Signaling under uncertainty
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Chapter 1

Introduction

...In that empire, the art of cartography attained such perfection that the map of a single province occupied the entirety of a city, and the map of the empire, the entirety of a province. In time, those unconscionable maps no longer satisfied, and the cartographers guilds struck a map of the empire whose size was that of the empire, and which coincided point for point with it. The following generations, who were not so fond of the study of cartography as their forebears had been, saw that that vast map was useless, and not without some pitilessness was it, that they delivered it up to the inclemencies of sun and winters. In the deserts of the west, still today, there are tattered ruins of that map, inhabited by animals and beggars; in all the land there is no other relic of the disciplines of geography.

Jorge Luis Borges, *On Exactitude in Science*

Communication is a social endeavor of information transfer. If we are told

(1) Alice went to Las Vegas and married,

we may learn just that. First, that Alice went to a place called Las Vegas. Second, that she married. However, we might also infer more. For instance, that Alice married in Las Vegas, taking *and* to indicate a temporal succession of events; or that *Las Vegas* refers to a famous place in Nevada rather than to the city of Las Vegas on the coast of Uruguay. With the appropriate background knowledge, we might even infer that Alice left her partner if the speaker is Alice’s (now former) spouse.

Some of these inferences, such as that of Alice leaving her spouse, are rather ad hoc. Others, such as the enrichment of *and* to convey *and then*, show striking regularities across languages. What they all have in common is that they go beyond what is said explicitly. On the one hand, this can give rise to uncertainty and misunderstanding. Hearers cannot be certain that what they infer is intended, nor can speakers be certain that the inferences they intend to convey are drawn. On the other hand, the trait of not codifying all information overtly is not exclusive to natural language but found in much of biological signaling, from
cellular communication to that of meercats and baboons (Greenough et al. 1998, Arnold and Zuberbühler 2006, Santana 2014). Rather than avoiding it, natural communication seems to thrive in the implicit; in the unsaid; in the contextually determined.

Framed in linguistic terminology, the information that is literally associated with an expression concerns its semantics. What is inferred beyond its literal meaning lies in the realm of pragmatics. This can involve the recruitment of contextual information, as well as mutual reasoning about interlocutors’ linguistic choices. Under this distinction the meaning of an utterance is the product of conventional semantic meaning and general pragmatic rules that apply on language use in context.

Following the classic distinction between semantics and pragmatics we may then ask: if all interlocutors cared about was faithful information transfer, why leave to pragmatics and the implicit what semantics can do? Three reasons come to mind. First, it might be that misunderstandings are rare. What speakers intend to convey and what hearers take them to convey usually coincides. Second, it might be that some degree of uncertainty is unavoidable. After all, natural communication takes place in open and changing environments. Additionally, language is not acquired from a single source, nor does it serve a single purpose. It might consequently be impossible to use language in such a way that all uncertainty is quenched. Third, some degree of uncertainty might be advantageous. For instance, it may help interlocutors cope with some of the aforementioned issues, leaving to pragmatics the job of filling in gaps impossible to fill only by semantic conventions; or it might confer them with means to convey information in a more efficient manner. Inversely then, if one or a combination of these answers holds, we should also ask why and under which conditions interlocutors would leave to semantics what pragmatics can do.

The overall goal of this investigation is to address both of these questions by elucidating conditions under which language may come to leverage or accommodate uncertainty in information transfer. In particular, we will focus on cases in which speakers could, in principle, provide more information overtly but nevertheless often choose not to do so. In analogy to Borges’ fictional empire, this investigation’s underlying theme is accordingly the communicative potential that less (overt) exactitude offers in a trade-off against (pragmatic) uncertainty, as well as the linguistic properties that this trade-off gives rise to. Is language that leaves no room for uncertainty even a stable alternative, or would it be left in tatters by future language users?

1.1 The Semantics-Pragmatics Distinction

Natural languages are acquired from different sources and used in novel situations, often with new interlocutors of which little to nothing is known. As mentioned
1.1. The Semantics-Pragmatics Distinction

above, some variation across speakers and uncertainty about their language (use) may therefore be unavoidable. It is nevertheless also true that speakers do not necessarily shy away from, but regularly make use of expressions that invite or even necessitate pragmatic inference. A request for a blanket can be politely veiled by saying I’m cold; a temporal succession of events can be communicated by the order in which conjuncts appear, as in utterance (1); an invitation can be declined by saying I have to work. Crucially, such information could be conveyed more explicitly.

An influential account of the relation between what is said and what is conveyed is due to Grice (1975; 1989), who characterized pragmatic language use and its interpretation as resulting from a process of mutual reasoning about rational language use. That is, pragmatic inference is an outcome of a hearer’s reasoning about why the speaker said what she said in the way she said it, taking into consideration the conversation’s background as well as goals and beliefs of interlocutors. Conversely, a speaker reasons about her addressee’s reasoning process, which she expects to effect a particular enrichment of her utterance. For instance, under the assumption that the speaker is cooperative and relevant, I have to work can be interpreted as providing a reason why the speaker will not be able to accept an invitation. Under this view, then, what is conveyed is explained in terms of the goals that language use is believed to serve. By contrast to many approaches in the philosophy of language contemporary to it, the Gricean project explicitly brings interlocutors, their goals, and the context of interaction into the picture instead of abstracting away from them.

Central to Grice’s pragmatic theory is the notion of rationality. He embodies it in a number of guiding principles postulated to underlie conversation, his so-called conversational maxims. Roughly put, these principles state that rational speakers should be as informative but not more informative than necessary; that they should be truthful, relevant, and brief, but that they should avoid ambiguity. As an overarching principle, they should speak in such a way that the conversational goal is furthered. According to Grice, at a fundamental level this goal is to reach mutual understanding. These principles are not meant to be descriptive but normative (Grice 1989:§2:29). That is, they are not intended to describe how interlocutors behave but how rational language users ought to behave to reach mutual understanding. Pragmatic inferences then follow from the mutual assumption that all conversational participants behave in this fashion. What is more, not only the compliance with conversational maxims can give rise to pragmatic inference but also their violation. Under the assumption that (rational and cooperative) speakers try to comply with the maxims as much as they can, flouting a maxim is a deliberate and therefore meaningful signal for the hearer. In sum, rationality is seen as not only guiding, but also as constraining language use in relation to interlocutors’ beliefs and goals (Westera 2017:6). Under this view, the role of semantics is to provide the groundworks on which pragmatic inference can build on.
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Of course, although widespread, this is a particular view of pragmatics and its relation to semantics. Much research has been devoted to the explanatory potential of alternative principles to those proposed by Grice (e.g., Sperber and Wilson 1986, Wilson and Sperber 2006, Carston 2006), or their reduction and refinement (e.g., Horn 1984, Levinson 2000). As detailed in Chapter 2 we will follow a third way and ground notions such as cooperativity directly in the beliefs and preferences of interlocutors in context (e.g., Parikh 1991; 2000, Benz et al. 2006a, Benz 2006, Benz and van Rooij 2007, Franke 2009, Frank and Goodman 2012, Franke and Jäger 2014; 2016a). Under this view, pragmatic inference follows directly from reasoning about such contextual beliefs and preferences, without need for appeal to maxim-like rules. Using game-theoretic models that embody this view will enable us to inspect predictions borne out from an interactive perspective of language use, as well as those that follow from linguistic pressures that apply on such interactions.

The approach we take here is notwithstanding Gricean in spirit. Information transfer is viewed as an endeavor of social reasoning about rational language use. Schematically, we will view what is conveyed as a product of (cf. Parikh 2000):

- an agent’s cognitive make-up
- context of utterance
- semantic meaning

As a coarse approximation, our general explanandum can be recast as asking for the conditions that may favor information transfer that relies more strongly on the third component than on one of the first two, and vice-versa.

1.2 General Methodology

Our analysis spans across three interwoven levels: single interactions, iterated interactions, and the level of populations. As made precise in Section 2.4, linguistic behavior in single interactions is the foundation on which we build. Such behavior results from the context of interaction and an individual’s cognitive make-up, her beliefs and preferences, the semantic conventions she holds to be true, and the conversational rules that she takes to operate on these conventions. Taken together, these factors determine agents’ choice probabilities in production and comprehension in a given situation. However, the particular behavior of an agent at a particular time is not informative about the effects that linguistic pressures have on her language and behavior in the long run. Our central tenant is that if we are to understand why languages exhibit the properties they do, we should consider the tasks they fulfill over time, as well as pressures that apply on them. Many, if not arguably most, of these tasks are social endeavors that involve joint rather than independent action. Our focus will accordingly lay on iterated interactions and population-level dynamics. The former trace linguistic change over the course of a sequence of linguistic interactions. This kind of change can be conceived as taking place over the course of (possibly multiple) dialog(s). The
latter trace change as a product of the expected outcome of repeated interactions of members of a population (horizontal change), as well as the effects of generational turnovers – when old population members are replaced by new ones (vertical change). The remainder of this chapter sets the stage for such an analysis by clarifying, in general terms, what we mean by words such as change, evolution and development; in which relation iterated and population-level dynamics stand; and on which level of analysis we operate.

1.2.1 Ontogeny and phylogeny; biological and linguistic change

The relation between horizontal and vertical language change bears similarity to the biological distinction between ontogeny and phylogeny. In broad strokes, ontogeny studies the development of an organism throughout its lifetime. Human ontogeny, for instance, spans from the ovum’s fertilization across embryogenesis, infant and adolescent development, up to the development of the traits of fully matured adults. Phylogeny instead studies the evolution of species or populations throughout generations, tracing their development and relationship to one another.

The relationship between the development of an organism on the individual level and that of its phylum was regarded as a fundamental topic in evolutionary and developmental biology before the turn of the 20th century. A popular view on this matter is illustrated by Ernst Haeckel’s famous theory of recapitulation, which holds that ontogeny recapitulates phylogeny (Haeckel 1866). In other words, Haeckel’s hypothesis was that the individual development of an organism passes through stages that represent the development of its species, with ontogenetic stages representing the features of its adult ancestors. The appeal of such a mechanistic view of an organism’s ontogeny, viewed as a (con)sequence of its phyletic history, is evident in light of its historical context: theories of recapitulation attempted to gain insight into the past through the analysis of the present, with Mendelian genetics still to gain traction and to ultimately displace recapitulation. Nowadays a relationship between ontogeny and phylogeny under any strong interpretation of recapitulation is widely taken to be untenable. The influence of phylogeny on ontogeny as well as the role of other, at recapitulation’s height unknown or disregarded, determinants turned out to be more complex than initially thought (see Gould 1977 for historical details).

What we learn from this snapshot of the history of biology is first and foremost that relating processes of individual development to macro-processes from which

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1 Whether individual development faithfully traverses all the stages of its phylum’s history, merely resembles (some of) them, and to which degree this is supposed to apply to an organism as a whole or to its parts individually, allowing for temporal divergence in their development, were issues of active debate at the height of recapitulation’s popularity. These details need not concern us here but see Gould 1977 for a historical overview.
they (partially) draw is often non-trivial. Caution is particularly called for in the face of seemingly intuitive parallels, as illustrated by the conclusions drawn from the ontogenetic expression of pharyngeal slits in human embryos to illustrate how humans pass through a developmental fish-like stage. Interestingly, precursors to recapitulation can be found in early theories of the origin of language (Danesi 1993). For instance, in the assumption that the language acquired by children deprived of linguistic input would correspond to a/the proto-language from which modern languages could have derived. As in the case of biology, a parallelism between linguistic change at an individual level and its historical development is appealing, for it would allow for a detailed inspection of its earlier stages in living specimens, so to speak. In the case of language evolution this issue is particularly pressing given that language “leaves no direct imprint in the fossil record” (Bolhuis et al. 2014:3). For the purpose of this investigation the origins of language itself are not of primary relevance. Our starting point is instead given by the change of pre-existing linguistic knowledge at different transmission levels with the goal to understand the conditions that lead to the adoption of linguistic strategies that may favor implicit over explicit information codification. Nevertheless, the question how the vertical transmission of linguistic knowledge affects its horizontal use and change, and vice-versa, is relevant here as well.

As with ontogeny and phylogeny, the emergence and change of language and its properties is also influenced by many intertwined factors. These range from biological and socio-ecological to cultural ones (Benz et al. 2006b, Steels 2011, Tamariz and Kirby 2016). Social and ecological pressures determine communicative needs, while biology determines the architecture that enables and constrains the means by which they can be fulfilled. Which of these factors is involved; whether change involves individual- or population-level processes; and on what timescale such change operates on are issues often obscured by the term language evolution. Let us therefore pause and briefly clarify these matters to set the scope of this investigation. With respect to the first issue concerning the nature of the described change, our focus will lay on cultural aspects. That is, we analyze processes of linguistic change as shaped by language use and its transmission: as a result of a process of cultural evolution (Christiansen and Chater 2008, Pagel 2009, Thompson et al. 2016). With respect to the second issue, drawing from the caution expressed above, we will analyze the effects of change at individual- and population-level separately, and contrast their outcome where pertinent. In analogy to the terminological distinctions often employed in connection to ontogeny and phylogeny, we refer to the former as (individual) development and reserve the term evolution for population change. Whether we analyze change at the individual- or population-level will depend on the phenomenon at hand. In Chapter 3, we will be concerned with contextual disambiguation in dialog. The inferences that resolve ambiguity in such cases can be rather ad hoc and idiosyncratic because they depend on the context and the interlocutors involved. Their treatment accordingly calls for models that make predictions about agents’
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choice in single interactions and track their change over repeated interactions. By contrast, Chapter 4 and Chapter 5 analyze the evolution of more systematic pragmatic inferences. This analysis abstracts from proximate causes, individual choices at particular points in time, and instead looks at the outcome of pressures that apply on populations of communicating agents. With respect to the third issue, as mentioned above, we constrain our attention to change effected by pressures such as ones for higher communicative success, learnability, or speaker-economy on populations or individuals that have some initial linguistic conventions to draw from; rather than their emergence, for example, from protocommunication systems, or the evolution of the cognitive endowment necessary to deploy pragmatic reasoning (see Woensdregt and Smith 2017 for a recent survey on these matters).

1.2.2 **A computational analysis of outcomes of ecologically rational linguistic behavior**

Marr (1982) famously argued for a tripartite distinction of analysis. His aim in doing so was to clarify how different perspectives taken toward an object of study are informed by different methodologies, and to clarify that they seek to answer different questions. More precisely, Marr proposes to categorize analysis according to the following complementary levels:

- **Computational level**: the what and why of a system/operation;
- **Algorithmic level**: the (computational) implementation of a system/operation. In particular, the representation of its input and output;
- **Implementational level**: the physical realization of a system/operation.

For example, in the case of vision Marr argues that a purely physiological description of its biological architecture may not necessarily add to our understanding of visual recognition. In particular, it may not add to our understanding of the motivations that underlie it; this being a computational rather than implementational question.

Of course, levels of analysis also interact and should therefore inform each other. Just as the physiology of vision may tell us something about its function, its computational description may guide its implementation. A transversal analysis is ultimately necessary to fully understand a complex system such as vision or, in our case, language; however impractical this task may be (Marr 1982:20).

Acknowledging at which level analysis is conducted has the advantage of constraining the perspective taken with respect to an object of study, as well as that of making clear the goals of the analysis. This is not only important to ensure internal coherence but also for critical assessment.
Our present aim is to gain insight in conditions under which language accommodates or leverages uncertainty “[...] by understanding the nature of the problem being solved [rather] than by examining the mechanism (and the hardware) in which it is embodied” (Marr 1982:27). Under Marr’s classification, this investigation is then conducted at the computational level. We focus on two fundamental and interrelated problems being solved. The first is efficient information transfer through language use. The second is the transmission of linguistic knowledge from one agent to another. This may involve two proficient language users that adapt their language use to each other through the course of their interactions (Chapter 3), or proficient language users from which naïve users learn (Chapter 4 and 5). Put differently, the second problem concerns the acquisition or adaptation of the means by which the first problem is solved. As we shall see, solutions to these problems can pull in opposite directions. A characterization of their joint influence and combined solution is therefore part of our overall goal.

With Grice and much work in Bayesian cognitive modeling, decision theory, and game theory, our approach is rationalistic at the level of individuals (Anderson 1990; see Griffiths et al. 2012 and Franke and Jäger 2016a for discussion). This means that we aim to give a teleological, rather than mechanistic, explanation of linguistic behavior. To analyze linguistic change, we couch this rationalistic approach in the ecological context in which behavior takes place. That is, we analyze linguistic change as shaped both by the behavior resulting from the computational capacities of an agent itself, as well as by the environment in which this behavior is embedded (Simon 1990). The former we assume to correspond to (an approximation of) bounded rational behavior (Chapter 2). The latter encompasses factors such as the interlocutor’s overt behavior and contextual information (Chapter 3 and 5), the population in which actors find themselves in (Chapter 4 and 5), as well as factors such as noisy perception (Chapter 6). In light of our main findings, we cast a critical light on this approach to the analysis of linguistic change in Chapter 6.

1.3 Overview and Source Material

Chapter 2 This chapter lays out the technical and conceptual foundations of our analysis, building on Lewis’ (1969) signaling games. We proceed by incrementally introducing some central game-theoretic notions and highlight how they can aid linguistic inquiry. In particular, we focus on how they can make the interplay of conventional meaning, interlocutors’ goals, information transfer, and mutual reasoning precise.

This chapter also discusses the limitations of static equilibrium analysis. With Franke (2013) and Huttegger and Zollman (2013), we argue that static approaches suffer from conceptual and technical issues that make them unsuitable for our purposes: they fail to make clear predictions when multiple
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equilibria exist; their procedural agnosticism lacks in explanatory force to address the question how language users may come to adopt a particular (way of using) language; and they can be taken to suggest outcomes that in some cases are seldom, if ever, reached. These shortcomings motivate a move from a static analysis of language to a dynamic one. This is the kind of analysis which we conduct throughout this investigation.

In the dynamic realm we differentiate between micro dynamics, which track change in language or behavior of individual agents, and macro dynamics, which abstract away from individuals and instead trace change in populations. Making predictions using either type of dynamic analysis presupposes that we characterize how language is used, as well as what counts as a language in the first place. To this end, we introduce a general model of rational language use at this chapter’s end.

Chapter 3

This chapter focuses on ambiguity in iterated interactions. In particular, on the question why ambiguity is such a pervasive property in biological signaling if, at first sight, functional considerations about efficient and accurate information transfer would seem to disfavor it. With previous justifications of ambiguity, we argue that context plays an important role in allowing for the (relatively) safe exploitation of ambiguity. However, we inject some wrinkles in this justification by calling into question the assumption that interlocutors have access to the same contextual information to disambiguate utterances. We then argue that this issue unravels into a larger one, where the interaction between context, interlocutors’ private contextual expectations, and their beliefs about each other’s expectations play an important role. These factors are argued to jointly determine the conditions under which a functional advantage for ambiguity crystallizes. We conclude that ambiguity can be viewed as an opportunistic adaptive device: it endows interlocutors with the ability to flexibly mold language use to suit their communicative preferences and the context of interaction.

Iterated interactions and alignment play an important role in this chapter. By interacting multiple times, interlocutors can learn something about each other’s contextual expectations. This reduces the speaker’s uncertainty about what her interlocutor is likely to infer from an ambiguous utterance.

We analyze the outcomes of iterated interactions without a common contextual prior using a conservative generalization of previous models of rational language use, paired with simple update rules. After exploring the theoretical predictions of the model, we show that it succeeds in explaining signaling patterns found in experimental data.

The content of this chapter is based on:

Chapter 1. Introduction


Chapter 4 This chapter focuses on the evolution of a division of labor between semantics and pragmatics. To analyze how such a division may come to be, we trace the effects that two evolutionary pressures have on the joint interaction between conventionalized lexical representations and conversational strategies of language use. These pressures are (i) a horizontal one for communicative success during information transfer within a population and (ii) a vertical one for learnability, which applies when linguistic knowledge is transmitted from one generation to the next. We model the ensuing dynamics using the replicator-mutator dynamic, where replication exerts fitness-based pressure for efficient communication and mutation captures the transmission fidelity by which linguistic knowledge is transmitted through a process of iterated learning. Importantly, learners do not have access to unobservable lexical representations and conversational strategies. They instead need to infer these latent properties from the overt linguistic behavior that results from their combination.

We analyze the separate and joint influence that these pressures have in a case study on the (lack of) lexicalization of scalar implicatures. This case study suggests that semantics and pragmatics play a synergic role in overcoming both pressures: pragmatic use allows maintenance of simpler lexical representations that are easier to learn; pressure toward representational simplicity indirectly promotes pragmatic over literal language use. As a consequence, iterated transmission and use of language lead to a regularization that may explain the lack of lexicalization of systematic pragmatic enrichments.

This chapter is based on:


Chapter 5 This chapter looks at ambiguity at the population level. Drawing from the individual-level analysis in Chapter 3, we ask under which conditions conventional semantic meaning that allows for functional ambiguity exploitation evolves. For signaling behavior to be functionally advantageous it needs to ensure that information is transmitted accurately. This means that, even if a signal is semantically ambiguous, in context it should be, by and large,
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unequivocal. However, such a signal may not necessarily suggest underlying semantic ambiguity to a naïve learner. If the learner only witnesses the signal being used in a single context to signal a single meaning, then she may not learn to associate this signal with other meanings. This poses a challenge for the acquisition of (unobservable) ambiguous semantic conventions.

We use the model from Chapter 4 to investigate how the context(s) in which communication and learning take place affect the evolution of semantic ambiguity. Our results suggest that ambiguity evolves when the environment is varied, with language use happening in multiple contexts that are informative about different meanings. An environment that instead favors a single context promotes precise semantic conventions rather than the pragmatic flexibility enabled by their underspecification.

Chapter 6 This chapter discusses the models proposed in previous chapters and the predictions they make from a general perspective. We begin by reflecting on what we learned about the conditions under which language may come to favor semantic underspecification and recruit pragmatics to effect efficient and successful information transfer. We argue that there are multiple evolutionary trajectories under which this may happen. First, if communication occurs in varied informative contexts, then underspecified semantics coupled with pragmatic abilities endow interlocutors with the ability to flexibly adapt their linguistic resources to the context of interaction and their interlocutors. Second, some underspecified lexical meanings may be simpler and therefore easier to learn; if interlocutors are sufficiently rational, then pragmatic reasoning can enrich these meanings and thereby counteract functional disadvantages otherwise incurred. Reversely, if the context of interaction is static or rationality is low, then precise semantics come to be favored over pragmatic recruitment. We then discuss the methodological issues raised by this kind of investigation and argue for a pluralistic approach that takes multiple likely factors of change into consideration.

This chapter discusses results presented in fuller detail in:


Chapter 7 This is where we conclude. This chapter gives a broad summary of our findings and a sketch of roads ahead.