Language Acquisition through Intention Reading and Pattern Finding

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Empirical studies on usage-based language acquisition have extensively documented how children acquire language through communicative interactions using general cognitive capacities [1]. Tomasello [12, 13] identifies two such capacities that play a crucial role: *intention reading* and *pattern finding*. On the one hand, intention reading allows to reconstruct the intended meaning of an observed utterance. On the other hand, pattern finding allows to generalise over utterances and meanings in order to learn more abstract linguistic schemata. While there is abundant theoretical and empirical evidence for both intention reading [2, 11, 8, 10] and pattern finding [5, 3, 4, 6], a faithful computational operationalisation of these cognitive capacities is still lacking. Yet, the development of precise mechanistic models of the processes underlying language acquisition constitutes a crucial step towards truly intelligent autonomous agents [9].

In this paper, we aim to computationally operationalise learning mechanisms inspired by the cognitive capacities of intention reading and pattern finding such that autonomous agents can use them to acquire language and solve communicative tasks. Specifically, we present an agent-based simulation in a tutor-learner scenario. The agents are situated in scenes of geometrical objects from the CLEVR dataset [7]. The learner's task is to acquire an inventory of form-meaning mappings, called *constructions*, that allow it to successfully ask and answer questions about these scenes.

The learning problem involved in this task is twofold. First, intention reading allows the agent to reconstruct the queries (i.e. meanings) that underlie the observed questions (i.e. forms) based solely on the observed scene and the answer that is provided at the end of every interaction. The learner is endowed with an inventory of cognitive operators, which it can combine to compose queries. Such a query constitutes a hypothesis about the meaning of the observed question, and can be executed in order to compute the answer. The problem faced by intention reading is that the space of possible queries that lead to a particular answer in any given scene is typically very large. Moreover, most of these queries are not adequate representations of the meanings of the questions. Second, pattern finding allows the agent to generalise over the observed questions and reconstructed queries. Initially, the learner cannot know which parts of the form correspond to

which parts of the meaning. Therefore, it stores the form-meaning mapping holistically. Through the observation of different questions and reconstructed queries, the process of pattern finding allows to generalise over reoccurring form-meaning patterns, yielding constructions that can cover (parts of) multiple observations. The key in bootstrapping language acquisition is the *interplay* of the intention reading and pattern finding processes. Concretely, intention reading facilitates pattern finding by providing meaning hypotheses. In turn, generalisations made through pattern finding allow to comprehend parts of novel utterances, yielding partial meanings. Crucially, these partial meanings drastically reduce the search process over possible queries involved in intention reading, as large parts of the search space that do not contain the partial meaning can be pruned.

The learning mechanisms operationalising intention reading and pattern finding result in an inventory of form-meaning mappings that can be used successfully for both comprehension, i.e. mapping questions to queries, and production, i.e. mapping queries to questions. This is demonstrated by the communicative success and the grammar size, shown in Figure 1. The communicative success rises rapidly and reaches 100% after 25,000 interactions. The grammar size (i.e. number of constructions) increases rapidly at first. More than 1000 constructions are reached as pattern finding keeps generalising over forms and meanings, thereby learning increasingly abstract constructions. Given that more abstract constructions are inherently applicable in a wider range of situations, they become more entrenched while the less abstract competing constructions gradually disappear. Across ten simulations, an average of 149 constructions remains at the end to cover more than 10,000 unique utterances.

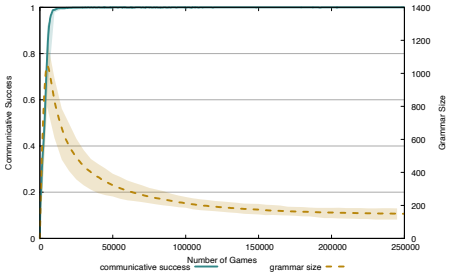

Fig. 1. Evolution of communicative success (teal-coloured line on left y-axis) and grammar size (yellow line on right y-axis) over time.

This work presents a powerful new methodology that allows an autonomous agent to acquire a bidirectional and open-ended communication systems in the form of a construction grammar, due to the operationalisation of cognitively inspired learning mechanisms for meaning reconstruction (i.e. intention reading) and schema abstraction (i.e. pattern finding). In other words, the agent acquires an inventory of question-query mappings that allows it to ask and answer questions, without ever observing the queries. The presented work also provides computational evidence for the cognitive plausibility of usage-based theories of language acquisition, in particular intention reading and pattern finding.

References

1. Ambridge, B., Lieven, E.: A constructivist account of child language acquisition. In: MacWhinney, B., O'Grady, W. (eds.) The Handbook of Language Emergence, pp. 478–510. John Wiley and Sons, Hoboken, NJ (2015)
2. Bruner, J.: Learning to use language. Oxford University Press, Oxford (1983)
3. Croft, W.: Explaining language change: An evolutionary approach. Pearson Education, Harlow (2000)
4. Diessel, H.: The acquisition of complex sentences. Cambridge University Press, Cambridge (2004)
5. Goldberg, A.: Constructions: A construction grammar approach to argument structure. University of Chicago Press, Chicago (1995)
6. Goldberg, A.: Constructions at work: The nature of generalization in language. Oxford University Press, Oxford (2006)
7. Johnson, J., Hariharan, B., van der Maaten, L., Fei-Fei, L., Lawrence Zitnick, C., Girshick, R.: CLEVR: A diagnostic dataset for compositional language and elementary visual reasoning. In: The IEEE Conference on Computer Vision and Pattern Recognition (CVPR). pp. 2901–2910 (July 2017)
8. Meltzoff, A.: Understanding the intentions of others: re-enactment of intended acts by 18-month-old children. Developmental Psychology **31**(5), 838–850 (1995)
9. Mikolov, T., Joulin, A., Baroni, M.: A roadmap towards machine intelligence. In: Proceedings of the International Conference on Intelligent Text Processing and Computational Linguistics. pp. 29–61 (2016)
10. Nelson, K.: Language in cognitive development: The emergence of the mediated mind. Cambridge University Press, Cambridge (1998)
11. Sperber, D., Wilson, D.: Relevance: Communication and cognition. Harvard University Press, Cambridge, MA (1986)
12. Tomasello, M.: Constructing a Language: A Usage-Based Theory of Language Acquisition. Harvard University Press, Harvard (2003)
13. Tomasello, M.: The usage-based theory of language acquisition. In: The Cambridge handbook of child language, pp. 69–87. Cambridge University Press, Cambridge (2009)