Situated Learning through the Use of Language Games: Solving the Hungarian Agreement Puzzle

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Abstract

Grammatical agreement is one of the most puzzling aspects found in natural language. Its acquisition requires intensive linguistic exposure and capacities to deal with outliers that break regular patterns. Other than relying on statistical methods to deal with agreement in a computational application, this paper demonstrates how agreement can be learned by artificial agents in a simulated environment in such a way that the open-endedness of natural language can be captured by their language processing mechanisms.

1. Introduction

It is nowadays common knowledge that models of human-like natural language processing deal with mechanisms for adaptation, alignment and expansion of the linguistic inventory. Language is far from being an absolute coding system: it is inherently inferential, ambiguous and noisy in nature. Moreover, language is huge in the sense that there is no such thing as a repository of all possible sentences, so language learning will always be partial but at the same time powerful enough to capture incongruencies. Therefore, language can be studied as a complex adaptive system (Steels, 2000), covering the open-endedness, fluidity and non-uniformity of linguistic processing.

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Building on the idea that there are no absolute language conventions this paper shows how simulated "grammarless" agents can reach 100% communicative success through situated language learning (Section 2). The work presented here concerns simulations of language acquisition of a particular subsystem of a language, in this case noun-verb agreement as it is found in contemporary Hungarian (see also Gerasymova and Spranger (2010) for a similar approach to acquisition of the Russian aspectual grammar). The linguistic rules that the simulated agents use are implemented in Fluid Construction Grammar (Steels & De Beule, 2006), a bi-directional grammar formalism specifically designed to cope with language acquisition and change (Section 3). The need of gradual learning stages will be demonstrated as they lead to a robust linguistic inventory of the learning agent, therefore facilitating expansion mechanisms that will lead to a higher processing accuracy on the long term (Section 4).

2. Situated Learning

In the theory of situated cognition (Clancey, 1995) learning is seen as something that is always integrated with the individual's identity and participation and constitutes an evolving membership and capability to participate in different forms. This idea supports *instance-based learning* (Aha et al., 1991) and can also be found in memory-based language processing (Daelemans & Bosch, 2005), where there is no strict separation between a learning phase and a usage phase: one instance can be enough to store a particular experience. In this sense, language learning becomes situated in actual language use and abductive reasoning meth-

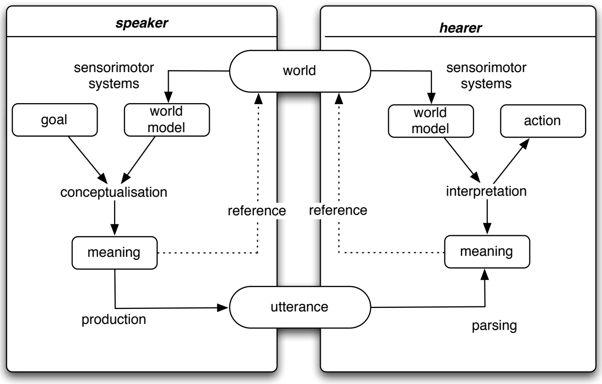


Figure 1. A full semiotic cycle: the basic architecture of every language game.

ods come into play. This type of learning behaviour is very different from inductive learning algorithms which show random performance for a long time until the right classes have been found (Steels, 2003). Fast acquisition in instance-based learning can of course be followed by performance degradation when new situations arise that require the storage of new views (ibid.).

The first computational implementation of situated learning was done by Luc Steels (Steels, 1995) and initiated a whole series of experiments on the emergence of lexicons and (more lately) also on grammar. Using language games (Wittgenstein, 1953) as the basis of each experiment, the important fact that all meanings are part of the situated context of use remains assured. A language game in this sense stands for a routinized set of situated embodied verbal interactions (i.e. following a script) within a particular domain of discourse, being performed to achieve a certain communicative goal. Usually a language game involves a sequence of interactions, and successful communication takes place when the communicative goal has been achieved. This can normally be observed or inferred by speaker and hearer. The set of processes underlying a language game such as it is used in this paper are depicted in Figure 1.

3. The Agreement Experiment

Agreement in language occurs when grammatical information appears on a word which is not the source of that information (Corbett, 2006). Building on the fact that language and meaning are not based on context-independent interactions but rather arise as part of their situatedness, it has to be learned by the agents which objects in the context give rise to which morphological changes.

3.1. Hungarian Object Agreement

The conjugation of a verb in Hungarian is – unlike in Indo-European languages – not only guided by event-inherent (tense, aspect, modality) or subject-inherent features (person, number, gender) but also by the presence and characteristics of the grammatical object of the verb. In this respect, there are two main aspects to consider when conjugating a Hungarian verb that takes an object: (1) the definiteness of the verb's object and (2) the animacy of event participants. There are two conjugational paradigms: the subject (default) and the object paradigm. Object conjugation takes place when the object is a definite referent in the context (the dog vs. a dog) and lower in the animacy hierarchy than the subject.[1]

3.2. Fluid Construction Grammar

Fluid Construction Grammar is a unification-based reversible grammar formalism that uses feature structures to represent linguistic knowledge (Steels & De Beule, 2006). In practice, the formalism works with bi-polar linguistic constructions (or rules) that map meaning into form and back. The repository of grammatical information, the constructicon, is usually thought to be hierarchically organized.

The different constructions necessary to operationalise Hungarian object agreement are characterised by different degrees of specialisation (i.e. different levels in the hierarchy). For this case study the inherent hierarchy is implemented by means of three different sets of rules, organized according to the functionality of the constructions: lexical entries, mapping rules and morphological rules.

- **Lexical entries** establish a coupling between form and meaning of a particular word. Additionally, semantic and syntactic features are incorporated into the rules.
- **Mapping rules** function as an internal layer that maps semantic or syntactic information onto a supporting construction that links multiple lexical constructions.
- **Morphological rules** specify the surface forms of abstract mapping constructions (case markers, agreement endings).

[1]In the animacy ranking 1st person singular referents are ranked higher than 1st person plural and 2nd person ones, which are in turn more animate than 3rd person agents/patients.

We briefly include an explanation on how such rules are applied in language generation and parsing so that the main benefits of using FCG become clear. The example sentence that is used here is *John loves you* (*János szeret téged*). As already mentioned, language processing in FCG is based on the unify-and-merge principle. Before any grammatical construction can apply to a linguistic structure, it has to satisfy the unification requirement. Only thereafter, the merging of the linguistic information is performed.

3.2.1. Production and Parsing

During the production process, the initial linguistic structure contains the meaning that has to be expressed on its semantic pole (in our example, the first-order predicate logic expression: *((john x) (you z) (love y) (love-agent y x) (love-object y z))*; the syntactic pole is still empty. In production, grammatical constructions that unify with the semantic pole merge new information into both sides of the current structure. This way applicable constructions enhance the current structure and, most importantly, add syntactic constraints, i.e. syntactic categories, words, and word order constraints, until no more constructions apply. During production, lexical entries are triggered first creating new units for 'john', 'love' and 'you'. Thereafter, mapping constructions apply and define the animacy and definiteness constraints of the agent(s) and patient(s) of an event (e.g. sem-cat: (animacy an+) syn-cat: (person 2)). Finally, the morphological rules add the accusative ending for the patient and the appropriate verbal agreement marker. At the end of production, the syntactic constraints of the created linguistic structure are rendered into an utterance (if possible); in our case *János szeret téged*.

The goal in parsing is to recreate a meaning from the perceived utterance (sequence of strings). This time, unification is performed on the syntactic side; merging takes place on both sides again. The process is therefore bi-directional in the sense that the same constructions can be applied both in production and parsing without change. However, the order of application of constructions typically differs for both cases, e.g. morphology in parsing is processed at a relatively early stage, whereas in production morphological markers are attached to the linguistic structure at the very end. The reason for that is the difference in the information available upon unification, which automatically reorders the application of constructions.

3.3. Language Game Script

Acquiring the notion of definite objects and the animacy hierarchy that exists between event participants is a precondition for the development of Hungarian agreement markers. We aim at demonstrating how such a system can be developed as the consequence of distributed processes whereby language users continuously shape and reshape their language in locally situated communicative interactions. Since our focus is not on lexicon formation (Steels, 1995) nor case marking (van Trijp, 2008), the interacting agents are already equipped with a fully developed lexicon and an accusative case marker.

A single interaction is best explained by looking at an example interaction between two agents – a speaker (language tutor here) and a listener (language learner). The example interaction described here would be one of the first in a sequence of many games. In that case the interaction might fail if the speaker is not yet able to dissolve possible ambiguities in the context. The communicative goal of the listener in this game is to point at the event that has been described by the speaker. Since our focus is neither on lexicon formation (Steels, 1995) nor case marking (van Trijp, 2008), the interacting agents are already equipped with a fully developed lexicon and an accusative case marker.

3.3.1. Example Interaction

Both agents perceive a context of two events that differ only in their subject, e.g. (1) *Mary sees the bird* vs. (2) *You see the bird*. As Hungarian is a prodrop language (i.e. it does not overtly express the subject of the verb), it is impossible to distinguish between the two events in the context if the agent lacks agreement markers. The speaker chooses one event as the topic of the language game (e.g.(2)) and runs the generation algorithm in order to produce an utterance that covers the conceptualized meaning of the topic: *a madar -acc lat -obj2sg*[2]. The learner parses this with the rules he has in his constructicon but fails to parse the agreement marker *-obj2sg*, which leads to multiple interpretations ((1) or (2)). When the hearer signals failure, the speaker points to the event he was referring to. With this information the learner adds a rule to his constructicon that links the meaning of the topic-event to the utterance of the game. The type of rule that is added depends on the history of interactions. This is explained further in Section 4. At the end of the game, the learner consolidates his grammatical knowledge based on the outcome of the interaction.

[2] Abstract case and agreement markers are used for clarification and word stress is omitted.

3.4. Learning Mechanisms

Following from our usage-based approach, the kind of linguistic information a learning agent adds to his constructicon depends on accumulated experience with language across the total number of usage events he participated in. As summarized by Tomasello (2000), this accumulated linguistic experience undergoes processes of enthrenchment, due to repeated use of particular expressions, and abstraction, due to variation in constituents of particular expressions across usage events. Tomasello (2007) proposes the following continuum of the major types of children's early constructions, which are grouped both in terms of the nature of abstractions involved and time of their acquisition:

1. **holophrases and early word combinations**: a particular context is covered by means of a single linguistic symbol, e.g. *nyom-obj1sg-a-doboz-acc, nyom-subj1sg-egy-doboz-acc*: I push the/a box
2. **item-based constructions**: systematic variations of holophrases are formed, e.g. *nyom-obj1sg-X, X-obj1sg-a-doboz-acc, etc.*. A more advanced phase of learning among the item-based constructions would be to abstract both verb and direct-object *X-obj1sg-Y, X-subj1sg-Y.*
3. **abstract constructions**: created by further schematization of already available constructions, usually without any linguistic material (abstract analogies). Analogies are made on the basis of functional similarities that exist between item-based constructions, rather than surface form. In the current experiment this means the acquisition of two abstract conjugational paradigms, that each cover different functional and formal situations.

The learning process is characterized by a dual architecture: one layer for routine processing is complemented with a meta-layer with diagnostics and repair strategies. A specific point in the language game script can host a learning situation, which – in case routine processing fails – can diagnose such a failure or inefficiency. A diagnostic signals a problem, which is organized as a data structure that contains all the information necessary to deal with the problem in question, such as when it is issued and which repair strategies would be able to deal with it. One repair strategy might be able to fix multiple problems.

Through iterations of the language game script, learning agents gradually pick up the target grammar by successfully repairing problems encountered in communication. For each of the subsequent learning phases, a different repair strategy is implemented, in correspondence with the kind of rules that have been accumulated in the learner's constructicon.

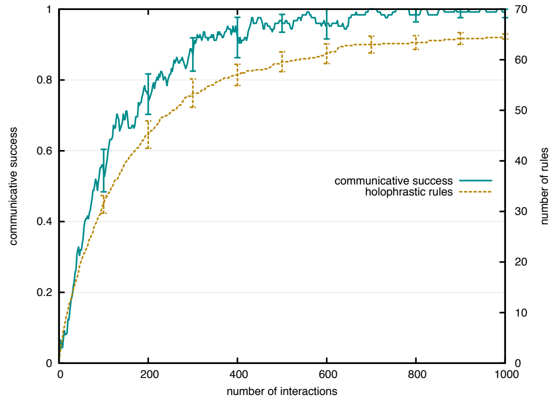


Figure 2. One repair strategy: internalize observed utterances. Optimal communicative succes is reached with an inventory of 65 holophrastic constructions.

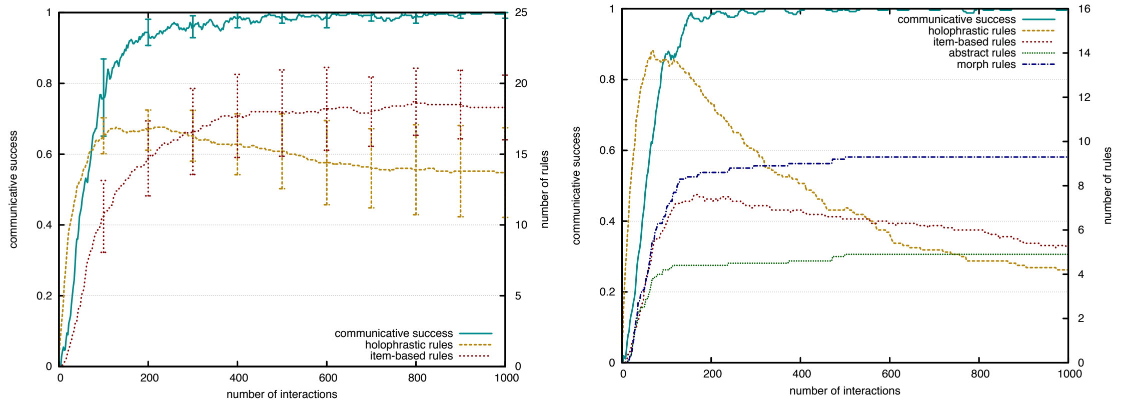
Rules all receive a score attribute, a number between 0 and 1 that is updated at the end of each language game, depending on the outcome of the game (success/failure) and the rule that was applied. If two rules are in competition, for instance, the holophrastic rule *nyom-obj1sg-a-doboz-acc* and the item-based rule *X-obj1sg-a-doboz-acc*, the rule with the highest score gets applied and, if resulted in a successful interaction, increases its score even more while the competitor's score is diminished.

All three repair strategies mentioned above attempt to solve the problem of ambiguity detected by the diagnostic *detect-multiple-interpretations*. The need for such a diagnostic follows from the example interaction: a problem arises when a marker is left unprocessed in the learner's parsing of an utterance and leads to an ambiguous interpretation of the context.

4. Results and Discussion

4.1. Learning Holophrases

The repair strategy that embodies the first learning stage is called *internalize-utterance*, stressing the fact that the learner internalizes the whole perceived utterance as a sample. This sample gets stored in memory in the form it was comprehended, namely so far as the agent could get in parsing, enhanced by the semantic information deduced from the context. The holophrase-constructions are fully operational, meaning that by the second time the learner hears the same



(a) Two-stage learning: item-based constructions take over from holophrases.

(b) Three-stage learning: item and holophrastic constructions die out.

Figure 3. Combining multiple learning stages

utterance, he will be able to parse it entirely, and, moreover, generate the exact same utterance when he is speaking.

When the learner is equipped with only one repair strategy, success in communication will reach 100% after learning by heart all the possible verb+ending(+object) combinations. However, flexible open-ended language use remains impossible with this repair strategy as the learner will be incapable of parsing previously unheard objects or verbs.

Figure 2 shows that communicative success and the number of holophrastic rules rise at almost the same pace. Note that the acquisition of the first 90% of the rules takes the same amount of time as memorizing the last 10%. The reason for this is that we implemented a linguistic bias so that not all conceptualizations have the same likelihood of occurence, just like in natural language there are more and less frequent things to say/hear (cf. Zipf's law).

4.2. Learning Item-based Constructions

For the second acquisition stage we created a repair strategy named *generalize-particular-item* that also triggers on referential ambiguity. Repair, however, can in this case only take place when the learner has already seen at least one holophrase that has the problematic marker so that a pattern can be inferred. Moreover, since we are dealing with polysemous markers, i.e. the subject agreement marker *-subj2sg* occurs, for instance, in the default case with intransitive verbs, but also with transitive verbs that have either a first person object or a third person indefinite object, holophrases can not just be generalized if they contain the same marker but also the semantic and syntactic categories of the verb should correspond [3].

Figure 3a shows that once the item-based constructions get introduced, the introduction of new holophrastic rules stops. This baseline experiment contains only item-based rules where either the verb or the direct-object is abstracted. They offer an advantage as they can be used more often and communicative succes rises faster but the holophrases that were learned are still used as their number does not decrease. The use of more general item-based rules where the only string in the construction would be the verbal suffix would probably reinforce a smaller inventory of holophrases.

4.3. Learning Abstract Constructions

The last stage is superior to both earlier acquisition stages because the learner will now acquire rules that are similar to the ones that his interlocutor (tutor) uses. In the setup of this experiment (only singular grammatical number is used) this means that only 6 abstract mapping rules (+ 1 definiteness rule) and 13 morphological rules (+ 1 accusative case marker) are necessary to communicate acurately.

The repair strategy that is used here, *generalize-markers*, triggers only when the learner has already acquired at least one item-based construction with the same valency (transitive/intransitive). Whereas both earlier repair strategies take place when a problem is diagnosed in interpretation, *generalize-markers* operates also when the learner encounters a problem in production. This might occur when item-based and

[3] Animacy hierarchy and definiteness information are also encoded in the verb categories.

holophrastic rules in his inventory are not sufficient to produce a new meaning because he has not encountered the necessary constellations before.

Whereas learning general rules communicative success is much more stable already from interaction number 350 onwards (cf. Figure 3b), failures keep occuring with item-based constructions up to interaction nr. 1000. What is more, item-based and holophrastic rules die out because of the continuous use of the abstract rules. The error bars show that the number of morphological and abstract rules (blue and green graphs) varies resp. between $[13, 11]$ and $[6, 4]$. When we looked at the inventory the learner had built up after 1600 interactions, it turned out that there were often no abstract rules for the 3 intransitive constructions. As the item-based constructions for the intransitive already made a generalization over the verb that could be used, the suffix string could be left specific in relationship to the features of the verb. However, when new suffixes would be introduced, the item-based rules would not trigger and the interaction fail.

5. Conclusion

Although situated learning is not known as a commonly used technique in machine learning, for cognitively heavy tasks such as language learning it has been shown to be an empirically valid learning method, as communicative success rose up to 100% quickly in all three experiments. Getting to the last stage, however, is important for the robustness of the system. With new data coming in, the abstract mapping rules will still work efficiently and new endings will be acquired by analogy with existing morphological rules. This brings situated learning and hence the use of abstract flexible grammar rules closer to human-like language processing. Although the model that is presented in this paper concerns a fairly small subsystem of a middle large European language, it can easily be expanded to multiple languages and more intricate forms of agreement. Language-independent learning operators are currently being developed and new FCG constructions can be designed to cope with agreement-related structure sharing in a different language. Moreover, the conceptual database that forms the "training set" of the agreement experiment should be developed further by means of a language-specific ontology.

References

Aha, D. W., Kibler, D., & Albert, M. K. (1991). Instance-based learning algorithms. *Machine Learning* (pp. 37–66).

Clancey, W. J. (1995). A tutorial on situated learning. *Proceedings of the International Conference on Computers and Education (Taiwan)* (pp. 49–70). Charlottesville, VA: AACE.

Corbett, G. G. (2006). *Agreement*. Cambridge Textbooks in Linguistics: Cambridge.

Daelemans, W., & Bosch, A. v. d. (2005). *Memory-based language processing (studies in natural language processing)*. New York, NY, USA: Cambridge University Press.

Gerasymova, K., & Spranger, M. (2010). Acquisition of grammar in autonomous artificial systems. *Proceedings of the 19th European Conference on Artificial Intelligence (ECAI-2010)*.

Steels, L. (1995). A self-organizing spatial vocabulary. *Artificial Life Journal*, *2*, 319–332.

Steels, L. (2000). Language as a complex adaptive system. *Proceedings of PPSN VI: Lecture notes in Computer Science* (pp. 17–26). Berlin: Springer-Verlag.

Steels, L. (2003). *Social language learning*, chapter 7, 133–162. Amsterdam: IOS Press.

Steels, L., & De Beule, J. (2006). Unify and merge in fluid construction grammar. In T. E. Vogt P. and N. C. (Eds.), *Symbol grounding and beyond: Proceedings of the third international workshop on the emergence and evolution of linguistic commun*, LNAI 4211, 197–223. Berlin: Springer-Verlag.

Tomasello, M. (2000). First steps toward a usage-based theory of language acquisition. *Cognitive Linguistics*, *1/2*, 61–82.

Tomasello, M. (2007). Construction grammar for kids. *Constructions [online]*.

van Trijp, R. (2008). The emergence of semantic roles in Fluid Construction Grammar. *The Evolution of Language. Proceedings of the 7th International Conference (EVOLANG 7)* (pp. 346–353). Singapore: World Scientific Press.

Wittgenstein, L. (1953). *Philosophical investigations*. Oxford: Blackwells.