Computational construction grammar and constructional change

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1. Introduction

After several decades in scientific purgatory, language evolution has reclaimed its place as one of the most important branches in linguistics, leading to high-profile publications in journals such as *Science* and *Nature* (e.g. Dunn et al. 2011, 2005; Gray and Atkinson 2003). This renewed interest is to a large extent driven by the development of quantitative methods that allow researchers to make powerful empirical observations about language change (Hall and Klein 2010; Heggarty et al. 2010; Kondrak 2002; Steiner et al. 2011; Wichmann et al. 2010). However, despite more sophisticated methods for retrieving *which* changes have taken place, the field is lacking methods for explaining *how* and *why* these changes come about, and what those changes can teach us about human cognition.

This special issue aims to shed new light on these questions by exploring two important proposals: (i) language is a *complex adaptive system* (Steels 2000; Beckner et al. 2009), and (ii) a constructional approach offers the most promising linguistic framework for exploring issues in language usage and cognition. Both proposals have major ramifications for the kinds of questions that linguists must find answers for, and which methods are acceptable within the linguistic enterprise. This introduction will first clarify what these proposals entail, and offers its readers with a gentle primer on some novel computational methods that we predict will soon become an indispensable part of the linguistic toolbox. Next, we present a brief overview of the articles that this special issue brings together.

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2. Language as a complex adaptive system: The third wave in usage-based linguistics

The growing interest in language change is accompanied by a resurgence in popularity of cognitive-functional linguistics and psycholinguistics, which are often grouped together under the umbrella term *usage-based linguistics* (Bybee 1985, 2010; Langacker 2000; Diessel 2015). It is by no means an understatement to say that the usage-based perspective is a paradigm shift from generative grammar, which has dominated the field for more than half a century (Daems et al. 2015).

In a usage-based model, the dynamics of communicative and social interactions are assumed to continuously shape and reshape the structure of language (Givón 1979; Bybee 1985; Hopper 1987). In order to explain why linguistic structures are the way they are, usage-based linguists therefore study how languages are processed (Hale 2003; Hawkins 2004; Jaeger and Tily 2011; Steels and Szathmáry 2016), acquired (Tomasello 2003; Goldberg et al. 2004; Lieven 2009) and developed over time (Hopper and Traugott 1993; Coussé and von Mengden 2014). Instead of assuming an ideal speaker-listener, usage-based linguistics adopts a *population view* (Croft 2000; Steels 2012b) in which variation is abundant (Weinreich et al. 1968; Labov 2000; Hollmann and Siewierska 2011). Usage-based linguists also put great emphasis on the degree of experience a language user has with particular linguistic elements, measuring a.o. frequency effects on linguistic development (Gries 2015).

The usage-based paradigm shift has occurred in multiple waves. The first wave consists of laying the conceptual foundations of the usage-based enterprise (a.o. Rosch and Lloyd 1978; Dik 1980; Bybee 1985; Geeraerts 1985; Halliday and Hasan 1985; Langacker 1987). The second wave is concerned with getting the empirical facts straight: the field is increasingly demanding scientific claims to be corroborated by empirical evidence such as corpus data or experimental studies (Glynn and Fischer 2010; Rice and Newman 2010). This special issue connects these developments to a third wave in usage-based linguistics: the study of language as a *complex adaptive system*.

A complex adaptive system (CAS) is a system that consists of many components (called *agents)* whose locally situated interactions lead to emergent properties of the system as a whole (Holland 2006). The system is adaptive because agents change their behavior based on past experiences and the challenges of their current interactions. The CAS perspective has become widespread in many branches of science for studying a.o. social insect colonies in biology or the stock market in economics. Likewise, language can be considered as a complex adaptive system, in which a population of multiple agents (speaker-listeners) engage in locally situated, communicative interactions (Steels 2000; Beckner et al. 2009).

The CAS perspective offers a unifying framework for usage-based research in all areas of linguistics, ranging from language acquisition to historical linguistics and interaction studies. It also makes clear that new methodologies need to be recruited, because some of the foundational assumptions of usage-based theory are still left unexplored because of the lack of data. For example, the core hypothesis that language users dynamically shape and reshape their language as they engage in communicative interactions remains out of the grasp of empirical scrutiny because (a) evaluating variation and discovering ongoing changes in corpus data requires in-depth analysis, which cannot be done on a large scale yet (Croft 1991, 34–35), and (b) experimental studies can carefully examine the dynamics of local interactions, but they cannot track how these interactions may have a lasting impact on the speech community as a whole.

Fortunately, many mathematical, computational and robotic tools have been developed for studying complex adaptive systems, which makes it possible to formulate precise hypotheses about the empirical data and then test the consequences of these hypotheses. The most important method is *agent-based language modeling* (see Smith 2014, for an overview). An agent-based language model typically includes the following components:

1. A population of multiple agents that model the speech community. Each agent models an individual language user capable of speaking and listening. Speech communities can range from unstructured, fixed populations (i.e. a fixed number of agents that are all equal) to communities that involve a generational turnover (i.e. new agents can enter the population and older agents may disappear), social and topological structure (e.g. social status, distance between agents, …) or multiple communities (e.g. for modeling language contact).
2. An interaction scenario embedded in either a simulated world (emulation) or a real-world environment (robotic experiment). For example, agents may describe events to each other that they witness in a shared communicative context.
3. An operationalization of the cognitive-functional mechanisms for learning and using particular linguistic structures. Each agent is endowed with these mechanisms. For example, if a particular kind of language change is hypothesized to be the result of analogical reasoning, the experimenter must endow the agents with this capability. Other mechanisms may include categorization, joint attention, spatial reasoning, automization, reanalysis, and so on.
4. An operationalization of the conceptual spaces and linguistic inventories that the experimenter wishes to examine. These can be empty (e.g. in scenarios where the emergence of a new language is investigated) or they can reconstruct attested phenomena (e.g. the basic color categories and lexicon for Japanese).

Agent-based language modeling is a theory-neutral methodology. The first reported experiment implemented a model of the Language Acquisition Device and subscribed to the leading approaches in generative grammar of its time (Hurford 1989). The first agent-based model that explored language as a complex adaptive system was pioneered by Steels (1995), who showed how a population of agents can develop a shared vocabulary from scratch without central coordination. Since then, CAS models have become the most successful ones in examining how linguistic phenomena may emerge as a side effect of the interactions between multiple agents (Steels 2000, 2012a; Kirby 2002; Smith 2014).

About two decades ago, there was a lot of skepticism about the viability of agent-based models as implementing an acceptable research methodology. Early studies were inevitably concerned with abstract questions (e.g. how can a compositional communication system emerge) and highly constrained due to the lack of computing power. However, as computational and robotic hardware were rapidly advancing, so was agent-based modeling. Between 1995 and 1999, these models focused strongly on vocabulary formation and the symbol grounding problem (Harnad 1990), which culminated in the Talking Heads experiment (Steels 2015), the largest-scale agent-based language model to date, which demonstrated how a population of agents – embodied through pan-tilt cameras – were able to develop a shared vocabulary and ontology grounded in sensorimotor processing. Models have subsequently tackled many grammatical phenomena, such as argument structure and case (van Trijp 2010a), agreement (Beuls and Steels 2013) and locative expressions (Spranger 2013). State-of-the-art models can now also target very specific case studies in language change, such as the evolution of personal pronouns in Spanish (van Trijp 2010b), case declension in German (van Trijp 2013b) and weak versus strong verbal inflection in Germanic (Pijpops et al. 2015).

All of the three waves in usage-based linguistics are important and need the other waves for achieving solid scientific theories. The conceptual foundations of the enterprise require refinement and validation through empirical studies; analyses based on empirical studies need to be tested through agent-based modeling; and agent-based modeling needs to be evaluated with respect to the empirical data.

3. Why construction grammar?

Mainstream linguistics has always upheld a distinction between core linguistic structures and a *periphery* of exceptions. The core of the language consists of systematic rules that combine phrases, whereas the periphery is typically listed as part of the lexicon. Usage-based linguistics rejects this distinction and proposes that

the linguistic inventory should be conceived as a syntax-lexicon *continuum* rather than a rules-and-lexicon model.

One reason for rejecting the rules-and-lexicon model is what Langacker (1987) dubbed the *Rule/List Fallacy.* The rules-and-lexicon model implies that linguistic expressions must either be composed through rules, or fetched from the lexicon without overlap in storage. Usage-based linguists, however, claim that even systematic expressions may be "redundantly" stored in memory depending on their frequency. Language users can use these ready-made chunks for efficient language processing, and there is an impressive body of evidence that supports the psychological relevance of this claim (Johansen and Palmeri 2002). Secondly, the sharp distinction between syntax and lexicon does not fit the linguistic data. Computational experiments have charted the many subregularities and pockets of exceptions in languages, and have shown that it is harmful to ignore these examples for language learning (Daelemans et al. 1999). Moreover, idiomatic phrases can range from fully fixed expressions to partially systematic (Nurnberg et al. 1994).

Construction grammar caters for the usage-based demand for an approach that can handle the syntax-lexicon continuum, because it grew out of a similar desire to account for the entirety of language instead of making a distinction between *core* linguistic structures and a *periphery* of exceptions. Early constructional analyses therefore focused on specific patterns that before were considered to be peripheral, such as the *Let Alone* (Fillmore et al. 1988) or the *What's X doing Y?* constructions (Kay and Fillmore 1999). More recent work has shown how construction grammar can also capture highly schematic linguistic phenomena such as argument structure (Goldberg 1995; Perek 2015).

At the heart of all constructional approaches is the proposal that the basic units of language are *constructions,* which are conventionalised mappings between function, form and usage constraints (Fillmore 1988). Moreover, since there are no constraints at what kind of function-form mappings constitute a construction, a constructional approach is perfectly suited for analyzing scenarios that involve variation, change and emergence. For instance, studies in language acquisition require an approach that is able to track the linguistic development of children ranging from single word utterances to verb islands and mature linguistic proficiency (Tomasello 2003; Goldberg et al. 2004; Lieven 2009). Likewise, the field of evolutionary linguistics has widely adopted construction grammar because of its adequacy for modeling emergent phenomena (Steels 2004; Arbib 2012; Pleyer and Lindner 2014), and for the same reasons construction grammar is becoming increasingly popular in diachronic linguistics (Fried 2009; Traugott and Trousdale 2013; Van de Velde 2014; Barðdal et al. 2015).

Construction Grammar has also attracted the interest of formal and computational linguists, who have argued that implementing the constructional perspective presents *"a formidable challenge [that may lead to] a more comprehensive account of language processing than our field is able to offer today"* (Schneider and Tsarfaty 2013, 451). An increasing number of researchers is taking up this challenge, and several ways of operationalizing ideas from construction grammar are currently being explored (Jurafsky 1996; Steels 2004, 2011; Bergen and Chang 2005; Bod 2009; Boas and Sag 2012; van Trijp 2013a, 2015). One of the most advanced projects in computational construction grammar is Fluid Construction Grammar, a fully operational and open-source platform for developing models of language processing, acquisition and evolution from a usage-based perspective (Steels 2004, 2011). Such computational processing models are important for validating many of the assumptions about language dynamics that are posited in usage-based linguistics, and a necessary step for moving linguistics forward towards a field that encompasses the study of both language competence and performance.

4. Contributions to this special issue

The papers in this volume can all be positioned in the plane formed by the two main axes of construction grammar and complex adaptive systems. Three main blocks can be distinguished: The first block present papers that take a constructional approach to language from a usage-based perspective. The next block serves as an introduction to agent-based modeling. And finally, a third block of papers puts these perspectives together.

4.1 Constructional approaches to language

The first block includes papers that are firmly rooted in usage-based, constructional approaches to language, starting with two position papers and then moving to empirical studies.

In "Chopping down the syntax tree: what constructions can do instead", Remi van Trijp compares the expressive power of phrase structure to construction grammar from an information processing perspective. He argues that tree-based analyses, popular in generative linguistics, are inadequate for handling multiple argument realization, word order variation and long-distance dependencies. As an alternative, he proposes that the concept of a construction (and its computational implementation in Fluid Construction Grammar) is capable of successfully

capturing these linguistic structures, while at the same time outperforming phrase structure grammars in terms of theoretical elegance and empirical coverage.

Dirk Noël argues "For a radically usage-based diachronic construction grammar" in his paper by tracing it back to historical construction grammar on the one hand and constructionist grammaticalization theory on the other hand. He argues that to arrive at truly usage-based models of change, a separation of internal and external constructicons is required, and uses this separation as assessment criterion for two usage-based models of constructional change: "Traugott/Trousdale" and "Fischer".

The three empirical studies in this special issue all relate to different aspects of complex adaptive systems and usage-based theory. The first paper, "Tracking shifts in literal versus intensifying use of the fake reflexive resultative construction" by Emmeline Ghyselinck and Timothy Colleman, illustrates how speaker preferences and collocations may evolve over time. More specifically, they explore ambiguous clauses such as *Hij werkte zich dood* (lit. 'He worked himself dead') and find that the intensifying use has become predominant over the course of the last two centuries. They investigate the notion of productivity by taking into account a variety of verbs that *dood* has occurred with since the early 19th century to assess whether the increased relative frequency of the intensifier has led to an extension of its collocational range.

The article "A reflection on constructional borrowing, with reference to a Dutch calque of the 'time'-away construction" by Timothy Colleman takes a clear population view and offers a case study of language contact. Colleman claims that the recent innovation in Dutch of an argument structure construction that mirrors the form and semantics of the English 'time'-away construction is the result of direct copying. The observed change would therefore qualify as an instance of instantaneous grammatical constructionalization.

In "Unidirectionality as a cycle of convention and innovation", Peter Petré zooms into the question of variation – even within the same speaker – and investigates the interaction between conventional and unconventional behaviour of language users in the developments of [BE Ving] and [*be going to* INF]. Petré argues that extravagance is a key driving force that pushes speakers to innovate, and that these innovations may then conventionalize again through routinization. He hypothesizes that the continuous spiral of the conventional leading to innovation leading to the conventional again, may explain unidirectionality in language change.

4.2 Agent-based language models

"A boy named Sue: The Semiotic Dynamics of Naming and Identity" by Luc Steels, Martin Loetzsch and Michael Spranger demonstrates how phenomena that may seem simple from a linguistic perspective – proper names – are already very complicated and elusive to mechanistic explanations. They put forward an agent-based model of the Grounded Naming Game that investigates the semiotic dynamics of naming and identity.

"A gentle introduction to the Minimal Naming Game" by Andrea Baronchelli looks at the Naming Game from the perspective of statistical physics. Such analytical models are required for answering important questions about the outcome of agent-based models: how can populations converge on a linguistic system? What is the role of the population size? Will a consensus always be reached?

The third contribution in this block, "The evolution of lexical usage profiles in social networks" by Gerhard Schaden, investigates how the structure of a social network (i.e. a population) may influence the semiotic dynamics of lexical learning. The model shows that even without any kind of functional pressures, lexical differentiation may occur depending on the distance between nodes of the network and depending on its size and structure. As such, the model can be used as a testbed for important questions in the formation of dialects, continua, and so on.

4.3 Bringing both worlds together

The contribution by Roxana Radulescu and Katrien Beuls "Modelling pronominal gender agreement in Dutch" shows how findings from the field of (diachronic) construction grammar can feed into agent-based models to investigate the causal mechanisms behind the observed changes. They study how anaphoric gender agreement in Dutch could shift from a firmly established syntactic system, accompanied by rich morphological marking, to a semantic-oriented system, in which animacy and countability of the referent determines the gender of the anaphoric pronoun. They experiment with different ways to simulate imperfect transmission of gender knowledge and find that a gradual replacement rate of agents leads to a more swift transition from a syntactic to a semantic agreement system than when constraints are added on the memory of agents, forgetting parts of their gender knowledge.

In "Embodied cognitive semantics for quantification", Simon Pauw and Joseph Hilferty propose an operational semantic model of natural language quantifiers and their use in quantified noun phrases. Focusing on embodied-interaction scenarios, they present a semantic model that is based on fuzzy quantification and standard computational clustering methods.

Finally, Javier Valenzuela, Joseph Hilferty and Oscar Vilarroya ask the question "Why are embodied experiments relevant to cognitive linguistics?" The paper critically examines the usage of computational and agent-based models for linguistics, and argues that these novel technologies are crucial for strengthening the methodological standards of cognitive-functional linguistics research.

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