

ITALK: The Challenges of Grammar Learning

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Introduction

In this paper, we outline what we consider to be the most important challenges for automatic language learning.

The first set of challenges we see concerns the learning process itself; in particular, a crucial problem is the locus and nature of generalization in language and its relationship with item-specific language learning.

A second set of challenges concerns the resources the language learner may draw on. These include certain cognitive prerequisites, linguistic prerequisites, i.e. the linguistic knowledge the learner may have previously acquired, and the linguistic and non-linguistic input the learner receives.

Finally, the most important challenge we see is the development of an appropriate, scalable, interactional learning architecture.

In each section we outline basic findings from language acquisition research that need to be accounted for as well as open questions that require further exploration; subsequently, we describe the challenges these findings create for automatic grammar learning; we close each section with the first steps already taken by the ITALK SDU group in the past months.

1. Generalization and Item-based Learning

Acquiring language, a specifically human capability, is an enormous task, even for humans, and it is not yet fully understood. Consider the following sentence:

(1) The marten eats the cormorant.

There is a lot to know about a simple sentence like this one. First of all, we have to know the meaning of the words. We have to know the function of the determiner *the* before a noun (indicating that there are only one marten and one cormorant that the hearer should be able to single out) and that it has to appear immediately before the noun, unless there is an adjective; for instance, *the young marten* would also work. Most importantly, however, we would have

to know who eats whom, a meaning that is conveyed by the grammatical structure of the sentence. The structure of the sentence provided by the grammar is linked to particular semantic roles that the participants in this sentence may fulfil; relating concrete linguistic material to possible semantic roles on the basis of the grammar of the sentence has been referred to as the *linking problem*. The structure itself, which is associated with the particular meaning, here that it is the marten that eats the cormorant, can be understood as a grammatical construction, more specifically as an argument structure construction.

An important observation in the development of construction grammar was that no matter which verb is used in a sentence, the structure of the sentence, the argument structure construction, determines the meaning of the sentence (Goldberg 1995). For instance, we like to think of *water* as a noun. In example (2), however, it receives a much more specific meaning:

(2) My neighbour has watered the flowers flat.

The implication that water is used to flatten the flowers is contributed by the resultative construction. That is, no matter which verb is used in this construction, it will always receive the interpretation that something is done with a particular result.

The linking problem constitutes a central problem in grammar learning, and yet it is only one among many, due to the many kinds of meanings and functions language can be used to express (as we have seen above on the example of the determiner, which expresses the speaker's beliefs about the accessibility of referents to the hearer).¹ The point we shall concentrate on in the following, however, is that grammar consists of structure that carries meaning as a generalization over specific tokens of linguistic experience.

Much research has been carried out in the past years on the relationship between words and constructions (Tomasello 2003; Casenhiser and Goldberg 2005; Goldberg, Casenhiser and Sethuraman 2004; Jackendoff & Goldberg 1996; Goldberg 2006, to appear). Yet, precisely what the productive units of grammar consist in, how they are acquired step-by-step from

1 In fact, many other complex linguistic processes are involved in the interpretation process as well. In particular, perceived as speech, a listener needs to segment the continuous signal at the appropriate places and identify the individual words that constitute the utterance. Moreover, the signal holds prosodic cues to a number of additional properties relating to, for instance, illocutionary force (is it a statement or a question?) and information structure (what's assumed to be given information, and what's supposed to be new?). Once recognized, the identified words need to be assigned to contextually appropriate meanings, a process involving a number of non-trivial subtasks such as reference assignment, disambiguation and various context-specific inferential enrichments. And, crucially, it is not enough to arrive at an understanding of the individual words and grammatical operators in the sentence in isolation, since hearers must also reconstruct the way in which these elements hang together in the given sentence, and how the encoded event relates to the present discourse context.

input and which combination operations lead to generalization are still open questions (Bod to appear). Moreover, during the last 15 years, research on child language has provided an impressive amount of evidence that children's early command of language is strongly item-based, i.e. centered around particular rote-learned formulas that are associated with specific communicative functions (cf. Tomasello 2000a, 2003 and Goldberg 2006 for overviews). Only later do children begin to transfer this knowledge to other items, identifying variable slots and their possible fillers, thereby creating more and more schematic representations over time (Theakston et al. 2004) – even though much item-specificity in fact persists and even adults do not necessarily extract the highest conceivable generalizations from the data (Dabrowska 2005; Zeschel 2007). Prototypicality, centrality and semantic relatedness of the input are suspected to play important roles in this process (Goldberg to appear; Stefanowitsch & Gries 2005; Zeschel 2007). Furthermore, generalization is facilitated by so-called skewed input, i.e. when a particular type in the input has a particularly high token frequency; presumably, this allows learners to model the properties of the more generalized structure on the properties of particularly salient instances (Goldberg 2006; Casenhiser and Goldberg 2005; Goldberg, Casenhiser and Sethuraman 2004). The core questions of precisely how and when exactly which kinds of linguistic abstractions are formed are still being explored (Abbot-Smith and Tomasello 2006; cf. also Goldberg 1999, Tomasello 2000b; Ninio 2005a, 2005b), and robotic experiments that selectively manipulate relevant factors in the process can provide a useful testbed for specific hypotheses from the literature.

We have designed and carried out an experiment specifically to investigate the relationship between words and constructions in German in which we tested whether naïve users rely on verb or on construction meaning when explaining the meaning of sentences. 30 dialogues were recorded in which participants had to explain the meanings of sentences that systematically varied verb – construction pairs to a simulated robot (Nagai, Muhl & Rohlfing 2008). The analysis will concentrate on whether explanations were driven by the inserted verbs or by the constructional meanings, and whether constructions were handled in unified ways or depending on the verbs used in them.

Moreover, we have proposed a set of experiments on argument structure construction learning to be carried out in cooperation with the Plymouth team that will address (among other things) the influence of semantic similarity of verbs for the acquisition of generalized constructional schemas.

2a. Cognitive Prerequisites

Another central question in grammar learning relates to the cognitive capabilities that constitute prerequisites for grammar learning. Until recently, linguists have postulated that natural language grammars can only be acquired given substantial pre-wired language-specific cognitive constraints that form a part of children's genetic endowment, a 'universal grammar' (cf. Chomsky 1981; Pinker 1994). More recently, scholars have provided evidence from a broad range of areas, such as cognitive linguistics (Langacker 1987, 2000; Goldberg 1995, 2006), developmental psychology (Tomasello 2003; Lieven et al. 2003; Carpenter et al. 1998a), language evolution (Zuidema 2005; Oudeyer 2006; Kinsella forthcoming), grammaticalization studies (Diewald and Bergs 2008; Traugott 2003, 2008), evolutionary anthropology (Deacon 1997; Tomasello et al. 2005; Herrmann et al. 2007), epigenetic robotics (Steels 2004; Steels and Kaplan 2002; Dominey and Boucher 2005) and computational modelling (Bod 2006; Lewis and Elman 2001; Chang 2004; Batali 2002; Kaplan et al. 2008), that general cognitive mechanisms, in contrast to language-specific capabilities, may account for many aspects of language learning. In particular, research in developmental psychology has shown that language development in children builds on a number of important social-cognitive prerequisites: at the time that they begin to engage in linguistic communication (or very early in language development), children

- have an understanding of the triadic structure of interactions between two interlocutors and an object that is being jointly attended to (Tomasello 1988, 1995; Carpenter et al. 1998a);
- understand the behaviour of others as intentional (Behne et al. 2005a, Behne et al. 2005b, Carpenter et al. 1998b);
- are aware of the normative structure of conventional activities, including social interactions (Rakoczy et al. 2008, Casler and Kelemen 2005; Rakoczy 2007); and
- understand the cooperative logic of human communication (Große et al. 2008; Liszkowski 2005, 2006; Tomasello et al. 2007).

Some of these prerequisites (for example, joint attention to salient objects or orientation to the turn-taking system) are obviously easier to implement in robotic systems than others (for instance, inferring a given partner's particular goal in a novel situation, which heavily depends on world knowledge). However, in line with cognitive linguistic hypotheses about the relevance of domain-general cognitive principles and mechanisms for language

acquisition, automatic language learning has been demonstrated to profit considerably from implementing more general cognitive capabilities such as perspective taking (Steels 2004, 2005) or referential intention (Yu, Ballard & Aslin 2003). In ITALK we have the chance to further experiment with the role and scope of such general social-cognitive constraints in a systematic manner and to explore useful operationalizations of these parameters for grounded language learning experiments.

However, the human use of grammatical languages as an efficient way to manipulate the attention, belief states and behaviour of others arises (in ontogeny and presumably also in phylogeny) in the context of a pre-established understanding of cooperative social interaction with intentional, goal-oriented communication partners who the speaker perceives to be like herself, and it is embedded in a rich world knowledge that permits learners to infer relations of similarity and functional equivalence between the numerous linguistic constructions that they encounter in different contexts of use. Therefore, even in automatic grammar learning experiments that aim at grounded learning in socially interactive settings, the two learning scenarios differ in crucial respects. As a consequence, useful suggestions are required as to how a given parameter known to influence (i.e., support) child language learning can be *adapted* for introduction into controlled robotic experiments.

In sum, progress in automatic natural language learning will require attention to both the internal prerequisites and external determinants of child language acquisition as well as finding useful operationalizations of these constraints for robot learning experiments.

2b. Role of Input

Children are not exposed to just a random set of utterances of varying complexity, but to very well designed utterances adapted to the child's respective state of language development (Pine 1994; Snow 1994). These adaptations, which constitute near-universals such that members (the effect has even been demonstrated for children as young as four years (Weppelman et al. 1998)) of almost every language community in the world employ them in speech to infants and small children, have been found to have many facilitating functions that children may exploit during language acquisition (Lieven 1994). Cartwright & Brent (1997) demonstrate in computational simulations that child-directed speech is much more suitable for automatic grammar learning than adult-directed speech. The adjustments of child-directed speech comprise features on all linguistic levels (cf. Brown 1977; Richards 1994): phonological adjustments, like hyperclear speech (Albin & Echols 1996; Kitamura et al.

2002); prosodic adjustments, to stress word and sentence boundaries, mark important information and encourage contributions from the child (Mattys & Jusczyk 2001); lexical adjustments, such that mostly basic level terms (such as *apple* and *dog* in contrast to either *golden delicious* and *golden retriever* or *fruit* and *mammal*) are used and that words and structures are used with their most typical meaning (Borovsky & Elman 2006; Stefanowitsch & Gries 2005); morphological adjustments, such that features are exaggerated that provide the child with extra information (Kempe et al. 2001), and structural variations (Küntay & Slobin 2002) that allow the child to identify constituent boundaries, morphological marking, subcategorization patterns, verb-specific uses, obligatory and optional constituents and pronoun replacement. On a discourse level, child-directed speech is highly repetitive, reformulative and based on the here and now of the current interaction with the child (Karmiloff & Karmiloff-Smith 2001). In the grammar learning experiments to be conducted in cooperation with the Plymouth team, we intend to explore the connection between skewed input frequencies and generalization performance further in a controlled experimental setting. Yet, as Cartwright & Brent's (1997) results show, the possible limits to facilitative effects of child-directed speech have not been determined yet for automatic grammar learning.

Another field of exploration concerns whether in human-robot interaction scenarios speakers produce similar facilitative input and if not, how robots can be designed to guide them into using such speech. In this connection we carried out experiments in human-robot interaction on the same tasks as previously elicited with children (Rohlfing et al. 2006) to compare the linguistic features of robot-directed and child-directed speech. Qualitative analyses moreover reveal the speakers' concepts about their artificial communication partner and their expectations regarding robot capabilities (Fischer 2006) and allow the comparison of developmental hierarchies in children and users' expectations about a robot's capabilities (Fischer & Moratz 2001).

2c. Linguistic Prerequisites

A related question concerns the ways in which linguistic knowledge constitutes a prerequisite for the acquisition of more linguistic knowledge, i.e. whether there are more basic structures that have to be acquired before others. Johnson (2001) has demonstrated that children rely on previously acquired constructions as well as on critical contexts, so-called 'primary scenes', when developing more abstract constructions. He refers to this process as 'constructional grounding'. Morris, Cottrell & Elman (2000) speak of a 'construction conspiracy', meaning

that in a computer simulation, some constructions had to be acquired before others for the system to generalize successfully to novel instances. Abbot-Smith & Behrens (2006) address this problem area by investigating a dense acquisition corpus. They also find evidence for facilitative (as well as for inhibitory) effects of prior learning.

This question ties in with the more general theoretical issue of how speakers' internalized inventory of words and constructions is organized (Fillmore, Kay & O'Connor 1988; Kay & Fillmore 1999; Goldberg 1995, 2006). All versions of construction grammar assume that lexicon and constructicon, the inventory of grammatical constructions, cannot be categorically distinguished and that both are highly structured. However, while it is well documented that the mental lexicon is organized according to a variety of both formal and semantic properties (such as phonological similarity, the rhythmic properties of words and word class membership on the one hand, and semantic relations such as synonymy, antonymy, meronymy and hyponymy, as well as membership in semantic fields and frames on the other), little is known about the structure of the constructicon so far. From an acquisition perspective, one promising starting point to look for such relations is the analysis child-directed speech: to this end, we have proposed an extended definition of *variation sets* (Küntay & Slobin 2002) to be investigated in corpora of child-directed speech, by means of which parents may support their children in finding relations between constructions. Analyses of these variation sets suggest that the constructicon is structured in similar ways as the mental lexicon.

3a. Measuring and Reporting Success

A considerable problem for all approaches to automatic language learning is measuring their success. In child language acquisition, children build up phonological categories, identify stress patterns, prosodic contours, and cues for word and utterance boundaries, build up semantic categories and extract central linguistic constructions all simultaneously (cf. Karmiloff & Karmiloff-Smith 2001). Thus, simulations of language learning that focus on certain linguistic aspects are bound to neglect that the child cannot necessarily base her grammar learning on, for instance, perfect word recognition, as the phonological, semantic and segmentational recognition may still be under development as well.

A related practical problem is that most software components that could be used for creating interactional scenarios are based on prior training with linguistic knowledge. While the infant has to build up phonological categories, prosodic knowledge, knowledge about word

boundaries etc. from the input herself, all current technology relies on components trained with, or explicitly modelling, linguistic information. Thus, there is a mismatch between the way children learn to recognise speech and the way in which speech recognition technology works. Moreover, measuring the success of language learning constitutes a challenge for interactional scenarios where the respective caretaker expects to receive feedback on her teaching efforts. That is, while *post hoc* analyses of, for instance, changes in neural networks during learning may be feasible for scientific purposes, for providing a human communication partner with information about progress in interaction new methods will have to be developed. While this is already a challenge for normal human-computer interfaces (Fischer 2006, Porzel 2006, Wrede et al. forthcoming), developing appropriate feedback methods for developmental scenarios constitutes a novel task.

In cooperation with the Bielefeld group we have carried out experiments with a simulated robot that will allow us to determine the effect of non-linguistic feedback based on attention to movement, objects and colours. We asked participants in a questionnaire after the interactions about their perception of the robot's non-linguistic feedback. First results indicate that non-linguistic feedback, though realistic and comparable to the feedback provided by a one-year old child, is not sufficient in human-computer/robot interaction since expectations about computers and robots tend to be so low (Fischer 2006) that many participants answered that they did not pay attention to the simulated robot's behaviour at all. Future work will have to develop appropriate methods for feedback on language learning in human-robot interaction.

3b. Scalability and Learning Architectures

At present, there is a huge gap between two different approaches to automatic language learning: On the one hand, there are the statistical grammar induction models of computational linguistics (e.g., Solan et al. 2005), in which algorithms trained on huge amounts of natural language data come to distil highly differentiated systems from their input. The data considered are mainly the distributional properties of words in their contexts, or, as Gries & Divjak (forthcoming) call them, *behavioural profiles* (cf. also Cartwright & Brent 1997; Morris et al. 2000; Jurafsky 2003). Similar contexts, or behavioural profiles, are seen as indicators for similar meanings. In certain respects, such bottom-up oriented 'pattern grammars' closely resemble the models of speakers' internalized linguistic knowledge that are postulated in current cognitive linguistic theories (Langacker 2000; Goldberg 2006).

However, current approaches in this paradigm are based on purely distributional information and hence are semantically empty.

On the other hand, there are the grounded learning experiments carried out in cognitive robotics (e.g., Sugita & Tani 2005; Roy 2005), in which physically embodied agents learn a (usually extremely simple) language by associating particular linguistic signs with certain aspects of their sensorimotor experience. The alternative approach is thus to consider pairs of sentences and visual (e.g. Steels 2004, 2005; Dominey 2005) or action (Sugita & Tani 2005) data, where the artificial agent has to derive the meaning of a linguistic structure as a generalization over several scenes or experiences. This approach is certainly more natural because the linguistic constructions learned are grounded in embodied experience and thus meaningful to the agent. However, they are usually extremely oversimplified as much as natural language is concerned. Yet the major problem that we see is not that the complexity of natural language is not yet accounted for, but that it is unclear whether current learning architectures can be scaled up in principle to a degree that comes close to the complexity of natural language.

In any case it would be desirable to have a system that combines the advantages of both approaches, i.e. that is both formally complex *and* symbolic in the Saussurean sense (i.e., a system in which all formal units also have an associated semantic pole).

With respect to semantics, the approach taken in ITALK is to build up conceptual knowledge about objects in the world by means of interaction with them and possibly also with a human interlocutor. But also tutoring and imitation may be useful resources for language learning for a humanoid robot like iCub. In most cultures, infants are exposed to tutoring speech (Lieven 1994) and action (such as *motionese*, cf. Rohlfing et al. 2006) as much as to interaction with their environment and with other humans. They are encouraged to imitate others and to handle objects themselves. So the human child is exposed to all of these kinds of data.

In automatic language learning, we have the chance to determine the impact of each of these input modes and to compare the different interaction scenarios with each other. We have therefore designed and proposed an experiment involving several ITALK partners in which the influence of different interaction scenarios can be tested. More specifically, the experiments will allow us to detail the role of embodiment for language learning, as well as the uses and limitations of imitation in language acquisition (cf. Chomsky 1959; Speidel & Nelson 1989), the influence of modified input (tutoring) and the role of particular cognitive

prerequisites.

Conclusion: Towards Realistic Interactional Language Learning Scenarios

We see the main goal for work within the next decade mainly in the development of realistic interactional learning scenarios, that

- do not underestimate linguistic complexity and take account of distributional regularities;
- provide testbeds to investigate systematically
 - the cues and resources provided in naturally occurring input;
 - different operationalizations of certain cognitive prerequisites;
 - the role of previously acquired linguistic knowledge;
 - the nature of linguistic generalization;
- learn language directly connected to meaning, allowing for different input modes (observing action, acting, tutoring, imitating, interacting etc).

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