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Size matters: Grounding quantifiers in spatial perception

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Chapter 1

Preface

1.1 Introduction

Human language is the product of *cultural evolution*. This is a point of view about language that is not accepted by all of its students, but it is a point of view that I share with other researchers in *evolutionary linguistics*.

Language is not a static collection of words and grammar rules, but a complex adaptive system. It changes over time in a way not unlike biological evolution. Speakers of a language continuously create variations: they make mistakes, they try to convey novel concepts. Some of these variations are more successful in communication than others. The most successful variations will continue to be used, other variations disappear. Just as the principles of biological evolution explain how species continuously adapt to their environment, these principles of cultural evolution do the same for language.

This might sound like a truism. In a post-Darwinian era, can we conceive of any other view? But, there are quite a number of prominent linguists and philosophers who can. Most notably, Noam Chomsky and Jerry Fodor, who take a nativist stance: we (humans) have an innate universal grammar, a dedicated mechanism in the brain that contains the basic structures of all languages[1] (Chomsky, 1986; Fodor, 1983). So, there is a task for empiricists (that favor an evolutionary view) to show that universal grammar is not a necessary assumption, that all aspects of language can be explained as the result of cultural evolution.

Lacking empirical data, the most common methodology in this field is the use of computer simulations. How can we show that language is the result of cultural evolution? By repeating it. And this time we pay attention. Of course it

[1] The main argument of such a view is that without a universal grammar, languages would not be learnable. If language is not constrained by a universal grammar, the discrepancy between the amount of possible languages and the data we have for learning them is too vast. We would never be able to learn a language. This is often referred to as the *Poverty of the stimulus* argument.

is not feasible, using computational simulations, to replicate the entire evolution of language, from its genesis to the current state of every language. So, typically researchers in the field focus their attention on one particular aspect of language. The earliest experiments mainly argued against a nativist view by showing that in principle it is possible for a language to emerge as a result of cultural evolution (Steels, 1999, 2008) and that languages will automatically evolve to be learnable (Kirby and Hurford, 2002).

But, the languages that evolved in those experiments do not get close to the complexity of real human languages. In search of more realism, recent experiments limited their focus to specific language domains. These experiments do not simulate the evolution of language from scratch, but assume a primitive existing language and isolate the emergence of one specific aspect of language (such as language to express color (Bleys et al., 2009), spatial relations (Spranger, 2011), or grammatical agreement (Beuls and Steels, 2013)).

Presently, I think we can see another step towards realism being taken, a new development of which this dissertation is a product. Some recent studies have started to look more carefully at the evolutionary paths themselves (van Trijp, 2012; Beuls and Steels, 2013). Words and grammatical constructions do not simply pop up in a language and then stay put. They come to exist as derivations of other words and then start to live their own life: they gradually change in function, meaning, and form. For example, the English conjunction *while*, stems from the Old English noun *kwīl* "time". This example fits a very common pattern in languages called *grammaticalization*. Grammaticalization describes the tendency of words to become more grammatical. The Old English *kwīl* had a clear semantical content, whereas *while* has mostly a grammatical function in English.

The process of grammaticalization is one of the central themes of this dissertation. I use the example of *gradable quantifiers* (words such as *many* and *few*). In English these gradable quantifiers belong to the grammatical class of quantifiers (just as *one*, *all*, or *half*). But they did not start out like that. For example, historical linguists established that the word *few* finds its origins in the Old-English *feawe*, which was not a quantifier, but an adjective that could also mean "small". In the last two chapters of this thesis I describe a cognitive mechanism that accurately simulates this grammaticalization path called *reanalysis*.

This reanalysis mechanism is a general mechanism that can explain the grammaticalization of any word into any grammatical category. But, not all words follow the same grammaticalization path. Some adjectives emerge as adjectives and stay that way (such as the word *big*), some quantifiers have different origins (for example *several* derives from the Latin verb *seperare* "to separate"). When explaining why *many* and *few* follow this particular evolutionary path, we also need to explain why other words don't. In this dissertation I hypothesize that this might be due to the unique cognitive properties of these gradable quantifiers.

Psycholinguists have shown that there is a close cognitive relationship between size and number. Judgments of size (underlying modifiers such as *big* and *small*) depend on perceptual features of objects (or sets of objects) in the environment. Judgments of approximate number (underlying terms like *few* and *many*) exploit a combination of spatial features that apply exclusively to sets of objects, such as their size and density (Durgin, 1995). This cognitive overlap between the concepts of size and number can account for this particular grammaticalization path: the dependence on size motivates their adjectival origins, while their application to sets of objects works as a syntactic magnet that draws them into the grammatical category of quantifiers.

Depending on your generosity, there are two ways to interpret the results of this dissertation: The stingy interpretation is that I show very accurately how and under which cognitive assumptions gradable quantifiers might emerge in a language. A more generous interpretation is to view the gradable quantifiers as a test case, leading to a better understanding of the process of grammaticalization. Furthermore, this work illustrates how the inclusion of data from psycholinguistics may illuminate the grammaticalization patterns found by historical linguists. Of course, I do not claim that this thesis has the final word on grammaticalization, or on quantifiers, or on language evolution for all that matters. The goal of evolutionary linguistics is to show that human languages are the product of cultural evolution. What I hope to convince you of is that using computational models of language evolution to bridge the gap between psycholinguistics and historical linguistics brings us closer to that goal.

1.2 Outline

Except for the present chapter and Chapter 2, all chapters in this thesis either have been published already or will be published in the near future as independent articles. This means that the chapters can be read (or ignored) on their own, and they can be read in any order. The organization of the chapters in this dissertation is therefore mainly thematic. The dissertation is divided into three parts. The first part of this dissertation contains this introduction and a discussion of the literature on cognition of gradable quantifiers. The second part of the dissertation consists of three papers that discuss my contributions to the technical machinery that is needed for conducting robotic language experiments. The final part consist of three papers that describe the experiments themselves.

1.2.1 Part 1

There are many factors influencing the interpretation of gradable quantifiers: the size of the type of object being quantified over, their density patterns, some expected norm, etc. There is a vast amount of literature from different scientific disciplines, addressing a variety of cognitive aspects of these gradable quantifiers.

Chapter 2 provides an overview of the results of these different disciplines. It is abundantly shown that spatial features such as size and density are essential for the judgment of gradable quantifiers.

1.2.2 Part 2

Developing robotic experiments requires an enormous amount of technical work that is normally skimmed over in papers on evolutionary language experiments. This part of the dissertation is dedicated to my contributions to the technical machinery.

Chapter 3 describes a fully operational procedural semantics that is created for robotic communicative interactions called Incremental Recruitment Language (IRL). IRL contains a number of mechanisms that are needed for conceptualization. The goal of this chapter is to provide a detailed overview of the most essential IRL mechanisms.

Grounding language in sensorimotor spaces is an important and difficult task. In order for robots to be able to interpret and produce utterances about the real world, they have to link symbolic information to continuous perceptual spaces. This requires dealing with inherent vagueness, noise and differences in perspective in the perception of the real world. **Chapter 4** presents two case studies for spatial language that show how cognitive operations—the building blocks of grounded procedural semantics—can be efficiently grounded in sensorimotor spaces.

Chapter 5 studies how quantificational expressions such as *few*, *three* and *all* can be grounded in real-world perception. I discuss a computational model, called *clustering quantification*, designed for use in robot-robot interaction scenarios which involve discrimination tasks for objects in the real world. The performance of this model is compared with an alternative type-theory based model. It is shown that clustering quantification is more suitable for real-world applications.

1.2.3 Part 3

This last part of the dissertation discusses the language evolution experiments themselves.

The gradable quantifier *many* does not refer to the same amount in the utterances "many students in the classroom" and "many teachers in the classroom". The interpretations of such quantifiers depend on an expected frequency (a norm)—normally we expect there to be more students than teachers in a classroom. **Chapter 6** provides a cultural-evolution explanation for the emergence of norm-dependent quantifiers, focusing in particular on the role of environmental constraints on strategy choices. Through a series of situated interaction experiments, we show how a community of robotic agents can self-organize a quantification system. Environments in which the distribution of objects exhibits some degree of predictability creates favorable conditions for context-dependent quantifiers.

Chapter 7 discusses a series of experiments in which it is shown that the adjectival origins of gradable quantifiers can be explained by the cognitive overlap between these quantifiers and adjectives such as *big* and *small*.

Chapter 8 illustrates the grammaticalization of gradable quantifiers into quantifiers. It is shown that other existing quantifiers can create attractor positions for other modifiers to grammaticalize into and that *many* and *few* follow this path in search of reducing cognitive effort. Thus, arguing that the shift from qualifying to quantifying expression has a cognitive motivation.