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Beuls, Katrien; Van Eecke, Paul

Published in:
CxGsNLP 2023 - 1st International Workshop on Construction Grammars and NLP (CxGs+NLP, GURT/SyntaxFest 2023), Proceedings of the Conference

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Link to publication

Citation for pulished version (HARVARD):
Beuls, K & Van Eecke, P 2023, Fluid Construction Grammar: State of the Art and Future Outlook. in *CxGsNLP 2023 - 1st International Workshop on Construction Grammars and NLP (CxGs+NLP, GURT/SyntaxFest 2023), Proceedings of the Conference.* CxGsNLP 2023 - 1st International Workshop on Construction Grammars and NLP (CxGs+NLP, GURT/SyntaxFest 2023), Proceedings of the Conference, pp. 41-50, GURT 2014 (Georgetown University Round Table on Languages and Linguistics), Washtington, United States, 14/03/14. <https://aclanthology.org/2023.cxgsnlp-1.6/>

Fluid Construction Grammar: State of the Art and Future Outlook

Katrien Beuls[1] and **Paul Van Eecke**[2,3,4]
[1]Faculté d'informatique, Université de Namur, rue Grandgagnage 21, B-5000 Namur
[2]Artificial Intelligence Laboratory, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels
[3]KU Leuven, Faculty of Arts, Blijde Inkomststraat 21, B-3000 Leuven
[4]KU Leuven, imec research group itec, Etienne Sabbelaan 51, B-8500 Kortrijk
`katrien.beuls@unamur.be`
`paul@ai.vub.ac.be`

Abstract

Fluid Construction Grammar (FCG) is a computational framework that provides a formalism for representing construction grammars and a processing engine that supports construction-based language comprehension and production. FCG is conceived as a computational operationalisation of the basic tenets of construction grammar. It thereby aims to establish more solid foundations for constructionist theories of language, while expanding their application potential in the fields of artificial intelligence and natural language understanding. This paper aims to provide a brief introduction to the FCG research programme, reflecting on what has been achieved so far and identifying key challenges for the future.

1 Introduction

Fluid Construction Grammar (FCG[1]) (Steels and De Beule, 2006; Steels, 2011, 2017; van Trijp et al., 2022) is a computational framework that aims to operationalise the foundational principles underlying constructionist approaches to language. On a high level, the FCG framework serves two main purposes. On the one hand, it aims to provide a solid methodological basis for studying the emergence, evolution, acquisition and processing of language from a construction grammar perspective, through a standardised formalisation and a tractable computational operationalisation. On the other hand, it aims to facilitate the building of intelligent agents that are capable of communicating with humans and each other through languages that exhibit the robustness, flexibility and adaptivity of human languages.

In this paper, we aim to provide a brief introduction to the FCG research programme, highlighting its relevance in the field of linguistics on the one hand, and in the fields of artificial intelligence and natural language understanding on the other. We start by situating the FCG framework within the field of construction grammar (Section 2) and then lay out in a step-by-step manner how FCG provides a faithful computational operationalisation of the basic tenets of construction grammar (Section 3). We then discuss how constructions are learned as compositional generalisations over recurring syntactico-semantic patterns (Section 4) and proceed with an overview of applications that integrate FCG technologies (Section 5). Finally, we consider a number of key challenges and opportunities for future computational construction grammar research and conclude that the automatic learning of large-scale, usage-based construction grammars that support both language comprehension and production is a promising and timely research direction that is now well within reach (Section 6).

2 Situating Fluid Construction Grammar

Over the last four decades, the linguistic community has become increasingly more interested in constructionist approaches to language, as witnessed by the increased presence of talks, tutorials, courses and workshops at international conferences and schools (van Trijp et al., 2022). The term 'constructionist approaches to language' (Goldberg, 2003) is used to refer to a variety of theoretical frameworks, which all share a number of key foundational principles. These principles, as laid out by among others Fillmore (1988), Goldberg (1995), Kay and Fillmore (1999) and Croft (2001), and which are commonly referred to as the *basic tenets of construction grammar*, are summarised by van Trijp et al. (2022) as follows:

1. **All linguistic knowledge is captured in the form of constructions**. Constructions (cxns for short) are defined as form-meaning pairings that facilitate the comprehension and production of linguistic utterances. Comprehension corresponds to the process of mapping

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[1] `https://fcg-net.org`

Proceedings of the First International Workshop on Construction Grammars and NLP (CxGs+NLP, GURT/SyntaxFest 2023), pages 41 - 50
March 9-12, 2023 ©2023 Association for Computational Linguistics

from an utterance to its meaning representation, while production corresponds to the inverse process of mapping from a meaning representation to an utterance that expresses it. All linguistic phenomena, whether they are traditionally seen as regular, irregular or idiomatic, are considered to be of equal interest. The same formal machinery is used to handle all phenomena.

2. **There exists a lexicon-grammar continuum, with no distinction between "words" and "grammar rules"**. Each construction is situated somewhere on this continuum. Constructions can range from entirely idiomatic expressions, over partially productive patterns, to entirely abstract schemata. Examples of these types of constructions are respectively (i) the BREAK-A-LEG-CXN, which constitutes a holistic pairing between the utterance "*break a leg!*" and the meaning of wishing an addressee good luck, (ii) the X-TAKE-Y-FOR-GRANTED-CXN, which includes variable slots for the agent and the undergoer, and expresses that the former does not value the latter, and (iii) the RESULTATIVE-CXN in "*the Tasmanian tiger was hunted to extinction*", which expresses that the Tasmanian tiger was extinct as a result of hunting.

3. **Constructions can contain information from all levels of linguistic analysis**. Construction grammar does not make an a priori distinction between the different layers of traditional linguistic analysis, such as phonetics, phonology, morphology, syntax, semantics and pragmatics. Constructions can, but do not need to, include information from any of these layers at the same time, as long as they constitute a mapping between some aspects of meaning and some aspects of form. It is entirely open what the form side and the meaning side of a construction can contain. For example, the form side typically includes phonetic, phonological, morphological, syntactic or multimodal information, while the meaning side typically includes semantic and/or pragmatic information.

4. **Construction grammars are dynamic systems, of which the constructions and their entrenchment are in constant flux**. Constructions always represent the linguistic knowledge of an individual language user. Constructions are acquired and change over time. They can be more or less entrenched as they are used more or less frequently and successfully in communication.

Constructionist theories of language have explicitly or implicitly built on these basic tenets since the 1980s, with initial formalisations being inspired by phrase structure grammars (Fillmore, 1988). Later, when the Lakovian/Goldbergian branch of construction grammar, often referred to as *cognitive construction grammar*, became predominant (Lakoff, 1987; Goldberg, 1995), the focus on formalisation gradually faded into the background. As is justifiable for an emerging field of research, the focus was more on the conceptual clarification of the loosely defined innovative ideas, rather than on the construction of a solid methodological framework (cf. Langacker, 1987, p. 1 and 42-45). However, the absence of such a framework led to the criticism that construction grammar was often not more than "*a set of insightful but untestable ideas*" (Bod, 2009, p. 2–3). Initial efforts to establish such a framework in the early 2000s gave rise to the emergence of the field of computational construction grammar, with Embodied Construction Grammar (ECG) (Bergen and Chang, 2005; Feldman et al., 2009), Sign-Based Construction Grammar (SBCG) (Sag, 2012; Van Eynde, 2016) and Fluid Construction Grammar (Steels and De Beule, 2006; Steels, 2011; van Trijp et al., 2022) being the most advanced projects in this area.

Computational operationalisations of construction grammar have four main objectives. First of all, they are important for verifying the internal consistency of construction grammar theories, which is impossible to do by hand for larger grammars. Second, they facilitate the large-scale empirical validation of these theories on corpora of language use. Third, they can serve as a standard for exchange and collaboration between construction grammar researchers. Finally, they make it possible to exploit construction grammar insights and analyses for the purpose of building language technology applications.

3 Operationalising Construction Grammar

We will now briefly discuss how the basic tenets of construction grammar can be computationally operationalised. We will focus solely on how this is achieved in the framework of Fluid Construction Grammar. For an introduction into the FCG system itself, including the syntax and semantics of the formalism, we refer the reader to Chapter 3 of Van Eecke (2018).

3.1 All linguistic knowledge is captured in the form of constructions

It is clear from the basic tenets of construction grammar that constructions are by definition pairings between (aspects of) form and (aspects of) meaning. However, the theory is less clear about what counts as form and what counts as meaning. In FCG, we approach this question from a communication perspective, starting from the role of constructions in language comprehension and production. We define form as the result of the language production process and as the starting point of the language comprehension process. Likewise, we define meaning as the result of the language comprehension process and as the starting point of the language production process. In other terms, form comprises all that is externalised by a speaker and observed by a listener. Meaning is then all that is expressed by a speaker and reconstructed by a listener. Typically, form comprises linguistic features that traditionally belong to the domains of phonetics, phonology, morphology, syntax and multi-modality, while meaning typically encompasses linguistic features that traditionally belong to the domains of semantics and pragmatics. Operationally defining form and meaning in this way excellently fits the constructionist perspective on language, as it starts from the role of form and meaning in linguistic communication. Not only is the distinction purposeful, it is also clear-cut and avoids other, more problematic, distinctions between the traditional levels of linguistic analysis.

FCG defines a dedicated data structure for representing constructions, which formalises form-meaning mappings in a way that is adequate for constructional language processing. FCG operationalises constructional language processing as a state-space search process, in which constructions can add linguistic information to a transient feature structure (see Bleys et al., 2011; Van Eecke and Beuls, 2017). The skeleton of FCG's construction data structure is shown in Figure 1. On the highest level, the information captured by a construction is structured in two parts, separated by a horizontal arrow. The right-hand side holds the preconditions for the construction to apply, and the left-hand side holds the information that the construction contributes during its application. The preconditions are divided into two sets, one set for comprehension written below a horizontal line and another set for production written above it. The application of a construction proceeds in two phases. First, the preconditions for the direction of processing are matched against the transient structure using a subset unification algorithm that checks whether these preconditions are compatible with the transient structure. If so, the postconditions are merged into the transient structure through another unification process (Steels and De Beule, 2006; Sierra Santibáñez, 2012), along with the preconditions of the other direction of processing. Solving a comprehension or production problem consists then in finding a sequence of constructions that adequately maps an utterance to its meaning representation (in comprehension) or a meaning representation to an utterance that expresses it (in production).

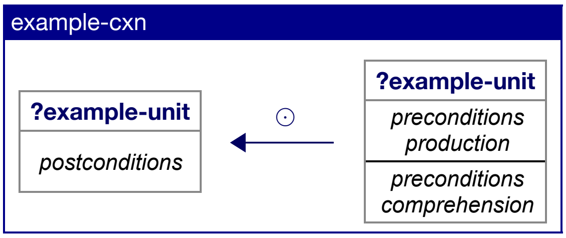

Figure 1: The skeleton of FCG's construction data structure.

FCG does not impose any specific features to be included in a construction, which means that the nature, use and names of features and their values is entirely up to the grammar designer or learning system.

3.2 There exists a lexicon-grammar continuum

FCG's construction data structure supports the constructionist view that there is no clear-cut distinction between "words" and "grammar rules". Constructions can capture form-meaning patterns of arbitrary size and degree of abstraction. This means that they can cover units that would traditionally be called phonemes, morphemes or words, but also larger units that range from idiomatic expressions over partially instantiated patterns to entirely abstract schemata. Constructions can thus include features encoding low-level material such as sounds/strings or meaning predicates, along with features that encode more abstract information, for example through the use of grammatical categories. Importantly, all constructions are represented using the same data structure and there is no formal distinction between constructions covering lexemes (sometimes called lexical constructions) and those covering larger, more abstract patterns (sometimes called grammatical constructions). Constructions do not assume any symmetry between their form pole and their meaning pole, not in terms of complexity, nor in terms of compositionality. For example, complex or compositional forms can correspond to atomic meaning predicates and complex semantic structures can correspond to atomic or non-compositional forms.

All information captured by constructions is expressed through the use of feature structures, of which the features and values are open-ended. As such, a construction can include features expressing constraints on the word order of its constituent parts and features that represent hierarchical structures. However, the complete or partial specification of word order patterns is inherently optional, and constructions do not necessarily correspond to tree-building operations (van Trijp, 2016).

3.3 Constructions can contain information from all levels of linguistic analysis

FCG operationalises constructional language processing through general mechanisms, in particular as a state-space search process in which the preconditions and postconditions of its operators (i.e. the constructions) are feature structures that are matched and merged through first-order syntactic unification algorithms (Steels and De Beule, 2006; Sierra Santibáñez, 2012; Van Eecke, 2018). This allows the system to process feature structures consisting of arbitrary symbols, which do not even need to be declared beforehand. The range of features and values that can be used is thus open-ended and there is no restriction on the kind of information that the feature structures can represent. Indeed, the symbols carry the meaning associated to them by the grammar engineer or learning system, and have no meaning to the FCG system itself apart from their occurrences in the feature structures. Consequently, both the preconditions and the postconditions of a construction can contain features encoding information on any or all levels of traditional linguistic analysis.

3.4 Construction grammars are dynamic systems

FCG considers grammars, i.e. inventories of constructions, to represent the linguistic knowledge of an individual, autonomous agent. It assumes that the grammars are learnt and evolve over time, adapting to changes in the environment and communicative needs of the agent. Constructions hold a score, which reflects their entrenchment in the grammar. During language comprehension and production, constructions with a higher entrenchment score are preferred over constructions with a lower score. While different experiments might implement the use of entrenchment scores differently, the general idea is that the scores of constructions are updated according to their successful or unsuccessful use in communication. Constructions that are frequently used successfully become more entrenched, while constructions that are used unsuccessfully become less entrenched until they might eventually disappear from the grammar. The fact that features and their possible values do not need to be declared beforehand (see 3.3) ensures that new constructions carrying new features can be dynamically added to the grammar should the need arise.

4 Learning Construction Grammars

Now that we have established computational representations for constructions, as well as processing mechanisms that use these constructions for operationalising language comprehension and production, we can approach the question of where these constructions originate and how they are shaped by the communicative needs of their hosts. Again, we start from theoretical and empirical work in usage-based linguistics with the aim of building mechanistic models that computationally operationalise the theoretical insights that were obtained and the empirical evidence that was gathered, in order to support communication in artificial agents.

Usage-based theories of language acquisition describe two main cognitive processes involved in the acquisition of language through communicative interactions: *intention reading* and *pattern finding* (Tomasello, 2003). Intention reading is the process through which listeners hypothesize about the intended meaning of an observed utterance, by reasoning about the situation in which this utterance was formulated. For example, when a child observes the utterance “more-milk?” and receives more milk at the same time, the child can hypothesise that the meaning of this utterance is that an additional portion of this thirst-quenching white liquid will be served. Pattern finding is then the generalisation process through which abstract patterns can be distilled. For example, if the same child then observes the utterance “more-mash?” in a situation where it is served an additional portion of this delicious soft mass, it can generalise to the pattern “more-X?” with the meaning of being served an additional portion of something. At the same time, it can infer that “milk" and “mash” respectively refer to this thirst-quenching white liquid and this delicious soft mass.

The processes of intention reading and pattern finding yield pairings between meaning and form and therefore, by definition, constructions. Initially, a child, or an intelligent agent in our case, cannot do more than store holistic mappings between observed utterances and their (hypothesised) meanings. Indeed, these holophrastic constructions are at this point not further decomposable, as the learner has no information on whether and how specific parts of their meaning might correspond to specific parts of their form. Later, when similar, yet not identical utterances are observed in similar, yet not identical situations, more general item-based constructions can be created, through generalisation over the compositional parts of the form-meaning pairings. The item-based constructions then capture the relations between these variable elements along with any non-compositional aspects of the original form-meaning mappings. Over the course of increasingly more communicative interactions, these generalisations lead to increasingly more abstract constructions. At some point, the constructions adequately reflect the compositional and non-compositional aspects of the language, and the construction inventory of the learner stabilises.

As intention reading hypothesises about the intended meaning underlying an observed utterance in a particular situation, it can yield a hypothesis that might hold in that situation but not in others. Consequently, generalisation over these suboptimal hypotheses might lead to more abstract constructions that are suboptimal as well. It is here that the entrenchment dynamics described in the previous section come into play. Over time, constructions that are used more frequently and successfully in communication become more entrenched. At the same time, suboptimal constructions, which often lead to communicative failure, become less entrenched until they eventually disappear from the construction inventory of the learner. After a sufficient number of communicative interactions, the construction inventory stabilises on a set of generally applicable constructions that cover the learner’s communicative needs.

The process of language acquisition through intention reading and pattern finding is operationalised in Fluid Construction Grammar through a meta-layer learning architecture that supports (i) the composition of meaning representations based on the situation (intention reading) and (ii) the generalisation over form-meaning mappings of various degrees of abstraction (pattern finding) (Van Eecke and Beuls, 2017; Van Eecke, 2018; Nevens et al., 2022; Doumen et al., 2023). An example of such a generalisation operation, taken from the experiment described in Nevens et al. (2022) is shown in Figure 2. In this figure, a learner agent observes the utterance “*how many cylinders are there?*” in a 3D scene of geometrical figures, but cannot understand it, as the utterance is currently not covered by the constructions in its construction inventory. The learner agent receives feedback in the form of the answer to the question (“*one*”). Starting from this answer, it can then construct a meaning hypothesis. In this case, the agent hypothesises that the utterance “*how many cylinders are there?*” corresponds to the meaning of segmenting the scene, activating the cylinder prototype, using that prototype to filter the segmented scene for cylinders and counting the items in the filtered set. Indeed, upon execution, this procedural semantic representation leads to the answer “*one*” in this scene. The result of the intention reading operation is shown in Subfigure A of Figure 2.

The agent then identifies a construction in its construction inventory that is minimally different from this pairing between the observed utterance and its hypothesised meaning, namely the holophrastic HOW-MANY-SPHERES-ARE-THERE-?-CXN shown in Subfigure B. This previously acquired construction maps between the utterance “*how many spheres are there?*” and the meaning of segmenting the scene, activating the sphere prototype, using that prototype to filter the segmented scene for spheres and counting the items in the filtered set. Based on this previously acquired construction, the observed utterance and its hypothesised meaning, the agent creates a new item-based

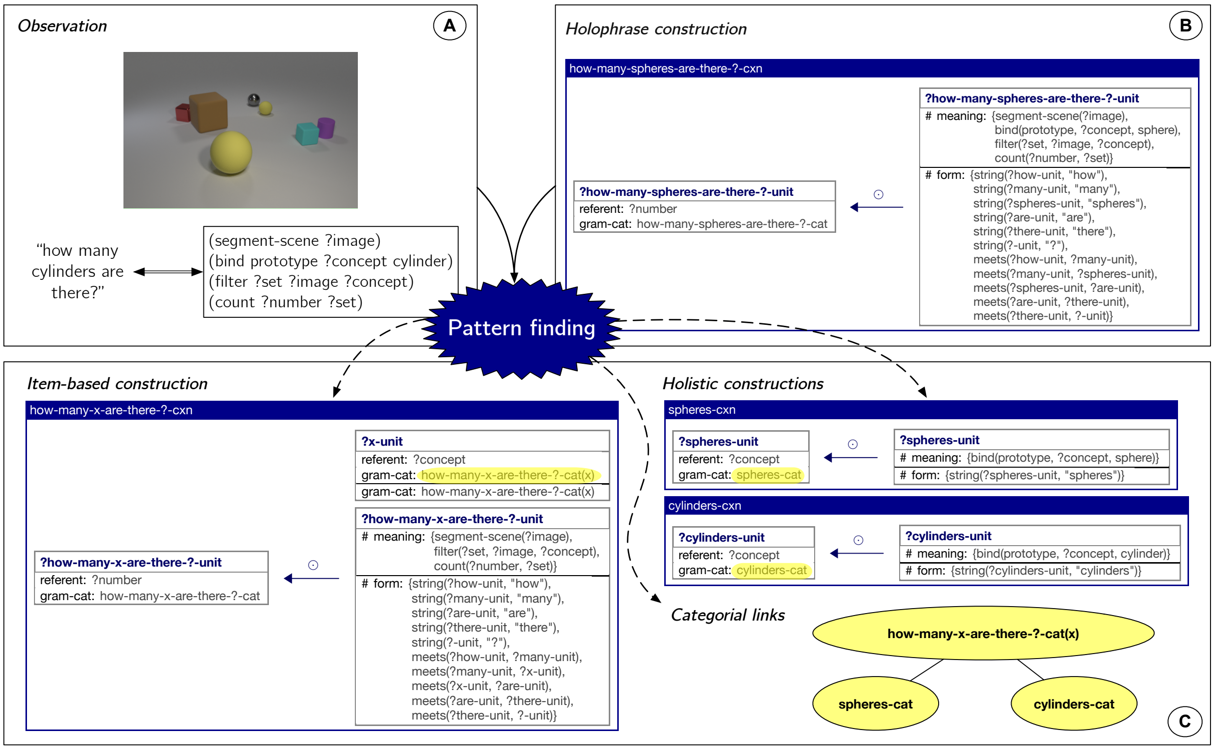

Figure 2: Example of a pattern finding operation that generalises over the observed utterance "*how many cylinders are there?*" paired with its hypothesized meaning (A) and an existing holophrase construction HOW-MANY-SPHERES-ARE-THERE-?-CXN (B). It thereby expands the construction inventory with a new item-based construction HOW-MANY-X-ARE-THERE-?-CXN, two new holistic constructions CYLINDERS-CXN and SPHERES-CXN, and two new categorial links that capture how these constructions can be combined (C).

construction along with two new holistic constructions, as shown in Subfigure C. The item-based construction maps between the form "*how many X are there?*", with X being a variable unit, and its meaning representation of segmenting the scene, filtering the segmented scene for the prototype specified by the variable unit and counting the items in the filtered set. The lexical constructions respectively map between the forms "*cylinders*" and "*spheres*" and the meaning representations of activating the cylinder prototype and activating the sphere prototype. Along with these three constructions, also two categorial links are learnt, which capture the way in which the holistic constructions can combine with the item-based construction. The constructions and categorial links that were acquired are bidirectional and can now be used by the agent for language comprehension and production.

The mechanisms of intention reading and pattern finding are combined with the entrenchment dynamics introduced above. New constructions and categorial links are introduced with a given initial entrenchment score. This score is increased if a construction or categorial link was used in a successful communicative interaction. The score is decreased if it was used in an unsuccessful communicative interaction, or if it was not used but could have been used (i.e. it was a competitor to a successful solution). If the score reaches a specified bottom threshold, the construction or categorial link is removed. These evolutionary dynamics of rewarding and punishing constructions and categorial links ensure that communicatively adequate constructions survive, while inadequate or suboptimal constructions disappear. Not only does this make the system robust against the introduction of inadequate constructions, for example due to bad hypotheses resulting from intention reading, it also ensures that the construction inventory eventually stabilises on the most generally applicable constructions. These are the most abstract constructions possible, i.e. those that are not compositional and can therefore not be further generalised over.

Figure 3, adopted from Nevens et al. (2022), shows the typical dynamics of an experiment in which a construction grammar is learnt through intention reading and pattern finding. The x-axis corresponds to the time dimension, expressed here

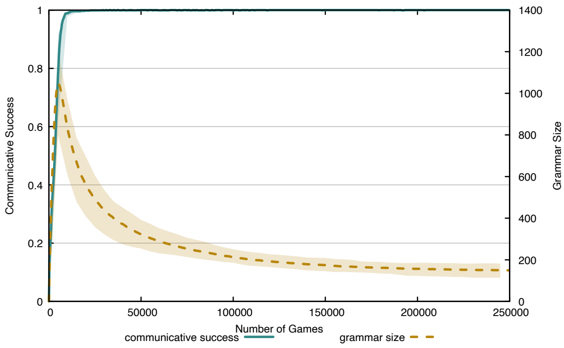

Figure 3: Typical dynamics of an experiment in which a construction grammar is acquired by an autonomous agent through the mechanisms of intention reading and syntactico-semantic pattern finding during communicative interactions. Figure adopted from Nevens et al. (2022).

in terms of the number of communicative interactions in which an agent has participated. The y-axis shows the average communicative success (green line) and the number of construction in the construction inventory of the agent (yellow line) over time. The communicative success starts at 0, as the agent starts without any constructions in its construction inventory. As more and more interactions take place, the communicative success rises to 1, which means that every communicative interaction is successful. The number of constructions in the construction inventory of the agent starts at 0 as well, and then rapidly grows to over 1000. It then starts to decrease, as a result of the entrenchment dynamics, and stabilises somewhere between 150 and 200. During this process, constructions capturing communicatively inadequate form-meaning mappings, as well as form-meaning mappings that are also captured by more generally applicable constructions, disappear from the grammar.

The example discussed in this section is meant to illustrate how an inventory of constructions can be learnt in a usage-based fashion through syntactico-semantic generalisation operations, and how the construction inventory of an agent is shaped by past successes and failure in communication. The exact mechanisms through which the intention reading and pattern finding processes are operationalised, along with the a precise definition of the entrenchment dynamics, fall outside the scope of this paper, although we happily refer the interested reader to publications such as Van Eecke and Beuls (2018) and Nevens et al. (2022).

5 Applications of FCG

Fluid Construction Grammar was originally developed to be used as the language processing component in experiments on the emergence and evolution of language (see e.g. Steels, 2004; van Trijp, 2008; Pauw and Hilferty, 2012; Beuls and Steels, 2013; Spranger, 2016; Cornudella Gaya et al., 2016; Nevens et al., 2019b). As such, it is designed to represent the emergent linguistic knowledge of autonomous agents, as well as to use this knowledge for language comprehension and production. The fact that FCG is rooted in such experiments is reflected in a number of important design choices.

First of all, FCG focusses on representations of linguistic knowledge that are adequate for both language comprehension and production. Second, it provides good support for grounded language processing, for example by providing the possibility to use procedural semantic representations (Woods, 1968; Winograd, 1972; Spranger et al., 2010) and procedural attachment in the constructions (Bundy and Wallen, 1984; Van Eecke, 2018). Third, it focusses on the data-efficient learning of constructions, whereby as much linguistic knowledge as possible is extracted from individual communicative interactions. Fourth, it uses transparent and human-interpretable representations. Finally, it is designed to represent and process ever-evolving grammars, in which new constructions can dynamically be added and in which adequacy of constructions can evolve as changes in the environment or task take place.

While experiments on the emergence and evolution of languages in populations of autonomous agents through task-based communicative interactions are the most prominent application domain for FCG, the design properties mentioned above also make it an attractive framework for a wider range of applications. A first series of applications tackles typical NLP/NLU benchmarks that focus on grounded language processing on the one hand, and on the integration of language processing and reasoning on the other. Typical examples of such tasks are visual question answering (VQA) and visual dialogue, in which the task consists in answering a series of questions about a given image. FCG is then used as a semantic parsing module, which maps from questions to executable queries (Nevens et al., 2019a). The main advantage of the use of FCG in such applications, as compared to the use of neural approaches, is that it provides a transparent and explainable model that can be learnt efficiently (Nevens et al., 2022). Interactive demonstrations of the use of FCG in NLP/NLU systems are provided at the following links respectively for VQA[2] and visual dialogue[3].

A second series of applications makes use of FCG to support the analysis of opinion dynamics expressed in online (social) media. In particular, FCG is used in such applications to extract semantic frames from textual data, such as newspaper articles and comments, subreddits, and parliamentary speeches. Concrete examples are the Penelope Climate Change Opinion Observatory[4] and the Penelope Opinion Facilitator[5]. The opinion observatory (Willaert et al., 2020, 2022) aims to provide social science researchers with a low-barrier tool for studying opinion landscapes expressed in a wide range of digital sources. The opinion facilitator (Willaert et al., 2021) aims to provide a reading instrument for the general public that automatically interlinks news articles based on the expression of similar or opposing views. Both tools focus on opinions expressed in the context of the climate change debate and thereby emphasise the detection and extraction of causal frames (Beuls et al., 2021).

A final series of applications makes use of FCG to support linguistic research. Apart from the obvious advantages that a computational construction grammar implementation brings to the construction grammarian, including the automatic verification and empirical validation of construction grammars, FCG can also serve as the basis for methodological tools supporting usage-based linguistic research. An example of such a tool is the CCxG Explorer[6], which enables usage-based linguists to search for corpus examples that instantiate a semantic structure of interest using any morpho-syntactic realisation. In this way, they can find examples of morpho-syntactic phenomena without the need to identify these phenomena beforehand as is required with other tools.

6 Conclusion and Outlook

The primary objective of this paper was to provide a brief introduction to the Fluid Construction Grammar research programme, reflecting on what has been achieved so far and identifying key challenges for the future. Let us start by reflecting on the achievements. First of all, we now have at our disposal a computational framework that provides a faithful formalisation and computational operationalisation of the basic tenets of construction grammar. This framework can be used to represent linguistic knowledge in the form of constructions and to use these constructions for language comprehension and production purposes. We also have a basic theory of how constructions can be acquired in a usage-based fashion through syntactico-semantic generalisation processes. Finally, the application potential of FCG has been demonstrated extensively in experiments on emergent languages and on a smaller scale in a number of proof-of-concept language technology applications.

While the last decade has undeniably witnessed major advances in the FCG framework and research programme, even more fascinating challenges and exciting opportunities lie ahead of us now. A first challenge concerns the scaling of constructionist approaches to language on both the theoretical and the computational level, in particular when it comes to modelling the systemic relations between hundreds of thousands of constructions. A second challenge concerns the further development of syntactico-semantic learning operators. This includes for example the design of pattern finding operators that can more elegantly handle linguistic phenomena related to grammatical agreement, more general algorithms for generalising over semantic structures, and techniques that can find minimal differences between speech signals rather than strings. A third challenge resides in converting the recent advances achieved in the domain of learning large-scale FCG grammars into powerful language technology applications. A final challenge concerns the abstraction of FCG's learning mechanisms into an accessible toolbox for end-users. This toolbox would enable AI and NLP engineers to equip intelligent agents with the ability to acquire communicatively adequate grammars during situated task-oriented interactions.

In sum, we strongly believe that the future of computational construction grammar looks brighter than ever and that hugely exciting times lie ahead.

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[2] `https://ehai.ai.vub.ac.be/demos/visual-question-answering`

[3] `https://ehai.ai.vub.ac.be/demos/visual-dialog`

[4] `https://penelope.vub.be/observatories/climate-change-opinion-observatory`

[5] `https://penelope.vub.be/opinion-facilitator`

[6] `https://ehai.ai.vub.ac.be/ccxg-explorer/`

Acknowledgements

We would like to express our gratitude to the multi-talented team of researchers that have contributed to the FCG research programme in the past, and to the current team who ensures that the future of computational construction grammar looks brighter than ever: Luc Steels, Remi van Trijp, Jens Nevens, Tom Willaert, Lara Verheyen, Jonas Doumen, Jérôme Botoko Ekila, Veronica Schmalz, Liesbet De Vos, Alexane Jouglar and Jeroen Van Soest. The research reported on in this paper was financed by the Research Foundation Flanders (FWO) through a postdoctoral grant awarded to Paul Van Eecke (75929) and the European Union's Horizon 2020 research and innovation programme under grant agreement no. 951846 (MUHAI - `https://www.muhai.org`).

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