Multilingual Generation of Grammatical Categories

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Abstract

We present an interlingual semantic representation for the synthesis of morphological aspect of English and Russian by standard backpropagation. Grammatical meanings are represented symbolically and translated into a binary representation. Generalization is assessed by test sentences and by a translation of the training sentences of the other language. The results are relevant to machine translation in a hybrid systems approach and to the study of linguistic category formation.

1 Introduction

In this paper, we propose a representation for grammatical meanings which are relevant to the morphological forms *progressive/simple* in English and *imperfective/perfective* in Russian. We show that these grammatical meanings are sufficient to predict the correct aspectual form in the generation of an English or Russian sentence by presenting a classifier which computes the necessary input-output function. The representation has the symbolic form of a number of distinct features and values for these features.

Descriptive work, exploring aspectual distinctions in many different contexts and collecting different uses and conveyed meanings, has sometimes led to a formulation of aspectual meanings in terms of binary feature sets [Bondarko, 1983], [Breu, 1980], [Scheler, 1984]. Being the outcome rather than the starting point of research, these feature sets however were not validated for their capability of producing and predicting the correct morphology for a given sentence.

In model-theoretic approaches to aspectual semantics [Hinrichs, 1988], [Dowty, 1979], [Verkuyl, 1993] the main effort consists in constructing logical representations for aspectual meanings. These representations are usually constructed for individual sentences, without paying attention to the functional dependency between overt morphological form and semantic representation and its computability.

We use simple feature-value representations instead of model-theoretic constructs for two reasons:

- we want the morphological form to be effectively computable from the semantic representation.
- we apply Occam's razor in the cybernetic formulation of Braitenberg [Braitenberg, 1984]: *Attribute a complex behavior to simple internal representations. As long as the behavior is predicted correctly, stay with it.*

Our work is similar in intention to work done by Munro et al. [Munro and Tabasko, 1991], [Munro *et al.*, 1991] on translation of spatial prepositions. Munro et al. use an interlingual approach to machine translation, designing a semantic representation, translating overt morphological forms (English prepositions) into it, and then translating new morphological forms (German prepositions) from the representation, using backpropagation for the translations.

However there are major differences. Generalization of the learned function is not attempted by Munro et al., which is a serious flaw, for practical application as well as theoretically. The learned classifier can translate the given examples by essentially looking up a function table, but it cannot predict the correct translation in a new context. The failure of prediction is probably due to the somewhat arbitrary character of semantic relations (e.g., "at" gets a context-independent meaning as always "N1 touching N2") and the form of the input representation which is limited to prepositions in the form "Noun-Prep-Noun" where the nouns are not tagged or categorized to increase the scope of the input forms.

In contrast, we have a system for the categorization of English and Russian aspect, capable in principle of handling all uses. The semantic representation is learnable, from free, albeit tagged text. We have generalization as a vital aspect to show that a functional dependence between semantic representation and grammatical form exists, not just a learned function table of correspondences.

2 Feature-based Representation

The complete analysis for the translation of aspectual forms consists of two parts: (a) transforming a binary input representation into a semantic representation, which is a task for a method of *function approximation*, and (b) categorizing the semantic representation consisting of a number of individual grammatical meanings into the language-specific grammatical categories, which is a *pattern classification* task. Figure 1 shows a whole system for the translation of aspects.

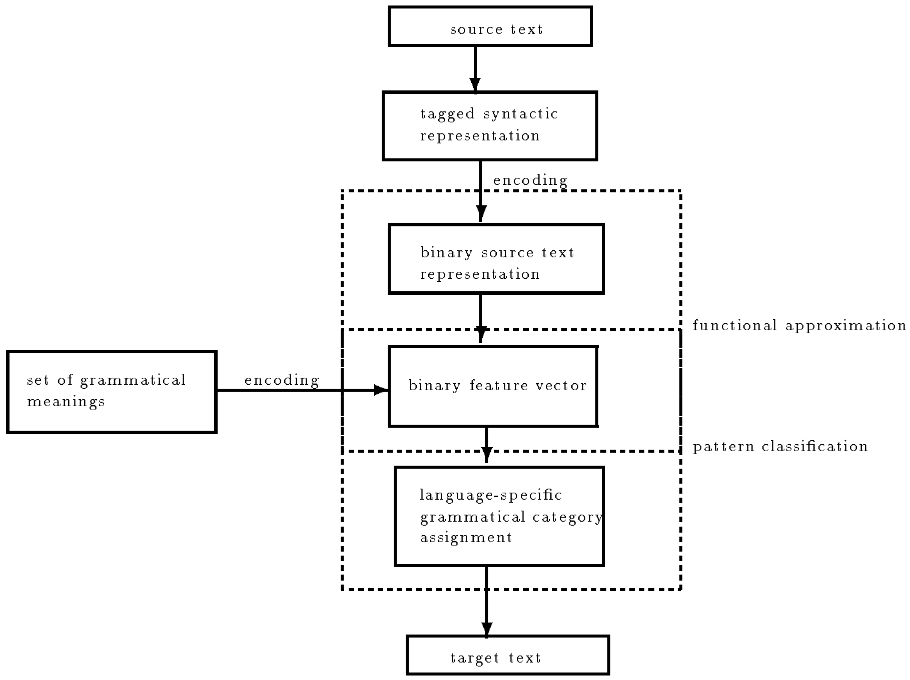

Figure 1: Learning grammatical category assignment

The analysis proceeds as follows:

- Set up a number of semantic features, which determine grammatical aspect and which are derivable from input texts, e.g. “habituality” , possible overt expression in English text: “usually” , “used to”, “every year”, “on Sundays” etc.

- Determine values for those features, e.g. “habitual”, “non-habitual”.

- Tag English or Russian input sentences with grammatical markers, which provide an initial classification in particular of verb lexemes and temporal adverbials.

- Find a functional mapping between tagged input sentence and feature representation.

- Find a functional mapping (classification) of feature representation to two categories, either English progressive/simple, or Russian imperfective/ perfective.

The first part of the task, namely the translation of a syntactic representation into a semantic representation is described in a companion paper, [Scheler, 1994a].

In the following, we concentrate on the pattern classification task, and the role of the set of grammatical meanings, which are important for translation as well as for more theoretical considerations of linguistic category formation.

The set of grammatical meanings used is given in Appendix A. They have been obtained by heuristic setting and fine tuning in the following way:

Grammatical meanings which have been claimed in the literature ([Scheler, 1984] and further references therein) as relevant for the selection of a morphological aspect have been set up as undefined semantic feature values. These were ordered into mutually exclusive groups, which are called "features".

The resulting feature sets can be fine-tuned by adding features/values until learning is perfect for the training set. It is also possible to use feature selection techniques for elimination of superfluous features/values (cf. [Duda and Hart, 1973]).

Note that features have to be functionally implicated in the selection of a morphological aspect to improve learning for the training set. Elimination of features may be important for generalization to new patterns, to exclude generalizing on irrelevant information. Thus we have an empirical test for the validity of a feature set.

Pattern classification has been performed with standard backpropagation, which is a powerful method of statistical regression [White, 1993], [Hornik, 1993], [Hornik *et al.*, 1989], [Rumelhart *et al.*, 1986].

3 Experiments and Results

In this section we present the results of the experiments on categorization. Experiments concerning the transformation of tagged input to semantic representation are reported in [Scheler, 1994a]. An example for a tagged input representation is given in Figure 2.

Standard backpropagation provides a method of pattern classification for binary or numeric patterns. We have used the SNNS-simulator [Zell and others, 1993].

For the input representation several binary codings of the symbolic feature representation for individual input sentences have been created. An additional value for each feature '*' as "neutral" has been provided for. This is particularly useful in the generation of the semantic representations from a source text, because there will usually not be enough overt grammatical indicators to set each feature to a definite value. An example for an English sentence with symbolic and binary feature representations is given in Figure 2. The binary codings used were:

sentence: *I go to church every Sunday.*
tagged syntactic representation: `* on_periods sing_def lexcat7 simple present to_place.`
symbolic feature representation: `* * * non_relational holistic * * all_periods action general telic * * single habitual`
symbolic output: `simple`
bincode: `0 0' 0 0 0' 0 0' 1 1' 1 1' 0 0' 0 0 0' 0 1' 0 1' 1 1' 0 1 0' 0 0 0' 0 0' 0 1' 0 1'`
lincode: `0 0 0' 0 0 0 0 0' 0 0' 0 0 1' 0 0 1' 0 0 0' 0 0 0 0' 1 0' 1 0' 0 0 1' 0 1 0 0' 0 0 0 0' 0 0' 1 0' 1 0'`
fixedlength: `0 0 0' 0 0 0' 0 0 0' 0 1 1' 0 1 1' 0 0 0' 0 0 0' 0 0 1' 0 0 1' 0 1 1' 0 1 1' 1 0 0' 0 0 0' 0 0 1' 0 1 0`

Figure 2: Symbolic and binary feature representations

- binary code: for each feature (15), it was determined how many bits are necessary to code all possible values for this feature. For 2 and 3 values (+ '*') 2 bits are necessary, for 4 and 5 values 3 bits are necessary. The coding has a length of $11 * 2 + 4 * 3 = 34$ bits.
- linear code: each value for each feature is coded in 1-of-n fashion, i.e. $n + 1$ bits are needed for n feature values (+1 for '*'). The result is 44 bits.
- binary code with fixed length: for each feature the same number of bits is reserved (fixed length). The number of bits is determined by binary coding of that feature which has most values. In this case, $3 * 15$ features = 45 bits.

In this way for each language exemplary sentences, taken from [Thompson and Martinet, 1969] for English and [Chawronina and Sirocenskaja, 1976] for Russian have been coded. They are given with their symbolic feature encoding in Appendix B. 20 sentences each were used as training set, and 13 English and 10 Russian sentences provided the test set. For generalization, the test set was applied without learning, as well as the training set for the respective other language to create a situation of translation.

The results of the classification experiment, i.e. learning and generalization of grammatical category assignment, are presented in Table 1 and Table 2. The method used was "Standard_Backpropagation" from SNNS, presentation of patterns in topological order, 5 hidden units, 2 or 3 output units, input units as indicated, learning rate $\rho = 0.2$.

coding (input nodes)	learning correctness (abs=20)	test sentences (abs=23)	translation (abs=20)	generalization total (abs=43)
bincode (34)	100%	17/74%	12/60%	29/68%
lincode (44)	100%	21/91%	17/85%	38/88%
fixedlength(45)	100%	18/79%	15/70%	33/77%

Table 1: Learning English morphological aspect

coding (input nodes)	learning correctness (abs=20)	test sentences (abs=23)	translation (abs=20)	generalization total (abs=43)
bincode (34)	100%	19/82%	17/85%	36/84%
lincode (44)	100%	22/96%	19/95%	41/95%
fixedlength(45)	100%	18/78%	17/85%	35/81%

Table 2: Learning Russian morphological aspect

The results can be summarized as follows:

(a) Learning of the training set was easy, fully possible and quick for each coding and both types of input.

(b) Generalization was consistently better for Russian morphology. Various explanations are possible: The training sets were better for Russian; the feature set is more suitable for Russian aspect (e.g. English progressive requires more features for mood, which are not included); Russian aspect is used more consistently, while English progressive is embedded in a system of tenses and special forms ('kept doing', 'used to do'), which were not generated, and which may lead to incorrect choices of aspect. Further experiments are necessary to see whether it is a consistent phenomenon or an artefact of a specific training situation.

(c) Generalization to new examples was present and can be considered successful. There was a fairly great difference according to the coding used, the linear code being most appropriate for back-propagation pattern classification. However, binary codes may be easily learnable with another method (cf. [Scheler, 1992], [Scheler, 1994b] for an alternative approach to symbolic pattern classification). We can also see that a bad matching of coding to learning method may lead to a (false) rejection of learnability. This system may not have reached peak performance yet, either because the features need further fine tuning, or because we can improve the learning method.

(d) There is not much difference of generalization for additional test sentences and translations. This shows that category formation proceeds from arbitrary input patterns, as long as these are cognitively adequate and describe a possible state of affairs. The feature set is interlingual, no special language-specific feature sets are required.

How do the results on 63 sentences relate to the language faculty in general? There are 5.6×10^8 theoretically possible feature representations. However, much less will actually occur, because many feature value combinations are not permissible or contradictory. We must consider that many sentences will translate to identical semantic representations in terms of aspectually relevant grammatical meanings. Accordingly, generalization between 88%–95% from a limited set of 20 patterns to 43 arbitrary new patterns leads us to expect the learned classifier to scale up well to large corpora.

4 Conclusion

We have presented a feature representation for aspectual grammatical meanings and a learned classifier for English and Russian morphological aspect. The learned classifier can be incorporated into an existing machine translation system as a specialized module which should be capable of improving rule coded translation of grammatical aspect and reduce coding effort for new languages considerably (only tagging input and back-propagation learning is required).

We have seen that the quality of generalization is dependent on the suitability of coding and learning method used. This is an important caveat on the empirical interpretation of a statistics-based approach. Until we have better ways of judging which classification and learning techniques are actually available in human symbolic processing, we can interpret our results simply as showing that a "flat" feature-value representation is in principle sufficient for generation of morphological aspect, and by extension grammatical categories in general.

The implication for the study of linguistic categorization is: rather than viewing the generation of grammatical categories as a single process relating a denotationally interpreted logical form to a morphological category, we look at it as a stepwise or continuous process from perception of events, cognitive constructs of events, objects and time, grammatical meanings to morphological form, using essentially the same techniques of categorization, feature representation and functional dependence for each step. Thus we may eventually link specialized linguistic investigation with a biologically inspired view of human cognition.

A Grammatical Meanings: Features and Values

1. **event-time**
   past - present - future (3)

2. **proximity (past)**
   recent - hodiernal - hesternal - less_than_a_year - more_than_a_year (5)

3. **proximity (for futuric action)**
   immediately - not_immediate (2)

4. **relational**
   relational_to_past - relational_to_present - non_relational (3)

5. **event-extension**
   punctual (instantaneous) - extended (processual,durative) - holistic (3)

6. **reference point in time**
   (event:) occurs_at - starts_at - extends_around (3)

7. **reference period**
   (event:) occurs_at_point_in - occurs_at_period_in - occurs_at_starting_point - occurs_at_end_point (4)

8. **reference times/periods**
   (event occurs at:) all_of_them (all/most) - some_of_them (2)

9. **action-status**
   action - non_action(2)

10. **reference-type**
    existential (indefinite) - referential (definite) - general (mass noun reference) (3)

11. **event-type**
state - atelic_event - telic_event - cause_state (4)
12. **degree of completion**
attempt - halfway_through - completed - negated (4)
13. **duration**
long_duration - limited_duration (short_duration) (2)
14. **number of occurrences**
single - repeated (2)
15. **habituality**
habitual - non_habitual (2)

B Symbolic feature representations

B.1 English examples

1. At six o'clock I *am bathing* the baby.
`* * * non_relational processual extends_around * * action existential telic halfway_through * single habitual`
2. He *is* always *doing* homework.
`present * * non_relational processual * * * action existential telic halfway_through long_duration single habitual`
3. I *taste* salt in my porridge.
`present * * non_relational punctual * * * non_action referential state * * * non_habitual`
4. I'*ve been hearing* all about this accident from him.
`past recent * relational_to_present processual * * * non_action existential state completed long_duration single non_habitual`
5. Tom *is thinking* of emigrating. What do you think of it?
`present * * non_relational processual * * * action existential state halfway_through * repeated non_habitual`
6. The children *are being* very quiet.
`present * * non_relational processual * * * non_action referential state halfway_through long_duration single non_habitual`
7. I *hear* you well.
`present * * non_relational processual extends_around * * non_action referential atelic halfway_through * single non_habitual`
8. Their children *are* really very quiet.
`* * * non_relational processual * * * non_action general state * * * non_habitual`
9. I can't open the door, I *am having* a bath.

present * * non_relational processual extends_around * * action referential telic halfway_through * single non_habitual

10. *Are* you *liking* this excursion? No I'm hating it.

present * * non_relational processual extends_around * * non_action referential state halfway_through long_duration single non_habitual

11. I *hate* excursions.

* * * non_relational processual * * * non_action general state * * * non_habitual

12. I *don't expect* much of him.

present * * non_relational processual * * * non_action general state * * * non_habitual

13. I *am expecting* a letter today.

present * * non_relational processual * occurs_at_period_in * non_action referential state halfway_through * single non_habitual

14. I usually *wear* a coat but I am not wearing one today.

* * non_relational processual * * * non_action existential state * * * habitual

15. My neighbor *is practising* the violin, she usually practices at about this time.

present * * non_relational processual extends_around * * action referential atelic halfway_through * single non_habitual

16. I *go* to church on Sundays.

* * * non_relational holistic * * all_periods action general atelic * * single habitual

17. She *goes* abroad every year.

* * * non_relational holistic * * all_periods action existential telic completed * single habitual

18. Birds *don't build* nests in autumn.

* * * non_relational holistic * * all_periods action general telic negated * single non_habitual

19. We *leave* London at 10am next Tuesday.

future * not_immediate non_relational punctual occurs_at occurs_at_point_in * action referential cause_state completed * single non_habitual

20. He *worked* in that bank for four years.

past more_than_a_year * non_relational holistic * occurs_at_period_in * action existential atelic completed * single habitual

21. The wind *was rising*.

past * * non_relational processual * * * non_action referential cause_state halfway_through * single non_habitual

22. At 8 he *was having* breakfast.

past * * non_relational processual extends_around * * action referential telic halfway_through * single non_habitual

23. He *was* always *having* breakfast at 8 in the morning.

past * * non_relational processual extends_around * * action existential telic halfway_through * single habitual
24. When he saw me he *put* the receiver down.
past * * non_relational punctual occurs_at * * action referential cause_state completed * single non_habitual
25. When he saw me he *had* just *put* the receiver down.
past * * relational_to_past punctual occurs_at * * action referential cause_state completed * single non_habitual
26. She heard voices and realized that there *were* three people in the next room.
past * * non_relational processual extends_around * * non_action referential state halfway_through * * non_habitual
27. She saw empty glasses and cups and realized that three people *had been* in the room.
past * * relational_to_past holistic * * * non_action existential state completed * * non_habitual
28. He *had been trying* to get her on the phone.
past * * relational_to_past punctual * * * action existential cause_state completed * repeated non_habitual
29. I *was talking* to Tom the other day.
past longer * non_relational processual * occurs_at_period_in * action referential atelic halfway_through long_duration single non_habitual
30. I *talked* to Tom several times.
past * * non_relational holistic * * some_periods action existential atelic completed * repeated non_habitual
31. I *talked* to Tom the other day.
past longer * non_relational processual * occurs_at_period_in * action referential atelic completed * single non_habitual
32. I *have been talking* to Tom several times.
past * * relational_to_past holistic * * some_periods action existential atelic halfway_through * repeated non_habitual
33. I *am* always *tripping* over this suitcase.
present * * non_relational punctual * * * action referential cause_state completed * repeated non_habitual

B.2 Russian examples

1. Ja *napisal* pis'mo svojemu drugu i otpravil ego.
past * * non_relational holistic * * * action referential telic completed * single
non_habitual
2. Erik dolgo *ucil* slova is teksta.

past * * non_relational processual * * * action referential telic halfway_through
long_duration single non_habitual
3. Kogda on vyucil ich, on nacal *pisat'* upraznenija.
past * * non_relational processual starts_at * * action referential telic halfway_through * single non_habitual
4. Cto ty delala? Ja *pisala* pis'mo materi.
past recent * non_relational holistic * * * action referential telic halfway_through *
single non_habitual
5. A upraznenija ty uze *napisala* ?
past recent * relational_to_present holistic * * * action existential telic completed *
single non_habitual
6. Rabocie *postroili* novuju skolu i osen'ju ona nacala rabotat'.
past longer * non_relational holistic * * * action existential telic completed * single
non_habitual
7. Oni *stroili* ee polgoda.
past longer * non_relational processual * occurs_at_period_in * action referential telic halfway_through long_duration single non_habitual
8. Ja *zaplatila* den'gi i vzjala gazety.
past * * non_relational punctual * * * action referential cause_state completed * single non_habitual
9. On *vspomnil* pravilo i choroso otvetil na vopros prepodavatelja.
past recent * non_relational punctual * * * action existential cause_state completed * single non_habitual
10. Obycno ja *beru* knigi v universitetskoj biblioteke.
* * * non_relational holistic * * some_periods action referential cause_state * * single habitual
11. Kazdyj mesjac on *posylaet* den'gi svoej materi.
* * * non_relational holistic * * all_periods action existential cause_state completed * single habitual
12. Eta studentka nikogda ne *opazdyvaet.*
* * * non_relational punctual * * all_periods action existential cause_state negated * single habitual
13. No segodnja ona *oposdala* na pjat' minut.
past hodiernal * non_relational punctual * occurs_at_point_in * action referential cause_state completed * single non_habitual
14. Vcera ja ocen' *ustala*, poetomu segodnja ja vstala posdno.
past hesternal * non_relational holistic * occurs_at_period_in * non_action referential cause_state completed * single non_habitual
15. V detstve on choroso *risoval* i vse govorili cto on budet chudosnikom.

past more_than_a_year * non_relational holistic * occurs_at_period_in * action existential atelic * * * habitual

16. Kogda ja byla malen'koj, otec casto *daril* mne knigi.

past more_than_a_year * non_relational punctual * occurs_at_point_in some_periods action existential cause_state completed * single habitual

17. Zavtra ja pojdu v magazin i *kuplju* sebe pal'to.

future * not_immediate non_relational punctual * occurs_at_point_in * action referential cause_state completed * single non_habitual

18. Vcera vecerom ja smotrela televizor a on *pisal* pis'mo bratu.

past hesternal * non_relational processual * occurs_at_period_in * action referential telic halfway_through * single non_habitual

19. Kogda on napisal eto pis'mo, on *posel* na poctu.

past hesternal * non_relational holistic starts_at * * action referential telic completed * single non_habitual

20. Ja poterala tvoj adres, poetomy ja ne *otvecala* na tvoje pis'mo.

* * * relational_to_present punctual * * * action existential cause_state negated * single non_habitual

21. Kazdyj den' nasi zanjatija *koncajutsja* v 3 casa.

* * * non_relational punctual occurs_at * * non_action general cause_state halfway_through * single habitual

22. Vcera posle urokov moj drug Erik bystro *poobedal*, a potom celyj cas cital gazety.

past hesternal * non_relational processual * occurs_at_period_in * action referential telic completed limited_duration single non_habitual

23. Vcera posle urokov moj drug Erik bystro poobedal, a potom celyj cas *cital* gazety.

past hesternal * non_relational processual * occurs_at_period_in * action referential telic halfway_through long_duration single non_habitual

24. Kogda Erik koncil delat' domasnee zadanie, on *posel* v klub.

past * * non_relational punctual occurs_at * * action referential cause_state completed * single non_habitual

25. Segodnja utrom, kogda my *pisali* kontrol'nuju rabotu, on napisal ee lucse vsex.

past hodiernal * non_relational processual * occurs_at_period_in * action referential telic halfway_through * single non_habitual

26. Segodnja utrom, kogda my pisali kontrol'nuju rabotu, on *napisal* ee lucse vsex.

past hodiernal * non_relational holistic * occurs_at_period_in * action existential telic completed * single non_habitual

27. Kogda ja byla malen'kaja, moja babuska casto *rasskazyvala* mne raznye skazki.

past more_than_a_year * non_relational processual * occurs_at_period_in some_periods action general atelic completed * single habitual

28. Starsij brat *podumal*, cto u mladsego brata bol'saja sem'ja i resil emu pomoc'.
`past * * non_relational punctual * * * non_action referential state completed * single non_habitual`
29. Starsij brat podumal, cto u mladsego brata bol'saja sem'ja i *resil* emu pomoc'.
`past * * non_relational punctual * * * action referential cause_state completed * single non_habitual`
30. Kogda *nastupila* noc', on vzjal mesok risa i posel v derevnju, gde zil ego brat.
`past * * relational_to_past holistic * * * non_action referential cause_state completed * single non_habitual`

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