A Language Strategy for Aspect: Encoding Aktionsarten through Morphology

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Abstract

This chapter explores a possible language strategy for verbalizing aspect: the encoding of Aktionsarten by means of morphological markers. The Russian tense-aspect system is used as a model. We first operationalize this system and reconstruct the learning operators needed for acquiring it. Then we perform a first language formation experiment in which a novel system of Aktionsarten emerges and gets coordinated between agents, driven by a need for higher expressivity.

1. Introduction

According to the selectionist approach to cultural language evolution sketched out in an earlier chapter (Steels, 2012b), language users employ language strategies for constructing, acquiring and maintaining some subsystem of their language. Here we work out and illustrate this hypothesis with a language strategy for aspect. We use the same methodology as used in earlier chapters (van Trijp, 2012; Bleys, 2012): An existing human language is taken as a model system and the parsing, production, and learning of this system is first reconstructed and tested experimentally with artificial agents. We focus on Russian because it features a well studied example of a rich aspectual system that encodes several Aktionsarten through prefixation. Once we have been able to reconstruct the existing system, we can study what invention

operators are required to see the self-organization of a novel system from scratch. A first preliminary case study is done in this respect, focusing on how an initial set of markers can get established.

The emergence of a novel system must be driven by satisfying a function that gives language users increased success in communication. What could this function be in the case of aspect? Consider the following sentences:

(1) a. *Pieter has been writing a thesis.*
b. *Pieter wrote a thesis.*

Sentence (1)a expresses the process of writing as ongoing while the same process in (1)b is closed as a single event in the past. Aspectual distinctions thus allow speakers to highlight the whole or a specific subpart of an event. This increases the expressivity of their utterances and therefore increases communicative success if that expressivity is helpful.

In English, most fine-grained aspectual distinctions are expressed periphrastically (e.g. 'she swims regularly', 'he finished writing', etc.) or by means of auxiliaries (e.g. 'he *has* written the letter'). Aspect marking is therefore optional. In Russian, aspect is obligatory and expressed grammatically by means of *prefixes* that are attached to the verb stem, e.g. по-прыгать^{p} ('jump for a while'). In the current chapter, we try to decompose the linguistic strategy that may have given rise to such a system of aspectual rising by actually implementing it and analyzing its effect on communicative success in multi-agent interactions.

The rest of this chapter follows the language game methodology as outlined in Steels (2012b). First, we introduce some basic linguistic facts of the Russian aspect system in Section 2. They are essential to fully understand the computational simulations which underly the present chapter. The reconstruction of the Russian aspect system is sketched in Section 3. Section 4 introduces the results of a first experiment on the learning of Russian aspect in a multi-agent setting with tutor agents and learner agents. Finally, Section 5 shows the results of the formation experiments where markers for Aktionsarten emerge, propagate and get coordinated in the agent population.

2. The Russian Aspect System

The notion of aspect is intricately intertwined with the notion of Aktionsart (Comrie, 1976). In this paper we use 'aspect' restrictively in the sense of a *grammatical* category, as in the Russian perfective/imperfective distinction. The category of Aktionsart introduces a more refined aspectual categorization of events, for

instance, the telic Aktionsart introduces the notion of an inherent goal or result, ingressive Aktionsart the notion of a beginning, delimitative Aktionsart the notion of a limited time span, etc. The categories of aspect and Aktionsart are inherently related: Perfective aspect highlights that the event described by a verb has boundaries, e.g. boundaries inherent to the Aktionsart of this verb. It is not important which boundaries – initial, final or both – are highlighted. On the other hand, the highlighting itself is done by the Aktionsart of the verb (Bickel, 1997; Stoll, 1998).

The grammar of Russian is heavily dependent on aspectual oppositions and every verb in all forms and tenses is either Perfective (from now on indicated as PFV) or Imperfective (IPFV). For instance:

(2) Левин слушал и придумывал и не мог
Levin listen.PST.IPFV and invent.PST.IPFV and not can.PST.IPFV
придумать что сказать.
invent.PST.PFV what say.INF.PFV.
'Levin listened and tried to think of something to say, but couldn't.' [L. N. Tolstoy. Анна Каренина (*Anna Karenina*)]

The above sentence exhibits an example of the same verb in different aspects: imperfective придумывал (' pridumyval, 'invent.PST.IPFV') and perfective придумать ('pridumat', 'invent.PST.PFV'), which is used here to express the contrast of first being in the process of thinking and then its unsuccessful result.

The Russian aspectual system is known to be very complex and differs from other aspectual languages, such as Turkish, English or the Romance languages, due to its overt marking of the Perfective aspect, rather than the Imperfective. The Imperfective aspect is often connected with the durative Aktionsart, but due to its unmarked nature it is also compatible with a wide range of contexts, even those where most languages would use a Perfective. The Perfective aspect signals the boundaries inherent to the lexical temporal semantics of a given verb – its Aktionsart. For example, in the verb нарисовать ('narisovat', 'draw.PFV') the Perfective highlights the inherent notion of completeness of the event, while in the verb заплакать ('zaplakat', 'start crying.PFV') the Perfective signals the notion of beginning.

The morphology of the Russian aspect mirrors the complexity of its semantics. There is no single morphological marker that marks either of the two aspects, such as for instance in English the Imperfective (Progressive) is marked with 'to be *infinitive* -ing', as in 'it is raining' vs. 'it rains'. Russian verbs can be roughly divided into 'simple' verbs, consisting of a stem and a conjugated ending, e.g. читать ('čitat', 'read.IPFV'), щипать ('ŝipat', 'pinch.IPFV'), and 'complex' verbs, which

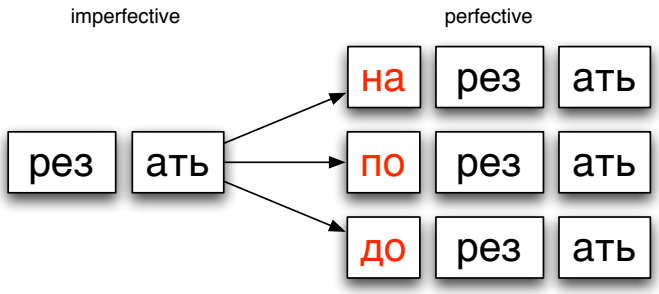

Figure 1. *Schema of the simple verb* резать *('rezat', 'cut.IPFV') and its perfective derivatives* нарезать *('narezat', 'cut.PFV'),* порезать *('porezat', 'cut for a while.PFV'),* дорезать *('dorezat', 'cut to the end.PFV'), which are formed by prefixation.*

are derived from the latter by the addition of aspectual markers, e.g. by prefixation перечитать ('perečitat', 're-read.PFV'),выщипать ('vyŝipat', 'pinch out.PFV'). Simple verbs typically describe activities and are Imperfective, e.g. резать ('rezat', 'cut.IPFV'). The addition of a prefix changes the aspect of simple verbs into Perfective, e.g. нарезать ('narezat', 'cut into small pieces.PFV'), порезать ('porezat', 'cut for a while.PFV'), дорезать ('dorezat', 'cut to the end.PFV'), etc., as it is schematically indicated in Fig. 1. Russian has nineteen verbal prefixes that productively form Perfective Krongauz (1998). There is also a perfectivising suffix -ну- leading to such forms as резануть ('rezanut', 'cut once.PFV').

Moreover, Russian verbs can undergo more than one aspectual derivation. After the prefix has been added to the verb stem (e.g. думать, 'dumat', 'think.IPFV'), thereby turning it into Perfective (придумать, 'pridumat', 'think of.PFV'), the so-called imperfectivizing suffixes can flip the verb's aspect to Imperfective again, as in придумывать ('pridumyvat', 'try to think of.IPFV'). But another prefix can be attached to this form changing the aspect to Perfective again – попридумывать ('popridumyvat', 'try to think of for a while.PFV'). In this paper, we focus on the first aspectual derivation – the addition of prefixes to simple verbs and changing them from Imperfective to Perfective. These forms account for about 80 percent of the total verb occurrences and awareness of the aspectual opposition is therefore likely to be focused precisely in the contrast between simple imperfective and pre-

fixed perfective forms (and not in that of secondary imperfective to perfective), as stated by Forsyth (1972).

3. Reconstruction of the Russian Aspect System

In order to study the communicative significance and expressive power of Russian aspect, we need a working implementation of it (or at least of some relevant subpart). To this end, we have operationalized the Russian aspectual system so we can analyze its performance in multi-agent simulations. The current section details this reconstruction effort. We first identify communicative interactions in which aspectual distinctions help agents to communicate successfully. This is followed by a discussion of the linguistic processing that enables artificial agents to be successful in these interactions. Overall this section defines the target for subsequent inquiries into acquisition and formation.

3.1. The Aspect Language Game

Psycholinguists have studied communicative interactions that elicit understanding of aspectual speech acts. An example of this is Stoll (1998) which is using particular interaction scripts, in order, to test the language proficiency of children and their development of understanding of aspectual forms. She interviewed preschool children after they watched pairs of short movies, each movie illustrating what would be described by a different aspectual form of the same verb stem. So for instance, there were two movies with different actors both of which laughed. One of the actors started laughing in the movie and the other laughed for the complete duration of the movie. Afterwards, she asked children questions about the movies which tested their understanding of the difference between the movies.

We have implemented similar interactions using the language game framework (Steels, 2001). Language games are routinized communicative interactions for our purposes between pairs of artificial agents. One interaction, i.e. language game, proceeds as follows:

1. Two agents are randomly selected from the population. One agent acts as a speaker, another one as a hearer.

2. Both agents perceive a shared context, which models their joint attentional frame (Tomasello, 1995). The context consists of two events of the same kind but with different temporal semantics, e.g., *ongoing reading* versus *reading*

for a while. The two events each feature different protagonists: Миша (Michael) and Маша (Masha). For example, a shared context might consist of two events 1) *Michael reading for a while* and 2) *Masha reading the whole time*.

Technically, events are coded in terms of type, as well as start and end times. Additionally, there is a global movie time frame. For instance, an event can be conceptualized as *ingressive*, if it starts in the movie time frame and ends after the movie time frame.

3. The speaker starts the interaction by choosing one event (the so-called focus event) from the context as a *topic*. Let us suppose the speaker chooses the event where Michael was *reading for a while*.

4. The *communicative goal* of the speaker is to ask a question about the protagonist of the focus event (in our case Michael) using the information about the event he was involved in. The question should unambiguously discriminate the protagonist, which entails that the event's temporal structure has to be incorporated into the question. For example, Кто почитал? (*Kto počital?*, 'Who read for a while?') discriminates Michael because only he was involved in the action for a short period of time (Masha was reading for the whole time). The speaker conceptualizes the meaning of the question and then produces an utterance which is transmitted to the hearer.

5. The hearer perceives the utterance, parses it, and then interprets the parsed meaning by comparing the result of interpretation to the context. The task of the hearer is to identify the protagonist of the focus event unambiguously; guessing is not allowed.

6. If the hearer is able to unambiguously answer the question, he verbalizes his answer by saying *Michael*. Otherwise, he gives up.

7. The speaker signals whether the answer is correct, i.e., whether the answer corresponds to the protagonist of the focus event. The right answer means communicative success, no answer or a wrong answer is considered to be a communicative failure.

8. In the case of either incorrect or absent answer, the speaker reveals the desired answer.

3.2. Routine Processing of Russian Aspectual Phrases

In order to successfully participate in Aspect Language Games, agents have to manage a considerable number of processes. Acting as a speaker, they have to conceptualize the perceived scene, find a discriminative meaning for the chosen topic, as well as produce an utterance to express the intended meaning. Similarly, the hearer has to be able to parse utterances and interpret their meaning in order to conceptualize answers to questions or decide on the correctness of given answers. Most of the implementational details fall outside the scope of this paper (see Gerasymova & Spranger, 2012b,a; Gerasymova, 2012; Gerasymova & Spranger, 2010; Gerasymova et al., 2009 for more detailed discussions). Next, we will briefly sketch the parts relevant for understanding subsequent experiments.

3.2.1. *Semantic Processing*

The implementation of the agents' conceptualization processes is based on *Incremental Recruitment Language* (henceforth IRL) (Steels, 2000, 2007; Spranger et al., 2010), which is a formalism for representing and computing semantic structure for the sake of communication. As the example interaction (see Section 3.1) has shown, the communicative goal of the speaker is to formulate a question that discriminates the protagonist of the focus event in a particular context (consisting of two events). Hence, the semantic representation of the question has to convey a sequence of cognitive operations that, when executed, lead to the focus event and thereby to its protagonist. This sequence of operations, or the semantic structure of the question, is represented as a program, also called *IRL-network*.

An example network is included in Figure 2, expressing the semantic structure underlying the question Кто почитал? ('Kto počital?', 'Who read for a while?') (for sake of simplicity this is a reduced structure which does not include the temporal aspect). IRL-networks link mental *operations* (e.g. `filter-set-event`) with concrete semantic *entities* (e.g. `read-event`). The latter are introduced through so-called bind statements and represent event categories, prototypes, concepts or particular temporal characteristics of events, i.e., Aktionsarten. Operations and semantic entities are connected through variables (whose names start with `?`). The network in Figure 2 reveals that the corresponding question prescribes operations that filter and profile events using event prototypes and Aktionsarten. Most importantly, the structure contains the aktionsart `for-a-while` which if understood by the hearer will lead him to identify the correct event.

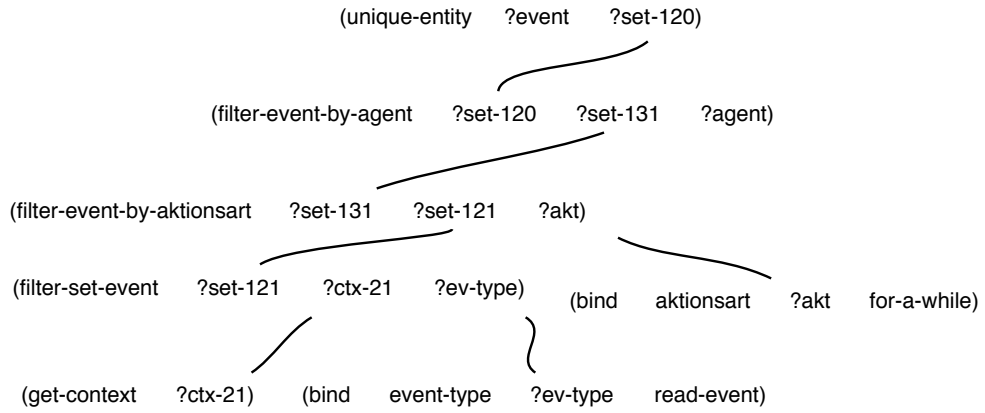

Figure 2. *Semantic structure underlying the question* Кто почитал? *(*Kto počital?*, 'Who read for a while?'). This structure was autonomously constructed by an agent based on the current context and the communicative goal of asking a question about one particular event, the topic*

3.2.2. *Grammatical Processing*

We implement grammatical processing using *Fluid Construction Grammar* (FCG) (Steels & De Beule, 2006; Steels, 2012a, 2011a). Importantly, the implemented grammar is organized using an intermediate layer of language specific semantic categories (Steels, 2011b). Figure 3 illustrates the grammar organization by showing how different types of constructions map meaning to form and back through a layer of semantic and syntactic categories. This intermediary layer is essential in order to capture the indirect link between meaning and form, that is, the same semantic categories can map onto different syntactic categories and specific syntactic categories can map onto different morphological markers, depending on the context.

Here is an overview of the different constructions involved and their function in processing of phrases. We only concentrate on the most important constructions for dealing with aspect and leave out, for example, the handling of tense, subject-verb agreement and word order.

Lexical constructions map lexical stems to particular event types, e.g. the event type `read` is mapped onto the stem "cita". (Figure 3, top).

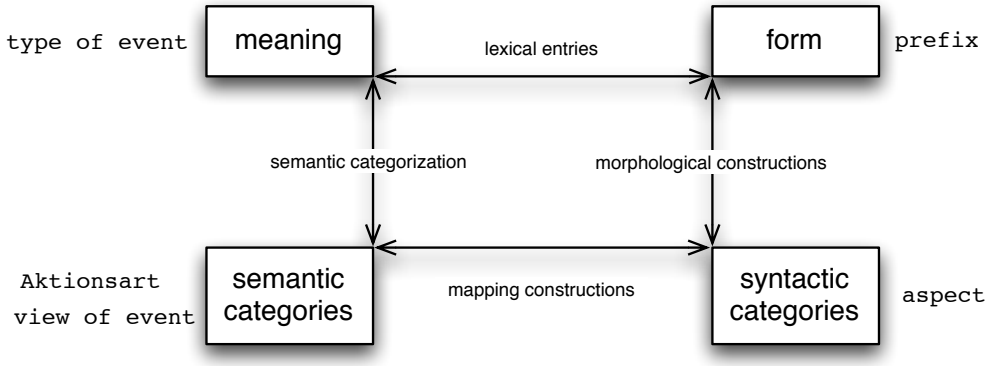

Figure 3. *The grammar square for aspect shows the division of labour between different construction types: lexical, semantic, mapping and morphological constructions, connecting different linguistic components. The arrows indicate the most essential flow of linguistic information in a construction of a particular type, whereas the parameters on the side of boxes (*`type of event`*,* `Aktionsart`*,* `prefix`*, etc.) are concrete linguistic parameters that the presented aspectual grammar makes use of.*

Semantic categorization constructions re-categorize the verb in terms of semantic categories (Figure 3 left). Here the larger semantic structure is used to identify the particular Aktionsart of the event. For instance, the usage of the Aktionsart (`for-a-while`) in the semantic structure will be identified and represented in processing.

Mapping constructions map abstract semantic structures to abstract syntactic structures (Figure 3 bottom). Here they map the Aktionsart (semantic category) of the event onto the syntactic category aspect. For example, is the event durative, then it will be expressed using the imperfective aspect.

Morphological constructions use the syntactic categorization and map it onto a particular morphological markers based on aspect and Aktionsart (Figure 3, right). For a read event that happened for a while the correct prefix is 'po-', as in Кто почитал? (*Kto počital?*, 'Who read for a while?').

3.3. Results

Lastly, we can measure the performance of our implementation. We tested the system in scenes which differed in 7 temporal semantics (ongoing, begin, for a while, finish, complete, alteration and exhaustion) and 14 event types. Success of two agents equipped with the full machinery is 100%. In other words, in all possible combinations of Aktionsarten and events, the speaker is successful in posing a question and the hearer successfully answers the question. This sets up the framework for the experiments reported in subsequent sections focussing on acquisition and formation.

There are two interesting conditions which clearly mark the relevance of the operational aspectual system with respect to the Aspect Language Game. First, if agents are stripped of the means to express aspectual characteristics, they will fail in the Aspect Language Game, because the only way to disambiguate between the two events in the context is by using Aktionsarten and aspect. Second, in contexts where agents are facing two events which have the same temporal characteristics, e.g. both events are ongoing, agents also fail because they lack means to distinguish two events of the same temporal characteristics (within the question-answer interaction).

4. Acquisition of the Russian Aspect System

We now turn to a computational model of the acquisition of a complex target grammar as the one previously outlined. For this, we use the language game described earlier. However, the population of agents now is setup such that there are tutors which are operating the target grammar, and learner agents which have only lexical constructions and miss all the grammatical knowledge related to aspect and Aktionsarten. Tutors and learners engage in Aspect Language Games. They each can take on the role of speaker and hearer. Most importantly, learners are trying to produce questions but also trying to answer questions posed by tutors or other learners. Given the right learning strategy, agents subsequently pick up the aspectual grammar, so that at the end of the experiment all agents have converged on the same set of grammatical constructions.

4.1. Learning Operators

At the heart of the acquisition model is the learning strategy which allows a learner to acquire the target grammar. Agents learn by enacting specific *diagnostics* and *repairs* (Steels, 2012b). Diagnostics monitor the production and parsing of sentences and signal problems that are encountered, for example the inability to parse

an utterance or ambiguity in interpretation. When problems are detected, repairs extend the linguistic repertoire of the agents in order to avoid the same problem in the future.

In the present case, there are two main communicative problems that may occur and they are detected by diagnostics that the agents are running during production and comprehension:

1. *Inability to express meanings* Imagine the speaker is confronted with the context as in the example interaction (see Section 3.1): there are two events *Michael read for a while* versus *Masha read the whole time*. Let us suppose that the focus event is *Michael read for a while*, so the question that needs to be verbalized is: 'Who read for a while?'. It is essential here that the temporal semantics *for a while* of the corresponding reading are incorporated into the question, since this information is necessary for discrimination. The speaker starts producing and, with the help of a given lexicon, ends up with the utterance: *Who read?*. In the process of testing the effect of the question on himself, a process called *re-entrance* (Steels, 2003), the speaker consequently finds two hypotheses for the answer to the question. This is diagnosed as a failure.

2. *Inability to parse strings* Imagine the hearer cannot entirely parse the question uttered by the speaker, e.g. 'Who po-read?'. The linguistic parts that can be processed are *who* and *read*, but the prefix *po-* is left unprocessed. This leads to ambiguity in the interpretation of the topic (since both events are about *reading*) and consequently two hypotheses about the protagonist involved in the event. Because of this ambiguity, the interaction fails and the speaker reveals the right answer.

Learners use three repair strategies: acquisition of *holophrases*, *item-based constructions* and *abstract constructions*. These strategies are based on what we know from psycholiguistics how children acquire complex grammatical knowledge. Each stage is characterized by an additional layer of abstraction. In the first stage agents store very specific information associated with one particular observed exemplar of language use. In subsequent stages, the examplars are used to generalize more and more abstract linguistic knowledge until at the end the full range of linguistic knowledge is acquired. The following sections each deal with one stage.

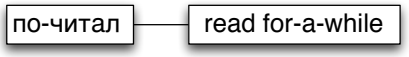

Figure 4. *Schema of the holophrase* почитал *('počital', 'read-for-a-while'). This holophrastic construction maps the form of the observed utterance* почитал *to its meaning* `read-for-a-while`*. The learner treats it as a single unit without knowing its composition.*

4.2. Holophrases

Developmentally speaking, holophrases are the first type of children's early constructions, where children use a single linguistic symbols to communicate their intentions about a specific scene (Tomasello, 2000). In a similar way, we model learning by the acquisition of holophrastic constructions during the first learning stage. This happens when the hearer (learning agent) cannot completely parse a question that the speaker posed, as in the example interaction Кто почитал? ('Kto počital?', 'Who read for a while?').

The linguistic parts that can be processed are 'kto' and 'čital', since agents are assumed to have a developed lexicon, but the prefix 'po-' is left unprocessed. This leads to ambiguity in the interpretation of the focus event (since both events are about *reading*), and consequently, two hypotheses about the protagonist involved in the event are created. Since the hearer is not allowed to guess, he gives up. The interaction is classified as a failure and the speaker subsequently reveals the right answer: *Michael*. The hearer tries to learn from this shortcoming and first stores the complete perceived utterance as a sample. Additionally, he searches the context for a semantic factor that could differentiate *Michael* from *Masha*, since questions are assumed to be discriminative. The distinctive feature for *Michael* is the temporal structure of his *reading*, which is *for a while*, in contrast to the *ongoing reading* of *Masha*. The stored sample is supplemented with this deduced information (schematically shown in Figure 4). The holophrase is implemented as an FCG construction – mapping of meaning and form. 'Kto' is not stored in the sample construction because it is already known to the learner.

The intuition behind holophrases is that the learning agent assumes that почитал is a single constituent after encountering it for the very first time. This way, the learning agent stores perceived samples creating undifferentiated holophrastic

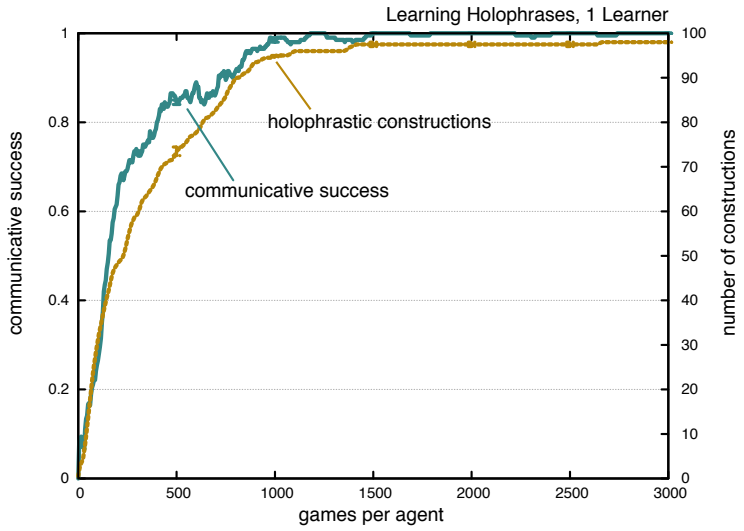

Figure 5. *Learning holophrastic constructions. The learner is equipped only with one repair strategy – store observed utterances. The communicative success is reached, but the inventory contains 98 holophrastic constructions (14 verbs × 7 different temporal semantics).*

constructions, e.g., поиграл (*poigral*, 'played-for-a-while'), порисовал (*porisoval*, 'drew-for-a-while'). These holophrasis constructions are fully operational, which means that by the second time the agent hears the same question, he will be able to parse it entirely and, moreover, generate this question when in the role of the speaker (but only the exact same question).

When learners are equipped with this repair strategy, they are able to communicate successfully after memorizing all possible prefix+verb combinations they have encountered. Figure 5 depicts the rate of communicative success accompanying the acquisition of holophrases for a population with one learner and one tutor agent. Nevertheless, such organization of the language inventory is unsatisfactory. With every additional verb floating in the population, the number of needed constructions increases by the number of temporal semantic features, and with every additional semantic feature by the number of verbs. Furthermore, such inventory organization lacks any notion of grammar, which contradicts the known abilities of adult native speakers of Russian to recognize two distinct aspects.

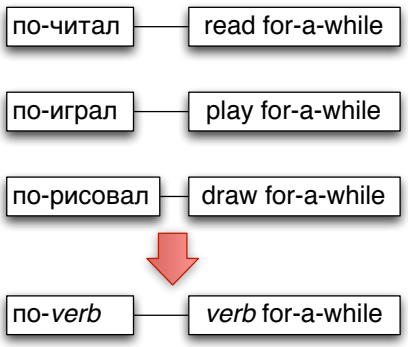

Figure 6. *Learning of the item-based construction* по+*verb (*po+verb*, 'verb+for-a-while'). Above the arrow: undifferentiated holophrases are stored in memory when encountered. Under the arrow: holophrases with a particular prefix become generalized to an item-based construction based on this prefix, enabling parsing of prefixed verbs.*

In summary, this stage is assumed to closely resemble how children initially master verbal aspect as part of the lexical meaning of the verb, by simply storing it.

4.3. Item-based Constructions

In the second stage, the learning agent creates more general constructions based on repeatedly encountered samples which have a similar internal structure. Developmentally speaking, this stage corresponds to the emergence of *item-based constructions* (Tomasello, 2000). For example, the hearer again faces the problem of ambiguous interpretation because of the inability to parse пописал ('popisal', 'wrote-for-a-while'). But now, instead of adding a new holophrastic construction, the hearer builds further on similarities he could detect between the current utterance and his stored samples, such as the constructions for почитал, поиграл, порисовал is the actual verb stem. Hence, the agent is able to create a more general construction for the usage pattern по+*verb* (with a slot for a verb), as shown in Figure 6, and successfully parse the utterance involving пописал. The discovery of this usage pattern corresponds to the acquisition of the delimitative Aktionsart. More precisely, the agent has learned that the presence of the prefix по- ('po-')

in front of a verb indicates that the temporal semantic feature *for a while* has been added to its meaning.

After this stage, the learning agent can correctly interpret any (known) verb prefixed by по- ('po-'), even if he has not encountered this particular combination before. However, although the agent has acquired the ability to comprehend the pattern по+*verb*, he is still lacking the general principle of deriving new Aktionsarten by prefixation as required to actively learn new prefixes and use them productively.

The process of generalization described here for the prefix по- ('po-') works exactly the same for other prefixes, so that generalizable material progressively builds up in the learner's linguistic inventory. In this phase, all the learned constructions are still item-based, the item being the particular prefix. This independent emergence of such item-based constructions for other prefixes mirrors the independent acquisition of Aktionsarten hypothesized by Stoll (1998). She claims that different Aktionsarten, that is, different means to highlight parts of events, are learned independently from each other in a context-specific way. Only later is the grammatical category of aspect abstracted away from this tight contextual connection by unifying several Aktionsarten into the abstract category of perfective. At this stage aspect finally becomes recognized as a category separate from the lexical meaning of verbs (Gagarina, 2000). The next section discusses this final stage.

4.4. Abstract Constructions

The final stage of the acquisition process in children is characterized by generalization over item-based constructions and formation of *abstract constructions*, in which children express their communicative intentions through utterances that instantiate relatively abstract, adult-like linguistic constructions (Tomasello, 2000). We use a similar strategy for the artificial learners.

When faced with a need to generate a question in dialogs, learners are still unable to construct a complete utterance. In particular, they are unable to express the temporal semantics of events needed for discrimination. This shortcoming is detected by the learner after he performs *re-entrance* on his own utterance, that is he parses what he just produced, and notices that the constructed utterance is insufficient to single out the topic from the context. As mentioned earlier, the idea behind re-entrance is to predict the effect of the utterance before actually passing it to the hearer.

In order to repair this communicative problem, the learner examines the inventory of his constructions. The accumulated item-based constructions reveal a gen-

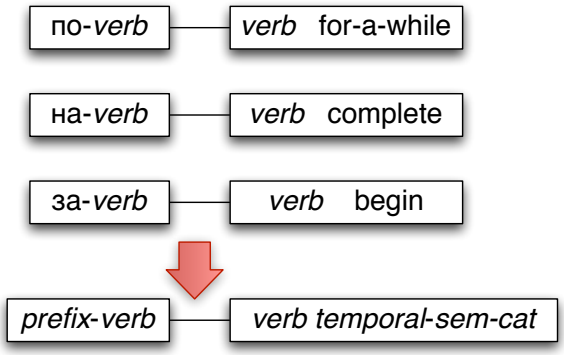

Figure 7. *Above the arrow: item-based constructions based on particular prefixes. Under the arrow: a single abstract construction expressing the general principle of prefixation for derivation of new Aktionsarten. It is learned through generalization over item-based constructions.*

eral pattern, namely that the temporal semantics of verbs (Aktionsart) is expressed by means of prefixation. This discovery can be captured by a novel abstract construction, where a prefixed verb, regardless of the actual form of the prefix and corresponding Aktionsart, becomes marked for the perfective aspect. The new construction operates only on the abstract semantic and syntactic categories of Aktionsart (*temporal-sem-cat*) and aspect and generates an abstract unit for a prefix without any concrete linguistic material (Figure 7). It is only after this stage that the agent is able to generate the perfective derivation of any (known) verb without having heard the resulting form before.

4.5. Results

Through repeated language games, artificial learners are able to acquire the aspectual grammar. Figure 8 displays the development of the grammar of a single learning agent that has been equipped with learning operators that cover all three developmental stages. In the world in which the learner is situated, events can exhibit 7 different temporal semantics: *ongoing, begin, for a while, finish, complete,*

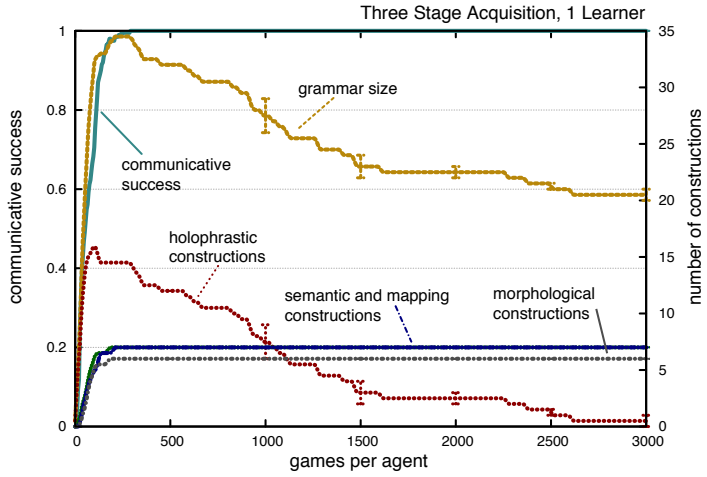

Figure 8. *Learning of aspectual grammar: communicative success and number of grammatical constructions of one learner during the acquisition process. The beginning of learning is characterized by the high number of holophrases indicated by the red line; at later learning phases other types of constructions appear. After abstract constructions have been acquired, holophrases become redundant and vanish.*

exhaustion, alteration. Therefore, the target grammar should contain 20 construction in total[1].

In the beginning, the only kind of grammatical constructions the learning agent creates are holophrases; their number is aligned with the total number of grammatical constructions the agent acquires. After a couple dozens of interactions, the learner starts to generalize, noticing the system behind the stored samples: other types of grammatical constructions are generated (semantic and morphological item-based and abstract grammatical constructions). The communicative success converges to the maximum value after approximately 300 interactions; each subsequent game will be a success.

1. This number results from the particular realization of the target grammar in FCG and is assembled from 7 semantic and 7 abstract grammatical constructions (for each temporal semantic facet) and 6 morphological constructions (durative Aktionsart coding the *ongoing* temporal semantics does not require a prefix and, therefore, lacks a morphological construction).

All constructions in the agent's inventory have a score in the range of [0,1] at any given time during the game. When a new construction comes into play, it is assigned an initial score of 0.5. In the course of the game, the scores of constructions are updated depending on their success in communication (unsuccessful constructions are punished). Once the target grammar has been acquired (20 constructions in total), the specific holophrastic constructions become redundant: they are in competition with more general item-based and abstract constructions. Eventually, holophrases lose and disappear after about 2500 interactions. Similar results are obtained for populations with more agents.

5. Emergence of Aktionsarten

The previous sections focused on reconstructing the parsing, production, and learning operations needed for handling the chosen model system, namely Russian aspect. Now we turn to the next challenge, namely to show how a system of aspect similar to the Russian aspect system can self-organize in a population of agents. This means that there is no longer a tutor that already comes endowed with the aspect system. Agents come scaffolded only with a basic lexicon. The diagnostics and repairs used in the previous experiment are all kept, and a new repair operator is added to implement the invention of new markers.

5.1. Learning Operators

The communicative problems defined in Section 4.1 remain the same in the emergence experiment but both agents can now encounter them. The repair strategies are now as follows:

1. To repair the first communicative problem, the inability to express a meaning, the speaker invents [2] a new marker, e.g. *hippi-*, to cover the needed meaning *for a while* and attaches it to the verb using a morphological construction. When the speaker tries to produce again, he now succeeds and can transmit the sentence to the hearer.

2. The second communicative problem, the inability to parse certain strings, is handled according to the first strategy, namely item-based constructions.

2. The agent could also reuse a device already existing in the language system, e.g. spatial preposition (*po* is preposition in Russian), but this possibility is not yet included in the present simulation.

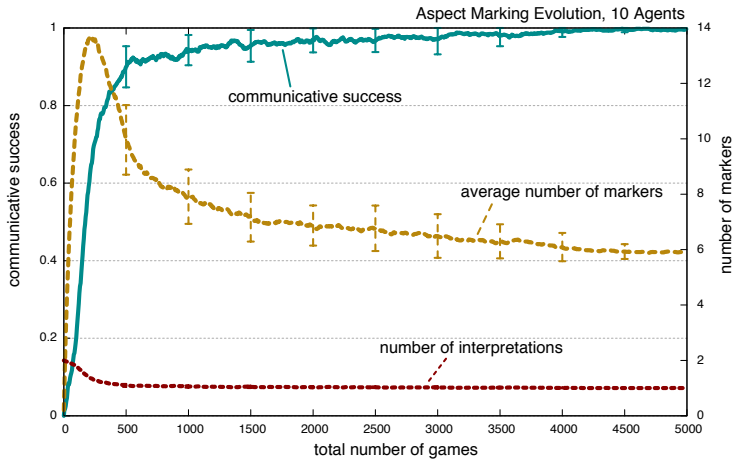

Figure 9. *Communicative success (fraction of successful games in the last 100 interactions) and inventory of markers in a population of 10 agents playing 5000 aspect language games (avg. 10 runs).*

5.2. Results

Let us look at the development of a prefixal system in a multi-agent population. According to the agents' ontologies, different events can take place and exhibit six temporal semantic features: *begin, finish, once, for a while, ongoing, complete*. Hence, grammatical markers for the *ingressive, terminative, semelfactive, delimitative, durative* and *telic* Aktionsarten, respectively, should pop up in the population driven by the need to express these when communicating about events. Figure 9 displays the communicative success and the inventory of markers throughout the game, averaged over 10 runs. The beginning is characterized by the overshoot of the required number of markers and later phases display their convergence on the optimal number of six. The communicative success grows very quickly when a sufficient number of markers starts floating in the population. There are however synonyms (same meaning, different form), which can be seen in Figure 10 that zooms in on one simulation and captures the formation of markers.

At the moment of their invention, markers are again assigned a score of 0.5 that is updated over time using a scoring mechanism (lateral inhibition) which rewards markers that were used often and successfully in communication and punishes com-

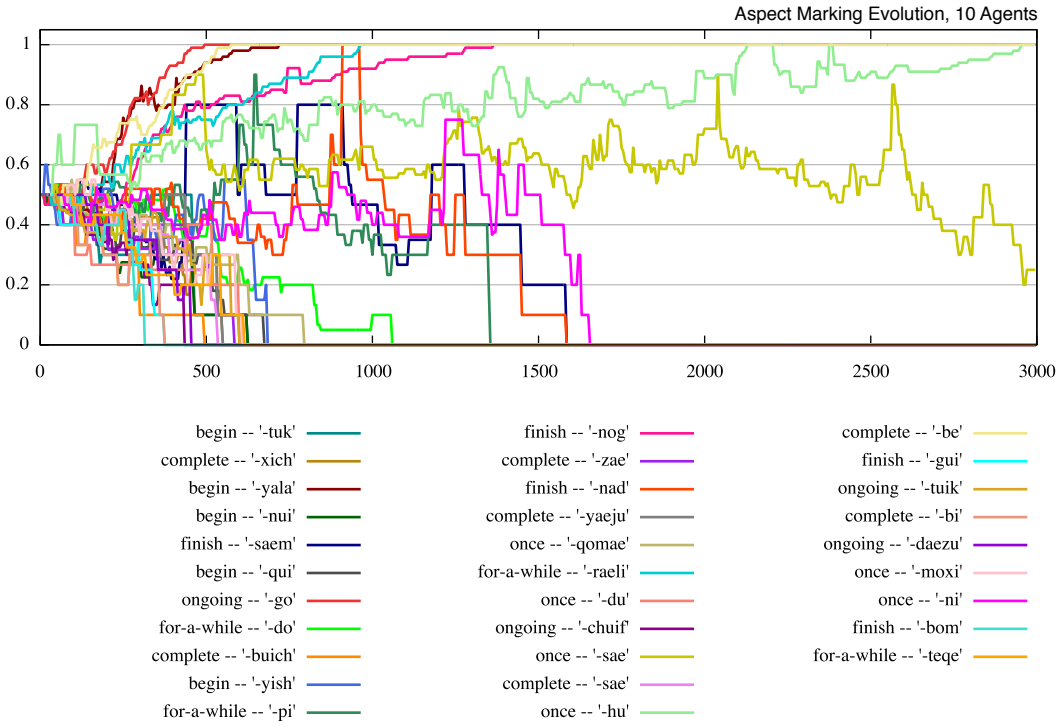

Figure 10. *Emergence of markers for Aktionsarten in a population of 10 agents (population avg.).*

petitors. Some markers lose the competition, reach the minimal score of 0.0 and are eliminated from the inventory. Others reach the maximum score of 1.0 and win the battle.

We see clearly that through the consecutive playing of language games, the population of agents was able to develop and coordinate a system of markers for Aktionsarten. Of course this is only the first step towards the emergence of the rich aspect system we find in Russian but it is nevertheless significant because it is the first bootstrap on which the system can then further complexify.

6. Conclusion and Future Work

This chapter has studied the emergence of Aktionsarten through an illustration of the grammatical operationalization of the Russian tense-aspect system and a demonstration of the learnability of the system by artificial agents that lack any notion of aspectual relations. The implementation of three subsequent learning stages that are also found in research into child language acquisition, has been shown to guide the agents towards a fully operational and robust language system that can handle multiple Aktionsarten.

The language formation experiment described in the final section has shown already how grammatical markers for aktionsart distinctions could arise *de novo* but it has not yet addressed all the issues, in particular the distinction between perfective and imperfective events. The tight interaction that exists between the categories of tense and aspect has so far also been ignored and would require a serious extension of the current model. Nevertheless the research presented so far constitutes a huge step towards more sophisticated experiments in which the grammatical categories of tense and aspect emerge and co-evolve.

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