical systems of equal complexity.

There are other semantic domains for which existing data could be analyzed in terms of efficiency, but such analyses have to our knowledge not yet been conducted. These domains include folk biology (Brown, 1984; Berlin, 1992), body parts (Enfield et al., 2006), and acts of cutting and breaking (Majid et al., 2008). A natural direction for future research is determining how well principles of efficiency generalize to these and other domains.

## 4 CULTURE

The efficient communication hypothesis holds that semantic systems are shaped in part by communicative needs. Thus, it predicts that when these needs vary across cultures, semantic systems should vary accordingly, reflecting *local* communicative needs. This idea echoes the work of many scholars, including Boas (1911), who suggested that the terms in any language “must to a certain extent depend upon the chief interests of a people” (p. 26). Sapir (1912) went further and suggested that the complete vocabulary of a language may be “looked upon as a complex inventory of all the ideas, interests, and occupations that take up the attention of the community,” and that “were such a complete thesaurus of the language of a given tribe at our disposal, we might to a large extent infer the character of the physical environment and the characteristics of the culture of the people making use of it” (p. 228).

Although there is broad agreement that the lexicon is influenced by culture, Sapir’s claim is almost certainly too strong (Hymes, 1964). One reason why cultural interests and the lexicon may diverge is that the two change at different rates, and vocabulary may lag behind current cultural interests (Malt and Majid, 2013). There are also other grounds for caution. A naive view of cultural need and language might lead one to always expect very different color naming systems among societies located in densely forested versus desert environments—but in fact there are instances of rather similar color naming systems from such dissimilar environments (Roberson et al., 2005). Finally, the distortion through popularization of the question of “Eskimo words for snow” (discussed in the following subsection) has lent an air of unsophistication and faint disreputability to the entire topic. For these reasons, the relationship between culture and the lexicon demands careful empirical study, and provides a useful testing ground for understanding the scope and limits of the efficient communication hypothesis.

### 4.1 Words for snow revisited

The claim that Eskimo/Inuit languages have unrelated forms for different types of snow is well-known among the public, but has also been grossly distorted. The idea originated with Boas (1911), was repeated by Whorf (1956), and then entered popular culture, with people attributing ever greater numbers of words for types of snow to Eskimo languages on the basis of essentially no evidence, as discussed by Martin (1986) and Pullum (1991). However, despite all the attention given to Boas’ original snow example, it is striking that remarkably little attention has been given to the central principle that his example was meant to illustrate. That principle is that the environment shapes local communicative needs—in Boas’ words, “the chief interests of a people” (p. 26)—which in turn shape the category system of a language. This causal chain can be seen as a specific instance of the more general hypothesis that language is shaped by the need for efficient communication, here modulated by locally determined communicative needs. This hypothesis predicts that concepts that are high-frequency in local lifestyle will receive semantically narrow categories (yielding low expected information loss), consistent with Boas’ original snow observation. Krupnik and





Figure 6: Words for snow revisited. (a) Locations of languages that have a single term for ice and snow. (b) Locations of languages that have different terms for ice and snow. (c) Temperature distributions associated with the two groups of languages. Languages with a single term for ice and snow are found in warm climates, consistent with the hypothesis of efficient communication, modulated by locally determined need. Adapted from Regier et al. (2016).

Müller-Wille (2010) argued that Boas’ original claim is in fact well-founded as regards several Eskimo/Inuit languages and dialects. Regier et al. (2016) tested a variant of the same principle more broadly across languages. They found that languages with a single term for ice and snow are found only in warm regions of the world, whereas languages with different terms for ice and snow are distributed more widely, as shown in Figure 6. They also analyzed Twitter posts in different languages and confirmed that communicative need to refer to ice and snow is lower in warmer than in colder regions. These findings are consistent with the theory of efficient communication modulated by local need. Thus, despite its awkward history, the well-known question of “words for snow” may contain an element of truth, along with the regrettable exaggeration. A natural direction for future analyses of this sort concerns terms for other environmental features such as mountains, rivers and the like (Burenhult and Levinson, 2008; Mark et al., 2011).

## 4.2 Culture and need probability

There are many ways in which communicative needs vary across cultures and may thereby influence local naming systems, but there are two kinds of variation that are tied especially closely to the theoretical framework outlined earlier. In Equation 1, the notion of communicative cost is formulated with respect to *object-level* need probabilities  $n(\cdot)$  that capture the frequency with which speakers refer to particular objects within a given semantic domain. These probabilities may vary across cultures. For example, need probabilities for the kin types in Figure 4a may be different for cultures with different social structures. To evaluate whether a given semantic system achieves an efficient tradeoff between cognitive and communicative costs, it is important to use object-level need probabilities that are appropriate for the language in question. A second way in which communicative needs vary across cultures is at the level of a semantic domain taken as a whole. For example, a given domain such as kinship may be more important and therefore more frequently discussed in some cultures compared to others. Need probabilities at the *domain-level* can be thought of as corresponding to the overall proportion of time spent by a representative member of a culture in talking about a given domain. As suggested by Figure 3b, the domain-level need probability for a given culture can be used to predict where along the optimal frontier that culture’s semantic system should lie. If the domain-level need probability is high, any information loss in communication will be compounded by many repetitions, and therefore the system should privilege low communicative cost even if the associated cognitive cost is high. In contrast, languages with low domain-level need probability should prioritize cognitive



cost over communicative cost, because any information loss occurs relatively rarely and therefore does not justify the cognitive investment of a complex semantic system.

### **4.3 Color**

The view of color naming reviewed earlier emphasized the interaction of perceptual constraints with a drive for efficient communication. To what extent does color naming across languages depend on local communicative needs? The picture is mixed. There is some evidence that the fine-grainedness of a color naming system is associated with societal complexity and degree of interest in color in the local culture (Berlin and Kay, 1969; Kuschel and Monberg, 1974), which may plausibly affect local domain-level need. There is also some preliminary evidence suggesting that color naming systems may vary systematically with local climate (Stickles, 2014). Relatedly, Baddeley and Attewell (2009) found that the number of lightness terms in a language (e.g. “black,” “white,” “gray” in English) can be explained by the distribution of surface reflectances in an urban vs. forest or rural environment. At the same time, caution is needed in interpreting these findings. As noted above, there is evidence for similar color naming systems from unrelated languages spoken in very different environments (Roberson et al., 2005). And it is intriguing that the theoretically optimally informative systems in Figure 5 above qualitatively match attested systems, given that that analysis assumed a uniform object-level need distribution over colors. This suggests that while local need may influence color naming systems, particularly at the domain level, these systems are also strongly influenced by underlying perceptual constraints.

### **4.4 Kinship**

The social organization of kin groups varies widely across cultures with respect to such factors as patterns of descent, marriage, and residence, and it seems natural to expect such socio-cultural factors to influence kinship terminologies. However the extent of this influence has been debated for more than a century (Kroeber, 1909; Rivers, 1914; Service, 1985). The most comprehensive analysis of the relationship between social factors and kinship terminologies was carried out by Murdock (1949), who presented a large set of statistical tests that revealed correlations between social factors and kinship terminologies. Murdock’s work did not control for phylogenetic relationships between languages, and therefore needs to be revisited using state-of-the art statistical methods (Jordan, 2011). Work in this direction has just begun, and Guillon and Mace (2016) present a phylogenetic study that finds only weak support for the hypothesis that cousin terms co-evolved with patterns of descent and residence rules. Future research can potentially use the D-PLACE database (Kirby et al., 2016) to determine which aspects of kinship terminologies (if any) are strongly linked with social variables.

Factors such as descent, marriage, and residence are plausibly linked to object-level need probabilities, but have no obvious implications for need probabilities at the domain level. It is commonly held, however, that the domain of kinship is more important in some cultures than others (Lévi-Strauss, 1963). We know of no studies that quantify the importance of kinship within a given culture, but this variable might be expected to decrease with societal complexity generally. Existing studies of the relationship between kinship terminology and societal complexity (Dole, 1972; Witkowski and Burris, 1981) could therefore serve as a starting point for assessing whether complex kinship terminologies tend to be found in cultures that place high importance on kinship.



## 4.5 Folk biology

Animals and plants can be categorized at multiple levels, and we will focus on folk-generic categories such as trout and oak that typically lie at the level of biological species (Berlin, 1992). Any given language includes names for only some of the local species, and the efficient communication perspective is compatible with the view that folk-generic categories often correspond to species of cultural importance (Hunn, 1982). This functionalist view has been contrasted with the view that folk-generic categories pick out natural kinds that are perceptually salient even if they have little cultural importance (Berlin, 1992). It seems likely that biological categories are shaped by both cultural importance and perceptual salience (Malt, 1995), and it remains to be seen whether the efficient communication framework can account for the relative weights of these factors.

Efficiency considerations may also help to explain the total number of folk-generic categories in a given language. One relevant factor is biological diversity: other factors being equal, it seems plausible that domain-level need probabilities would be greater in areas with high biological diversity. Another is mode of subsistence: it seems plausible that domain-level need probabilities for plants would be higher for cultivators than for hunter-gatherers, and low for urban populations (e.g. Witkowski and Burris, 1981). Berlin (1992) reports that the number of folk-generic categories increases as biological diversity increases. Consistent with an earlier proposal by Brown (1985), Berlin also reports that cultivators tend to have larger numbers of folk-generic plant categories than hunter-gatherers, and subsequent work has supported this claim using comparisons between cultivators and hunter-gatherers that occupy the same environment (Balée, 1999; Voeks, 2007). All of these results suggest that the number of folk-generic categories identified by a culture is systematically related to domain-level need probability.

## 4.6 Future directions

Given the state of the literature, our discussion of variation in need probability across cultures has been unavoidably speculative. Two directions for further work seem especially important. Operationalizing communicative need is not straightforward, but a natural first step is to estimate need probabilities at the object and domain level on a *per-language or per-culture* basis, using direct measures such as corpus frequency or some reasonable proxy. This step is essential in order to move beyond intuitions about how need probability relates to other variables that characterize the physical and social environment.

The second important direction is to explore factors that can potentially explain when predictions based on need probability are supported and when they are not. We find it striking that intuitions about need probability lead to some predictions that appear to be false (e.g. color naming should be very dissimilar in rainforest languages vs. desert languages), and others that seem to be true (e.g. languages in warm regions are more likely to have a single term for snow and ice). One possible explanation is that domains may vary in the extent to which the structure of the domain itself outweighs any influence of need. For example, the asymmetric shape of perceptual color space (Jameson and D’Andrade, 1997) may place strong structural constraints on naming systems, even if need does exert some influence—whereas in other domains the structural constraints may be weaker, allowing need to “tilt the balance” more easily.

# 5 LANGUAGE CHANGE

If semantic systems support efficient communication about the concerns of a given culture, it is important to ask how they ended up this way (e.g. Levinson, 2012). A natural explanation is that semantic systems are outcomes of an evolutionary process that tends toward efficient communication (e.g. Kirby



et al., 2015). Characterizing this evolutionary process is critical in order to understand diachronic data (e.g. Biggam, 2012), and may also lead to a more comprehensive account of synchronic data. For example, in an informativeness-vs.-simplicity plot such as Figure 3a, a point corresponding to a given language migrates as that system changes over time. Some points on the optimal frontier may be unreachable in the sense that they cannot be attained by any plausible evolutionary sequence, whereas other points (either on or off the optimal frontier) may correspond to local optima that are endpoints of many plausible evolutionary sequences. Characterizing evolutionary dynamics is therefore important in order to understand why attested systems lie where they do relative to the optimal frontier.

The tradeoff between simplicity and informativeness has a long history in investigations of language change (e.g. von der Gabelentz, 1901; Hopper and Traugott, 2003), but as yet only a handful of studies have applied this idea to change in systems of word meanings. Carstensen et al. (2015) used iterated learning (Kirby et al., 2014) to study semantic change in the laboratory. They considered the semantic domains of color (Xu et al., 2013) and spatial relations, and showed for both domains that as semantic systems evolved through simulated cultural transmission, the communicative cost of those systems gradually decreased. These results are consistent with the idea that semantic change brought about by cultural transmission tends toward informative, efficient communication. In a separate line of research, Xu et al. (2016) explored the process of historical semantic chaining, by which a name for one idea is extended to also cover a similar idea, and from there on to an idea similar to it, and so on, resulting in a chained structure (Brugman, 1988; Heit, 1992; Lakoff, 1987; Bybee et al., 1994; Hopper and Traugott, 2003; Zalazniak et al., 2012). Across three languages, they found evidence for such historical chaining in the names for household containers (Malt et al., 1999), and also found that the process of chaining itself appeared to be constrained by the need to support efficient communication.

An important direction for future research is to build on existing work that uses phylogenetic techniques to reveal how semantic systems have changed over time. Over the past several decades researchers have proposed evolutionary sequences for domains including color (Berlin and Kay, 1969), biology (Brown, 1984) and kinship (Dole, 1972; Witkowski, 1972), and recently phylogenetic methods have been applied to suggest which pathways actually produced the semantic systems that are attested in the literature (Jordan, 2013; Zhou and Bowern, 2015; Haynie and Bowern, 2016). To our knowledge, there are currently no systematic analyses of the extent to which these evolutionary pathways are consistent with selective pressure for efficient communication. Another important direction is to explore the extent to which semantic change may reflect changes in need probability over time. For example, Figure 3c shows a hypothetical case in which a semantic system becomes more complex over time, and such an increase in complexity could result from an increase in need probability for the domain in question.

## 6 EXTENSIONS AND FUTURE DIRECTIONS

Previous sections have already mentioned several directions for future work, and we now outline several additional directions that seem especially important. One major direction concerns loosening some simplifying assumptions. To evaluate whether a system of categories supports efficient communication, it is critical to think carefully about the way in which words are actually used in practice (e.g. Enfield, 2014). The communicative scenario in Figure 2 is only a starting point, and future efficiency analyses should consider communicative scenarios that come closer to the richness of real-world communication in several important respects. For example, word use is heavily dependent on context, both linguistic and nonlinguistic (Halff et al., 1976; Frank and Goodman, 2012), and informativeness would ideally be measured by considering the information that a word adds to an already-established context (e.g. Piantadosi et al., 2012). Another



characteristic of real-world language use is that while words are often used to refer to specific objects, as we have assumed here, they are also used for a wide variety of other functions, including making generic statements such as “grandmothers should help their grandchildren”, or for communicating particular features of an object, such as the information about expected social role that is generally conveyed by a word like “grandmother” (Service, 1960). Future efficiency analyses should assess whether systems of categories are near-optimal with respect to this multiplicity of uses. One possible starting point is corpus analyses that carefully characterize the ways in which words are actually used (e.g. Wisniewski and Murphy, 1989).

The work we have reviewed here has mostly discussed one semantic domain at a time, but the notion of communicative efficiency may generalize to larger subsets of the lexicon than have been considered thus far, and at least in principle to the lexicon as a whole. One possible approach would be to consider a broad conceptual universe that includes a wide range of concepts, such as those represented in Swadesh lists and similar resources (List et al., 2016), and to use efficiency considerations to predict when a language will use a single word to refer to two or more concepts in this universe (Brown, 2001; Koptjevskaja-Tamm, 2008; List et al., 2013; Youn et al., 2016). Finally, beyond scaling up to larger chunks of the lexicon, it is enticing to consider the prospect of integrating the formal treatment we have explored here with very closely related ideas that concern grammar, and the pathway from lexicon to grammar via grammaticalization (Bybee et al., 1994; Heine and Kuteva, 2002; Hopper and Traugott, 2003).

## **7 CONCLUSION**

At first glance, the proposal that word meanings reflect a need for efficient communication might seem unpromising as a framework for approaching the semantic typology of the lexicon. In terms of the two dimensions we have discussed throughout, the proposal seems both too simple and relatively uninformative. We have suggested, however, that formulating this idea in computational terms opens up a large space of empirical questions that have begun to be tested only recently. In particular, the efficient communication perspective is appealing as an integrative framework that brings together work across multiple semantic domains, work on the relationship between language and culture, and both synchronic and diachronic approaches. We have suggested how the efficient communication framework motivates new research directions in all of these areas, and are optimistic that the framework may also be applied in directions we have not envisioned.

## **DISCLOSURE STATEMENT**

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## References

- Aylett, M. and Turk, A. (2004). The smooth signal redundancy hypothesis: A functional explanation for relationships between redundancy, prosodic prominence, and duration in spontaneous speech. *Language and Speech*, 47:31–56.
- Bach, E. and Chao, W. (2009). On semantic universals and typology. In Christiansen, M. H., Collins, C., and Edelman, S., editors, *Language universals*, pages 1–33. Oxford University Press.
- Baddeley, R. and Attewell, D. (2009). The relationship between language and the environment: Information theory shows why we have only three lightness terms. *Psychological Science*, 20:1100–1107.
- Balée, W. (1999). Mode of production and ethnobotanical vocabulary: A controlled comparison of Guajá and Ka’apor. *Ethnoecology: Knowledge, resources, and rights*, pages 24–40.
- Baronchelli, A., Gong, T., Puglisi, A., and Loreto, V. (2010). Modeling the emergence of universality in color naming patterns. *Proceedings of the National Academy of Sciences*, 107(6):2403–2407.
- Berlin, B. (1992). *Ethnobiological classification: Principles of categorization of plants and animals in traditional societies*. Princeton University Press.
- Berlin, B. and Kay, P. (1969). *Basic color terms: Their universality and evolution*. University of California Press.
- Biggam, C. P. (2012). *The semantics of colour: A historical approach*. Cambridge University Press.
- Boas, F. (1911). Introduction. In *Handbook of American Indian Languages, Vol. I*, pages 1–83. Government Print Office (Smithsonian Institution, Bureau of American Ethnology, Bulletin 40).
- Boster, J. S. (1986). Can individuals recapitulate the evolutionary development of color lexicons? *Ethnology*, 25(1):61–74.
- Boster, J. S. (2005). Categories and cognitive anthropology. In Cohen, H. and Lefebvre, C., editors, *Handbook of categorization in cognitive science*, pages 91–118. Elsevier.
- Bowerman, M. (1996). Learning how to structure space for language: A cross-linguistic perspective. In Bloom, P., Peterson, M. A., Nadel, L., and Garrett, M. F., editors, *Language and space*, pages 385–436. MIT Press.
- Bowerman, M. and Pederson, E. (1992). Topological relations picture series. In Levinson, S. C., editor, *Space stimuli kit 1.2: November 1992, 51*, pages 53–56. Max Planck Institute for Psycholinguistics.
- Bowerman, M. and Pederson, E. (1993). Cross-linguistic studies of spatial semantic organization. In *Annual Report of the Max Planck Institute for Psycholinguistics 1992*, pages 53–56. Max Planck Institute for Psycholinguistics.
- Brown, C. H. (1984). *Language and living things: Uniformities in folk classification and naming*. Rutgers University Press.
- Brown, C. H. (1985). Mode of subsistence and folk biological taxonomy. *Current Anthropology*, 26(1):43–53.



- Brown, C. H. (2001). Lexical typology from an anthropological point of view. In Haspelmath, M., König, E., and Oesterreicher, W., editors, *Language typology and language universals: An international handbook, volume 2*, pages 1178–1190. De Gruyter Mouton.
- Brown, R. W. and Lenneberg, E. H. (1954). A study in language and cognition. *The Journal of Abnormal and Social Psychology*, 49:454–462.
- Brugman, C. M. (1988). *The story of over: Polysemy, semantics, and the structure of the lexicon*. Garland.
- Burenhult, N. and Levinson, S. C. (2008). Language and landscape: A cross-linguistic perspective. *Language Sciences*, 30:135–150.
- Bybee, J., Perkins, R., and Pagliuca, W. (1994). *The evolution of grammar: Tense, aspect, and modality in the languages of the world*. University of Chicago Press.
- Carstensen, A. (2011). Universals and variation in spatial language and cognition. Linguistics Undergraduate Honors Thesis. University of California, Berkeley.
- Carstensen, A., Xu, J., Smith, C., and Regier, T. (2015). Language evolution in the lab tends toward informative communication. In *Proceedings of the 37th Annual Meeting of the Cognitive Science Society*.
- Chater, N. and Vitányi, P. (2003). Simplicity: A unifying principle in cognitive science? *Trends in Cognitive Sciences*, 7(1):19–22.
- Comrie, B. (2013). *Numeral Bases*. Max Planck Institute for Evolutionary Anthropology, Leipzig.
- Croft, W. (2003). *Typology and Universals, 2nd edition*. Cambridge University Press.
- Croft, W. and Poole, K. T. (2008). Inferring universals from grammatical variation: Multidimensional scaling for typological analysis. *Theoretical Linguistics*, 34:1–37.
- Cysouw, M. (2001). Review of Martin Haspelmath, Indefinite pronouns (1997). *Journal of Linguistics*, 37:607–612.
- Cysouw, M., Haspelmath, M., and Malchukov, A. (2010). Introduction to the special issue “Semantic maps: Methods and applications”. *Linguistic Discovery*, 8:1–3.
- Dehaene, S. (2011). *The number sense: How the mind creates mathematics*. Oxford University Press.
- Dole, G. E. (1972). Developmental sequences of kinship patterns. In Reining, P., editor, *Kinship studies in the Morgan centennial year*, pages 134–166.
- Dowman, M. (2007). Explaining color term typology with an evolutionary model. *Cognitive Science*, 31(1):99–132.
- Enfield, N. J. (2014). *The utility of meaning: What words mean and why*. Oxford University Press.
- Enfield, N. J., Majid, A., and van Staden, M. (2006). Cross-linguistic categorisation of the body: Introduction. *Language Sciences*, 28:137–147.
- Evans, N. (2011). Semantic typology. In Song, J. J., editor, *The Oxford Handbook of Linguistic Typology*, pages 504–533. Oxford University Press.



- Fedzechkina, M., Jaeger, T. F., and Newport, E. L. (2012). Language learners restructure their input to facilitate efficient communication. *Proceedings of the National Academy of Sciences*, 109:17897–17902.
- Ferrer i Cancho, R. and Solé, R. V. (2003). Least effort and the origins of scaling in human language. *Proceedings of the National Academy of Sciences*, 100:788–791.
- Frank, M. C. (2017). What’s the relationship between language and thought? The optimal semantic expressivity hypothesis. Available at <http://babieslearninglanguage.blogspot.com/2017/07/whats-relationship-between-language-and.html>.
- Frank, M. C., Everett, D. L., Fedorenko, E., and Gibson, E. (2008). Number as a cognitive technology: Evidence from Pirahã language and cognition. *Cognition*, 108(3):819–824.
- Frank, M. C. and Goodman, N. D. (2012). Predicting pragmatic reasoning in language games. *Science*, 336:998.
- Gärdenfors, P. (2014). *The geometry of meaning: Semantics based on conceptual spaces*. MIT Press.
- Gordon, P. (2004). Numerical cognition without words: Evidence from Amazonia. *Science*, 306:496–499.
- Greenberg, J. H. (1978). Generalizations about numeral systems. In Greenberg, J. H., editor, *Universals of Human Language, Volume 3: Word Structure*, pages 249–295. Stanford University Press.
- Greenberg, J. H. (1990). Universals of kinship terminology: Their nature and the problem of their explanation. In Denning, K. and Kemmer, S., editors, *On language: Selected writings of Joseph H. Greenberg*, pages 310–327. Stanford University Press.
- Greenberg, J. H. (2005). Universals of kinship terminology. In *Language universals: With special reference to feature hierarchies*, pages 72–87. Mouton de Gruyter. Chapter 5.
- Guillon, M. and Mace, R. (2016). A phylogenetic comparative study of Bantu kinship terminology finds limited support for its co-evolution with social organisation. *PLOS ONE*, 11(3).
- Haiman, J. (1985). *Natural syntax: Iconicity and erosion*. Cambridge University Press.
- Halff, H. M., Ortony, A., and Anderson, R. C. (1976). A context-sensitive representation of word meanings. *Memory & Cognition*, 4(4):378–383.
- Haspelmath, M. (1997). *Indefinite Pronouns*. Clarendon Press.
- Haspelmath, M. (1999). Optimality and diachronic adaptation. *Zeitschrift für Sprachwissenschaft*, 18:180–205.
- Haspelmath, M. (2003). The geometry of grammatical meaning: Semantic maps and cross-linguistic comparison. In Tomasello, M., editor, *The new psychology of language, Volume 2*, pages 211–242. Erlbaum.
- Hawkins, J. A. (2004). *Efficiency and complexity in grammars*. Oxford University Press.
- Haynie, H. J. and Bowern, C. (2016). Phylogenetic approach to the evolution of color term systems. *Proceedings of the National Academy of Sciences*, 113(48):13666–13671.
- Heine, B. and Kuteva, T. (2002). *World lexicon of grammaticalization*. Cambridge University Press.



- Heit, E. (1992). Categorization using chains of examples. *Cognitive Psychology*, 24:341–380.
- Hopper, P. J. and Traugott, E. C. (2003). *Grammaticalization*. Cambridge University Press, 2 edition.
- Hunn, E. (1982). The utilitarian factor in folk biological classification. *American Anthropologist*, 84(4):830–847.
- Hymes, D. (1964). *Language in culture and society: A reader in linguistics and anthropology*. Harper and Row.
- Jaeger, T. F. (2010). Redundancy and reduction: Speakers manage syntactic information density. *Cognitive Psychology*, 61:23–62.
- Jameson, K. A. (2005). Why GRUE? An interpoint-distance model analysis of composite color categories. *Cross-Cultural Research*, 39(2):159–204.
- Jameson, K. A. and D’Andrade, R. G. (1997). It’s not really red, green, yellow, blue. In Hardin, C. L. and Maffi, L., editors, *Color categories in thought and language*, pages 295–319. Cambridge University Press.
- Jones, D. (2010). Human kinship, from conceptual structure to grammar. *Behavioral and Brain Sciences*, 33:367–416.
- Jones, D. (2015). Grammars of kinship and color: Cognitive universals and optimal communication. In Jones, D. and Milicic, B., editors, *Kinship, Language, and Prehistory: Per Hage and the Renaissance in Kinship Studies*, pages 196–211. University of Utah Press. Project MUSE.
- Jordan, F. M. (2011). A phylogenetic analysis of the evolution of Austronesian sibling terminologies. *Human Biology*, 83(2):297–321.
- Jordan, F. M. (2013). Comparative phylogenetic methods and the study of pattern and process in kinship. In McConvell, P., Keen, I., and Hendery, R., editors, *Kinship systems: Change and reconstruction*, pages 43–58. University of Utah Press.
- Jurafsky, D. (1996). Universal tendencies in the semantics of the diminutive. *Language*, 72:533–578.
- Kay, P., Berlin, B., Maffi, L., Merrifield, W. R., and Cook, R. (2009). *The World Color Survey*. CSLI Publications.
- Kay, P. and Kempton, W. (1984). What is the Sapir-Whorf hypothesis? *American Anthropologist*, 86:65–79.
- Kay, P. and McDaniel, C. K. (1978). The linguistic significance of the meanings of basic color terms. *Language*, 54:610–646.
- Kay, P. and Regier, T. (2003). Resolving the question of color naming universals. *Proceedings of the National Academy of Sciences*, 100:9085–9089.
- Kemp, C. and Regier, T. (2012). Kinship categories across languages reflect general communicative principles. *Science*, 336:1049–1054.



- Khetarpal, N., Neveu, G., Majid, A., Michael, L., and Regier, T. (2013). Spatial terms across languages support near-optimal communication: Evidence from Peruvian Amazonia, and computational analyses. In Knauff, M., Pauen, M., Sebanz, N., and Wachsmuth, I., editors, *Proceedings of the 35th Annual Meeting of the Cognitive Science Society*, pages 764–769. Cognitive Science Society.
- Kirby, K. R., Gray, R. D., Greenhill, S. J., Jordan, F. M., Gomes-Ng, S., Bibiko, H.-J., Blasi, D. E., Botero, C. A., Bowern, C., Ember, C. R., Leehr, D., Low, B. S., McCarter, J., Divale, W., and Gavin, M. C. (2016). D-PLACE: A global database of cultural, linguistic and environmental diversity. *PLOS ONE*, 11(7).
- Kirby, S., Griffiths, T., and Smith, K. (2014). Iterated learning and the evolution of language. *Current opinion in Neurobiology*, 28:108–114.
- Kirby, S., Tamariz, M., Cornish, H., and Smith, K. (2015). Compression and communication in the cultural evolution of linguistic structure. *Cognition*, 141:87–102.
- Koch, P. (2001). Lexical typology from a cognitive and linguistic point of view. In Haspelmath, M., König, E., and Oestreich, W., editors, *Language typology and language universals: An international handbook, volume 2*, pages 1142–1178. De Gruyter Mouton.
- Komarova, N. L., Jameson, K. A., and Narens, L. (2007). Evolutionary models of color categorization based on discrimination. *Journal of Mathematical Psychology*, 51(6):359–382.
- Koptjevskaja-Tamm, M. (2008). Approaching lexical typology. In Vanhove, M., editor, *From polysemy to semantic change: Towards a typology of lexical semantic associations*, pages 3–52. John Benjamins.
- Koptjevskaja-Tamm, M., Vanhove, M., and Koch, P. (2007). Typological approaches to lexical semantics. *Linguistic Typology*, 11:159–185.
- Kroeber, A. L. (1909). Classificatory systems of relationship. *Journal of the Royal Anthropological Institute of Great Britain and Ireland*, 39:77–84.
- Kroeber, A. L. (1917). *California kinship systems*. University of California Press.
- Kronenfeld, D. B. (1974). Sibling typology: Beyond Nerlove and Romney. *American Ethnologist*, 1(3):489–506.
- Krupnik, I. and Müller-Wille, L. (2010). Franz Boas and Inuktitut terminology for ice and snow: from the emergence of the field to the “Great Eskimo Vocabulary Hoax”. In *SIKU: Knowing our ice*, pages 377–400. Springer.
- Kuschel, R. and Monberg, T. (1974). ‘We don’t talk much about colour here’: A study of colour semantics on Bellona island. *Man*, 9(2):213–242.
- Lakoff, G. (1987). *Women, fire, and dangerous things: What categories reveal about the mind*. University of Chicago Press.
- Lévi-Strauss, C. (1963). *Structural anthropology*. Basic Books.
- Levinson, S. C. (2012). Kinship and human thought. *Science*, 336:988–989.
- Levinson, S. C. and Meira, S. (2003). ‘Natural concepts’ in the spatial topological domain—adpositional meanings in crosslinguistic perspective: An exercise in semantic typology. *Language*, 79:485–516.



- Levy, R. (2008). Expectation-based syntactic comprehension. *Cognition*, 106:1126–1177.
- Lindsey, D. T. and Brown, A. M. (2006). Universality of color names. *Proceedings of the National Academy of Sciences*, 103(44):16608–16613.
- Lindsey, D. T. and Brown, A. M. (2009). World Color Survey color naming reveals universal motifs and their within-language diversity. *Proceedings of the National Academy of Sciences*, 106(47):19785–19790.
- List, J.-M., Cysouw, M., and Forkel, R., editors (2016). *Concepticon*. Max Planck Institute for the Science of Human History, Jena. <http://concepticon.clld.org/>.
- List, J.-M., Terhalle, A., and Urban, M. (2013). Using network approaches to enhance the analysis of cross-linguistic polysemies. In *Proceedings of the 10th International Conference on Computational Semantics - Short Papers*, pages 347–353.
- Lucy, J. A. (1997). The linguistics of “color”. In Hardin, C. L. and Maffi, L., editors, *Color categories in thought and language*, pages 320–346. Cambridge University Press.
- Lucy, J. A. (2004). Language, culture, and mind in comparative perspective. In Achard, M. and Kemmer, S., editors, *Language, Culture, and Mind*, pages 1–22. CSLI Publications.
- Majid, A. (2015). Comparing lexicons cross-linguistically. In Taylor, J. R., editor, *The Oxford Handbook of the Word*, pages 364–379. Oxford University Press, Oxford, UK.
- Majid, A., Boster, J. S., and Bowerman, M. (2008). The cross-linguistic categorization of everyday events: A study of cutting and breaking. *Cognition*, 109:235–250.
- Majid, A., Bowerman, M., Kita, S., Haun, D. B., and Levinson, S. C. (2004). Can language restructure cognition? The case for space. *Trends in Cognitive Sciences*, 8:108–114.
- Malt, B. C. (1995). Category coherence in cross-cultural perspective. *Cognitive Psychology*, 29(2):85–148.
- Malt, B. C. and Majid, A. (2013). How thought is mapped into words. *Wiley Interdisciplinary Reviews: Cognitive Science*, 4(6):483–597.
- Malt, B. C., Sloman, S. A., Gennari, S., Shi, M., and Wang, Y. (1999). Knowing versus naming: Similarity and the linguistic categorization of artifacts. *Journal of Memory and Language*, 40(2):230–262.
- Mark, D. M., Turk, A. G., Burenhult, N., and Stea, D. (2011). *Landscape in language: Transdisciplinary perspectives*. John Benjamins Publishing.
- Martin, L. (1986). “Eskimo words for snow”: A case study in the genesis and decay of an anthropological example. *American Anthropologist*, 88:418–423.
- Michael, L., Beier, C., Farmer, S., Neely, K., Skilton, A., Finley, G., Sylak, J., and Neveu, G. (2013). *Diccionario Bilingüe májiki-castellano y castellano-májiki*. Májiki Project. [http://linguistics.berkeley.edu/~levmichael/pubs/mai\\_ore\\_diccionario\\_oct\\_2013.pdf](http://linguistics.berkeley.edu/~levmichael/pubs/mai_ore_diccionario_oct_2013.pdf).
- Murdock, G. P. (1949). *Social structure*. Macmillan, New York.
- Murdock, G. P. (1970). Kin term patterns and their distribution. *Ethnology*, 9(2):165–208.



- Nerlove, S. and Romney, A. K. (1967). Sibling terminology and cross-sex behavior. *American Anthropologist*, 69:179–187.
- Neveu, G. (2013). Spatial relations in Máíjìkì. Linguistics Undergraduate Honors Thesis. University of California, Berkeley.
- Piantadosi, S. T., Tily, H., and Gibson, E. (2011). Word lengths are optimized for efficient communication. *Proceedings of the National Academy of Sciences*, 108:3526–3529.
- Piantadosi, S. T., Tily, H., and Gibson, E. (2012). The communicative function of ambiguity in language. *Cognition*, 122(3):280–291.
- Pica, P., Lemer, C., Izard, V., and Dehaene, S. (2004). Exact and approximate arithmetic in an Amazonian indigene group. *Science*, 306:499–503.
- Puglisi, A., Baronchelli, A., and Loreto, V. (2008). Cultural route to the emergence of linguistic categories. *Proceedings of the National Academy of Sciences*, 105(23):7936–7940.
- Pullum, G. (1991). The great Eskimo vocabulary hoax. In *The great Eskimo vocabulary hoax and other irreverent essays on the study of language*, pages 159–171. University of Chicago Press.
- Read, D. W. (2007). Kinship theory: A paradigm shift. *Ethnology*, 46(4):329–364.
- Regier, T., Carstensen, A., and Kemp, C. (2016). Languages support efficient communication about the environment: Words for snow revisited. *PLOS ONE*, 11(4).
- Regier, T., Kemp, C., and Kay, P. (2015). Word meanings across languages support efficient communication. In MacWhinney, B. and O’Grady, W., editors, *The Handbook of Language Emergence*, pages 237–263. Wiley-Blackwell.
- Rivers, W. H. (1914). *Kinship and social organisation*. Constable & Co.
- Roberson, D., Davidoff, J., Davies, I. R., and Shapiro, L. R. (2005). Color categories: Evidence for the cultural relativity hypothesis. *Cognitive Psychology*, 50:378–411.
- Roberson, D., Davies, I., and Davidoff, J. (2000). Color categories are not universal: Replications and new evidence from a stone-age culture. *Journal of Experimental Psychology: General*, 129:369–398.
- Rosch, E. (1999). Principles of categorization. In Margolis, E. and Laurence, S., editors, *Concepts: Core readings*, pages 189–206. MIT Press. Reprinted from Rosch, Eleanor and Lloyd, Barbara B. (Eds.) (1978), *Cognition and categorization* (pp. 27–48). Hillsdale, NJ: Erlbaum.
- Sapir, E. (1912). Language and environment. *American Anthropologist*, 14(2):226–242.
- Sapir, E. (1929). The status of linguistics as a science. *Language*, 5:207–214.
- Service, E. R. (1960). Kinship terminology and evolution. *American Anthropologist*, 62(5):747–763.
- Service, E. R. (1985). *A century of controversy: Ethnological issues from 1860 to 1960*. Academic Press.
- Steels, L. and Belpaeme, T. (2005). Coordinating perceptually grounded categories through language: A case study for colour. *Behavioral and Brain Sciences*, 28(4):469–489.



- Stickles, E. (2014). The relation of color naming and the environment. In Bello, P., Guarini, M., McShane, M., and Scassellati, B., editors, *Proceedings of the 36th Annual Meeting of the Cognitive Science Society*, page 3408. Cognitive Science Society.
- Talmy, L. (2000). How language structures space. In Talmy, L., editor, *Toward a cognitive semantics, Volume 1*, pages 177–254. MIT Press.
- Valdés-Pérez, R. E. and Pericliev, V. (1999). Computer enumeration of significant implicational universals of kinship terminology. *Cross-Cultural Research*, 33(2):162–1174.
- van der Auwera, J. and Plungian, V. (1998). Modality's semantic map. *Linguistic Typology*, 2:79–124.
- Voeks, R. A. (2007). Penan ethnobotany: Subsistence strategy and breadth of knowledge. In Sercombe, P. G. and Sellato, B., editors, *Beyond the green myth: Borneos hunter-gatherers in the twenty-first century*, pages 262–288.
- von der Gabelentz, G. (1901). *Sprachwissenschaft, ihre Aufgaben, Methoden, und bisherige Ergebnisse*. Weigel.
- Whorf, B. L. (1956). Science and linguistics. In Carroll, J. B., editor, *Language, Thought, and Reality: Selected Writings of Benjamin Lee Whorf*, pages 207–219. MIT Press.
- Wierzbicka, A. (1972). *Semantic primitives*. Athenum.
- Wierzbicka, A. (1980). *Lingua mentalis: The semantics of natural language*. Academic Press.
- Wierzbicka, A. (1992). *Semantics, culture and cognition: Universal human concepts in culture-specific configurations*. Oxford University Press.
- Wilson, D. and Sperber, D. (2004). Relevance theory. In Horn, L. R. and Ward, G., editors, *The Handbook of Pragmatics*, pages 607–632. Blackwell, Oxford, UK.
- Winawer, J., Witthoft, N., Frank, M. C., Wu, L., Wade, A. R., and Boroditsky, L. (2007). Russian blues reveal effects of language on color discrimination. *Proceedings of the National Academy of Sciences*, 104:7780–7785.
- Wisniewski, E. J. and Murphy, G. L. (1989). Superordinate and basic category names in discourse: A textual analysis. *Discourse Processes*, 12(2):245–261.
- Witkowski, S. R. (1972). Guttman scaling of semantic distinctions. In Reining, P., editor, *Kinship studies in the Morgan centennial year*, pages 167–188.
- Witkowski, S. R. and Brown, C. H. (1978). Lexical universals. *Annual Review of Anthropology*, 7:427–451.
- Witkowski, S. R. and Burris, H. W. (1981). Societal complexity and lexical growth. *Cross-cultural research*, 16(1-2):143–159.
- Xu, J., Dowman, M., and Griffiths, T. L. (2013). Cultural transmission results in convergence towards colour term universals. *Proceedings of the Royal Society of London B: Biological Sciences*, 280(1758).



- Xu, Y. and Regier, T. (2014). Numeral systems across languages support efficient communication: From approximate numerosity to recursion. In Bello, P., Guarini, M., McShane, M., and Scassellati, B., editors, *Proceedings of the 36th Annual Meeting of the Cognitive Science Society*, pages 1802–1807. Cognitive Science Society.
- Xu, Y., Regier, T., and Malt, B. C. (2016). Historical semantic chaining and efficient communication: The case of container names. *Cognitive Science*, 40:2081–2094.
- Youn, H., Sutton, L., Smith, E., Moore, C., Wilkins, J. F., Maddieson, I., Croft, W., and Bhattacharya, T. (2016). On the universal structure of human lexical semantics. *Proceedings of the National Academy of Sciences*, 113(7):1766–1771.
- Zalizniak, A. A., Bulakh, M., Ganenkov, D., Gruntov, I., Maisak, T., and Russo, M. (2012). The catalogue of semantic shifts as a database for lexical semantic typology. *Linguistics*, 50(3):633–669.
- Zhou, K. and Bower, C. (2015). Quantifying uncertainty in the phylogenetics of Australian numeral systems. *Proceedings of the Royal Society of London B: Biological Sciences*, 282(1815).
- Zipf, G. K. (1949). *Human behavior and the principle of least effort*. Addison-Wesley.