

Uncovering semantic relations conveyed by Russian prepositions

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Abstract— This paper describes performance of an interpreter uncovering meanings of prepositions in “master” — preposition — “slave” constructions. The basis of the semantic interpreter is a set of “if A, then B” rules, with the left parts containing lexical and semantic markers of the “masters” and the “slaves” and morphological markers of the “slaves” (cases) and the right parts containing the meanings of the prepositions which should be attributed if the conditions of the left parts are fulfilled. It is described how, on the basis of the interpreter, the basic onto-semantic rules can be formalized to be implemented into an onto-semantic analyzer and how performance of the analyzer can be improved with implementation of new rules.

Keywords— semantic analyzer, prepositions interpreter, natural language processing, syntactic relations, ontologies.

I. INTRODUCTION

Owing to growing number of human-written documents, natural language processing remains an increasingly important task. To solve this task, we need, inter alia, to learn how to uncover semantic relations in texts automatically.

While on the subject of the Russian language, it should be mentioned that a great number of semantic relations are conveyed by prepositions. Almost every Russian sentence contains a preposition or some of them. Thus uncovering semantic relations conveyed by prepositions is an important task which seems challenging as the majority of the Russian prepositions are polysemantic. Table 1 gives examples of different relations conveyed by the same Russian prepositions.

Our aim was to create a corpus-based semantic-grammatical description of Russian prepositional constructions using empiric data, to formalize the basic onto-semantic rules (BOSP), and to implement these rules into an onto-semantic analyzer (OSA).

II. STATE OF THE ART

In contrast to the classical linguistic methodology focusing on the primary units of different language levels, modern studies practice synthetic methods trying to catch and describe language structures embracing different levels' units: words, collocations, etc. Constructions – combinations of lexical, semantic, morphological, syntactical and other features – are of peculiar interest for modern linguists. To describe and systematize constructions, we should elaborate constructions

identification methods with manual and automatic techniques and carry out analysis of their paradigmatic and syntagmatic features, frequency, and strength. Nowadays, corpus-based resources for the Russian language appear (the National Corpus of the Russian Language (<http://www.ruscorpora.ru/>), the Helsinki Annotated Corpus (<http://www.ling.helsinki.fi/projects/hanco/>), and other). The modern corpus-based studies pay peculiar attention to verbs. One can mention the distributive-transformative models described by Apresian [1], the Lexicograph Lexical Database [2], the FrameBank Collocations Database [3], and the Dictionary of Verbal Collocations with Abstract Russian Nouns [4], to mention but a few. One can also mention dictionaries describing multi-word units which focus on meaningless words ([5], [6], etc.). These resources usually treat constructions with meaningless words as independent modifiers. Such constructions, however, can appear as parts of more complicated constructions. Moreover, though prepositions have abstract meaning, they manage to organize meaningful context when connecting meaningful parts of speech.

In classical linguistic papers, prepositional constructions used to be described from the grammatical point of view and their semantics used to be neglected. One can hardly mention any corpus-based works dedicated to the Russian prepositions except for the paper by Klyshinsky [7], and a couple of others. It is also difficult to transform a set of constructions into a construction-based dictionary or grammar. To solve this task, one should pay attention to synonymy and variability of the constructions, variability of their grammatical features, and so on. For example, different constructions with the verb *прятаться* [to hide] differ in dynamical-statical aspect (in Russian meanings of such constructions would depend on the preposition chosen and on the case of the dependent component), while different constructions with the verb *ударять* [to strike] differ in manner of action (you can *strike someone* or you can *strike the bell*: in Russian, these constructions would include different prepositions). Treating constructions this way, we can grasp and describe normal “behavior” of constructions as well as abnormal cases (like the classical Goldberg's example *to sneeze the napkin off the table* [8]).

III. SEMANTIC RELATIONS

Here we should formalize the term *semantic relation*. By *semantic relation* we mean a certain universal relation that a native speaker beholds in the language. This connection is binary: it connects two semantic nodes with each other [9]. By *semantic nodes* we mean *syntaxems* (*syntaxem* is an irreducible semantic-syntactic unit conveying primitive categorical meaning and acting as a structural component of a more complicated syntactic composition [10]). Let us say, that two different semantic nodes α and β are connected by the semantic relations $R(R(\alpha, \beta))$ if there is a universal binary connection between α and β [9]. Direction of the connection is defined so that the formula $R(\alpha, \beta)$ would be equivalent to one of the following statements:

- “ β is R for α ”
- “question R can be asked from α to β ”

SEMANTIC RELATIONS CONVEYED BY PREPOSITIONS

Preposition	Text	Semantic relation
в [in]	Сегодня Боб пришел в костюме [Today Bob came in his suit]	Одежда(приходить, в костюме) Cloth(come, in suit)
	В Тайланде началась мощнейшая засуха [Dreadful drought broke out in Thailand]	Место(начинаться, в Тайланд) Place(break out, in Thailand)
	В июне на Камчатке еще лежит снег [In June, the Kamchatka is still covered with snow]	Время(лежать, в июнь) Time(be covered, in June)
на [on\ for\ by]	Алиса положила книгу на стол [Alice put her book on a table]	Место(положить, на стол) Place(put, on table)
	Боб опоздал на час [Bob was late for an hour]	Время(опоздать, на час) Time(late, for hour)
	Алиса обиделась на Боба [Alice resented Bob]	На кого(обидеться, на Боб) Object(resent, Bob)
из [from\ of]	Сумка из кожи [Bag of leather]	Материал(сумка, из кожа) Material(bag, of leather)
	приехал из отпуска [came from vocation]	Место(приехать, из отпуск) Place(come, from vocation)
	Промолчал из скромности He kept silence out of modesty	Причина(промолчать, из скромность) Reason(keep silence, out of modesty)

Below you can find examples of the semantic relations equivalent to the first statement:

- Description(*вечер* [evening], *теплый* [warm])
- Action(*дету* [children], *пошли купаться* [went for a swim])

- Characteristic_of_action(*разodelись* [dressed], *в них и нпax* [to kill])
- Time(*опоздать* [be late], *на час* [for an hour])

Below you can find examples of the semantic relations equivalent to the second statement:

- With_who(*прийти* [come], *с другом* [with a friend])
- What_for(*уронил* [drop], *нарочно* [on purpose])
- Whose(*мамин* [mother's], *шарф* [scarf])

IV. “MASTER” – PREPOSITION – “SLAVE” CONSTRUCTIONS

A. Preliminary comments

We suggest that meanings of prepositions do not exist by themselves but realize in a specific context. We also suggest that there is a correlation between morphological, lexical, and semantic features of the immediate context and the meaning of a preposition and we argue that this correlation can be formalized. By *immediate context* we mean a pair of meaningful words connected with a preposition syntactically: a one-word “master” and a one-word “slave”.

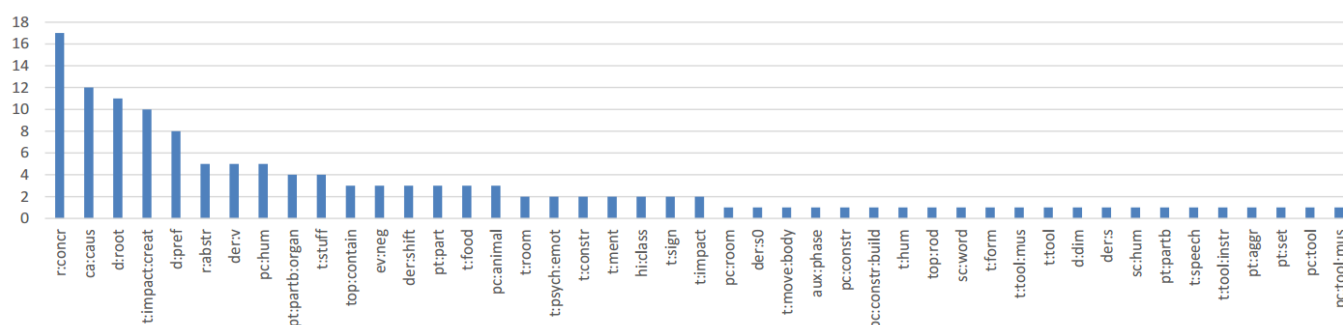
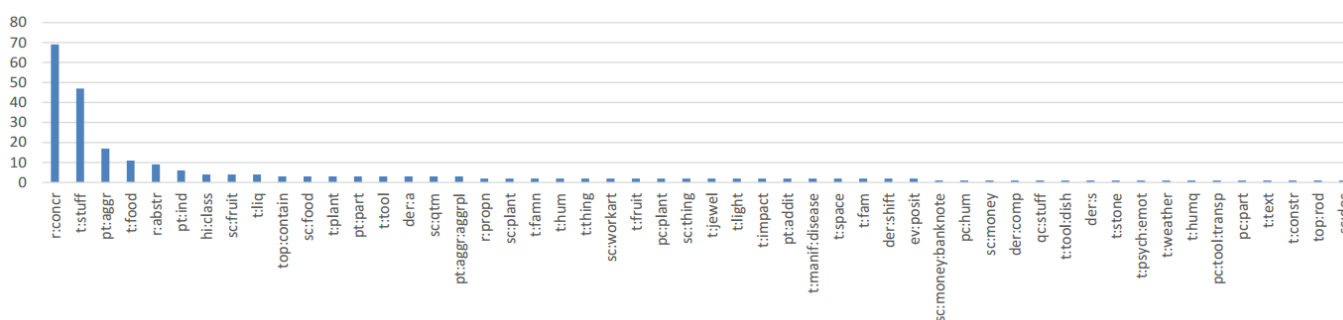
Our hypothesis can be stated as the following: having analyzed a large set of threefold “master” – preposition – “slave” constructions tagged morphologically and semantically, the correlation between the meaning of a preposition and the features of its “master” and “slave” can be described. When described, the correlation can be formalized as a set of rules uncovering the meaning of a preposition automatically. The rules should include lemmas and semantic and morphological tags as components.

B. Preliminary research: extracting markers of prepositions' meanings

Distinguishing and tagging the constructions: The set of “master” – preposition – “slave” constructions could be formed by cutting the sentences with prepositions given in some Russian dictionary as usage examples. For this purpose, we have chosen the Syntactic Dictionary by Galina Zolotova [10] that provides a great number of such sentences. The next step was to tag the elements of the constructions with semantic and morphological information. To reach this goal, we created a script, extracting tags from the National Corpus of Russian Language. This Corpus cannot be called a perfect source of semantic and morphological tags but it seems to be the only available source for the Russian language. Table 2 gives a set of constructions where the fabricative meaning of the preposition *из* [from/of] is realized, the semantic tags extracted from the National Corpus being attached.

Analyzing the tagged constructions: The corresponding tables were created for every meaning of every preposition described by Zolotova. Using this information we charted bar graphs showing frequency of the semantic tags for “masters” and “slaves”. Figures 1 and 2 shows the bar graphs of semantic tags for “masters” and “slaves” of the constructions where the fabricative meaning of the preposition *из* [from/of] is realized.

Sentences	Extracted construction	Semantic tags: “master”	Semantic tags: “slave”
Из одной муки хлеба не испечешь. [You cannot bake bread from flour only]	испечешь из муки [bake from flour]	ca:caus, d:pref, der:v, t:impact:creat	r:abstr, r:concr, t:psych:emot, t:stuff – r:concr, t:stuff
Дядячиха шила из грубого рядна мешки. [Sexton's wife sew bags from sackcloth]	шила из рядна sew from sackcloth	ca:caus, d:root, t:impact:creat – d:root	r:concr, t:stuff
Это только дудочка из глины, Не на что ей жаловаться так. [It's just a pipe of clay. It has to reason to complain]	дудочка из глины [pipe of clay]	d:dim, der:s, r:concr, t:tool:mus	r:concr, t:stuff
Помилуйте, футляр из черной кожи. [Give me the case of leather]	футляр из кожи [case of leather]	r:concr, t:tool, top:contain	pc:hum, r:concr, t:stuff

Frequency of the semantic tags of “masters” of the preposition *из* [from/of] when the fabricative meaning is realizedFrequency of the semantic tags of “slaves” of the preposition *из* [from/of] when the fabricative meaning is realized

Having analyzed the most frequent semantic tags, we managed to extract the semantic markers of every meaning. The set of tags used at the National Corpus is rather poor hence we sometimes failed to pick out any markers though it was evident that “masters” (“slaves”) had much in common. We also noticed that some words appeared so frequently that could be called markers themselves. In such cases, we would pick out *lexical markers*. It was also noticed that sometimes different meanings of prepositions are realized with different cases of “slaves”. Thus we picked out some morphological markers as well.

V. CREATING THE SCRIPT UNCOVERING MEANINGS OF PREPOSITIONS IN “MASTER” – PREPOSITION – “SLAVE” CONSTRUCTIONS

Having described the markers of the meanings, we managed to use the markers as components of the rules

defining the meaning of a preposition looking at the tagged “masters” and “slaves”. We have described 290 rules for 5 polysemantic prepositions: *om* [from] (9 meanings), *do* [to] (5 meanings), *над* [over] (3 meanings), *из-под* [from under] (3 meanings), *из-за* [from behind] (2 meanings). 5 rules are given in Table 3 as examples.

The table should be read this way:

IF (SEMANTIC_DESCRIPTION(“MASTER”).CONTAINS (t:impact:creat OR r:concr) AND PREPOSITION == “ИЗ” AND SEMANTIC_DESCRIPTION(“SLAVE”).CONTAINS (t:stuff)) THEN MEANING = “fabricative”.

If a construction can be construed with more than one rule, the rule of highest priority is to be chosen. A rule with morphological markers as components has higher priority as compared to a rule with semantic or lexical markers. A rule with lexical markers as components has higher priority as compared to a rule with semantic markers. A rule with more

semantic markers as components has higher priority as compared to a rule with less number of semantic markers. When choosing between equipollent rules, the interpreter gives ambiguous outcome.

MARKERS AND THE CORRESPONDING MEANINGS

Lexical markers: “master”	Semantic markers: “master”	Prepositions	Semantic markers: “slave”	Case: “slave”	Meaning: preposition
	t:impact :creat	из [from]	t:stuff		fabricative
	r:concr	из [from]	t:stuff		fabricative
	t:move: body	над [over]	pc: space		locative
мастер [expert]		на [of]		Gen	potentive
	t:unit	от [from]	r:concr		locative dimetive

In the first case, the submissive meaning was chosen as the corresponding rule is the only one that has a lexical marker as a component. In the second case, the locative meaning was chosen as the corresponding rule includes the greatest number of semantic markers as components.

A. Evaluating the interpreter

To evaluate the semantic interpreter, a test corpus was needed. As there were no suitable Russian corpora, we had to create a suitable test corpus ourselves. To make this corpus, we extracted 500 “master” – preposition – “slave” constructions with morphological and semantic tags from the Russian National Corpus manually and attributed prepositional meaning to every construction. To get the meaning, we would find a similar example from the Syntactic Dictionary: for example, to attribute directive meaning to the construction *выпльвало из-за холма* [appeared from behind the hill] we found the similar construction from the dictionary: *выплывал из-за острова* [appeared from behind the island].

A fragment of the test corpus can be found in Table 4.

CHOOSING THE RULE OF HIGHEST PRIORITY

Construction	The variants provided by the interpreter	Basis	Final decision made by the semantic interpreter
<i>преобладает над содержаниями</i> [prevail over meaning]	submissive	“master” = prevail	submissive
	locative	the “slave” has the tag PT:PART, the “slave” has the tag PT:AGGR	
	object-deliberative	the “slave” has the tag T:TEXT	
<i>наклонился над полотном</i> [bow over the canvas]	locative	the “master” has the tag T:MOVE, the “master” has the tag T:MOVE:BODY, the “slave” has the tag PT:PART, the “slave” has the tag PC:SPACE	locative
	object-deliberative	the “slave” has the tag WORK	

FRAGMENT OF THE TEST CORPUS

Constructions from the test corpus	Semantic tags: “master”	Semantic tags: “slave”	Case: “slave”	Meaning: preposition
<i>тащили из-под колес</i> [dragged from under the wheels]	ca:caus, d:root, t:move	pc:tool:device, pt:part, r:concr, t:tool, top:disk — r:concr, t:tool:transp	Gen	directive
<i>смеюсь над ошибками</i> [laugh at mistakes]	ca:noncaus — ca:noncaus	r:abstr	Ins	objective-deliberative
<i>нагнется над столом</i> [bow over a table]	ca:noncaus, d:pref, der:v, t:move:body	r:concr, t:tool:furn, top:contain, top:horiz — pt:aggr, r:concr, sc:food, t:org, t:space, t:tool:furn	Ins	locative
<i>выпльвало из-за холма</i> [appeared from behind the hill]	d:impf, d:pref, der:v, t:move	r:concr, t:space, top:hill — r:concr, t:space, top:hill	Gen	directive

EVALUATION SYSTEM

Outcome	Evaluation
The semantic interpreter's decision is unambiguous and is congruent with the meaning manually defined	1
The semantic interpreter's decision is ambiguous and includes the meaning manually defined	1/(number of variant)
The semantic interpreter's decision is unambiguous and is not congruent with the meaning manually defined	0
The semantic interpreter's decision is ambiguous and does not include the meaning manually defined	0

B. Evaluation of the interpreter

To evaluate the semantic interpreter, we had to juxtapose prepositions' meanings defined manually and prepositions' meanings uncovered by the semantic interpreter (Table 7, Columns 2,3). Table 6 shows how the evaluation system has been used. Table 8 shows the results we got, having tested the interpreter against our test data.

The average percentage of the successful outcomes (82,6%) can be considered a high for the interpreter deliberately devoid of semantic and morphological disambiguation or pragmatic information. We argue that the percentage of successful outcomes could increase if we used the semantic tags were used were disambiguated and more detailed.

COMPARING THE MEANING DEFINED MANUALLY WITH THE MEANING UNCOVERED BY THE INTERPRETER

Construction	The meaning defined manually	The meaning defined by the interpreter	Evaluation
<i>власть над грамматикой</i> [rule over grammar]	submissive	submissive	1
<i>заходясь от драйва</i> [jumped from delight]	causative	the meaning was not defined	0
<i>ящике из-под сигар</i> [box of cigarettes]	directive content	content	0,5

OUTCOMES ESTIMATION

Preposition	Number of constructions	Outcomes estimation (estimation: number of constructions which got this estimation)	Percentage of successful outcomes
<i>от</i> [from]	165	1: 135 0,5: 3 0: 27	82,7%
<i>до</i> [to]till]	90	1: 60 0,5: 4	68,8%

		0: 26	
<i>над</i> [over]	87	1: 75 0,5: 1 0,33: 2 0: 9	87,5%
<i>из-за</i> [from behind]	80	1: 62 0,5: 8 0: 10	82,5%
<i>из-под</i> [from under]	78	1: 72 0,5: 1 0: 5	92,9%
Total:	500	1: 404 0,5: 17 0,33: 2 0: 77	82,6%

Below, you can find an example rule defining the meaning PLACE:

```

rule "1048" // name of the rule (№1048)
salience 100 // /* priority of the rule (not to be confused with
the priority queue; a rule with higher the priority is to be
selected when choosing between different equipollent rules) */
when // opening of an IF clause
$w0 : Fact( partOfSpeech == "I") /* $w0 – address of a fact.
Fact -> a fact with its attributes */
$w1 : Fact ( prev == $w0, partOfSpeech == "ПРЕДЛ",
wordName == "над") /* $w1 - address of a fact. Fact -> a fact
with its attributes. prev -> previous fact */
$w2 : Fact ( prev == $w1, partOfSpeech == "C", hsAttrs
contains "тв", hsAttrs contains "но") /* $w2 - address of a
fact. */
then // opening of an THEN clause
SemanticRelation sem = new SemanticRelation("PLACE"); /*
creating an object sem with a type PLACE */
sem.setLeftAutoPosInText($w0); // appoint $w0 the left
argument
Concept conceptRight = new Concept($w1, $w2);
sem.setRightAutoPosInText(conceptRight); // appoint $w1 и
$w2the right argument
String strIndexConcRight = conceptRight.getIndexString();
boolean changed =
myQueue.addOrUpdateCheckToDelete(conceptRight, 11); /*
add facts $w1 и $w2 to the removal queue: priority: 11. If the
new priority for removal is less or equal to the old one (which
is stored in the queue for removal myQueue), then changed =
false. Otherwise changed = true; */
if(changed)
update(myQueue); /* update the queue for removal myQueue
in the ES Drools */
String indexSem = sem.getIndexString();
if(hsAllIndexedSemanticRelations.contains(indexSem) ==
false) /* if the semantic relation has not been found till this
moment, create a new fact -> semantic relation */
{
hsAllIndexedSemanticRelations.add(indexSem);
insert(sem);
}
end // end of the rule

```

In the previous section, the algorithm of the analyzer defining the meaning of a preposition in “master” – preposition – “slave” constructions was cited. The basis of the semantic analyzer is a set of “if A, than B” rules, with the left parts containing lexical and semantic markers of “masers” and “slaves” and morphological markers of “slaves” (cases) and the right parts containing the meanings of the prepositions which should be attributed if the conditions of the left parts are fulfilled. We have formalized 290 rules which can be transformed into BOSRs and implement in the OSA (performance of the OSA is described in [11] and [12]).

Due to implementation of new BOSRs, the OSA performance can be improved. Enlarging the number of rules can also grade up the outcomes.

Below you can find a BOSR, based on one the rules implemented in the interpreter uncovering prepositional meanings in “master” – preposition – “slave” constructions (the rule can be found in Table 3, Row 3):

MORPH→{Г} && ONT→{t:move:body}

VAL→{над} && MORPH→{ПРЕДЛ}

MORPH→{C} && ONT->{pc:space}

RELATION→Место (0, 1 2)

Below you can find a rule for the Drools Expert System generated by the program from the BOSR automatically:

rule "NEW"

salience 100

when

\$w0 : Fact(partOfSpeech == "Г",

ontology.containsAll("t:move:body") == true)

\$w1 : Fact (prev == \$w0, partOfSpeech == "ПРЕДЛ",
wordName == "над")

\$w2 : Fact (prev == \$w1, partOfSpeech == "C",

ontology.containsAll("pc:space")

then

SemanticRelation sem = new SemanticRelation("PLACE");

sem.setLeftAutoPosInText(\$w0);

Concept conceptRight = new Concept(\$w1, \$w2);

sem.setRightAutoPosInText(conceptRight);

String strIndexConcRight = conceptRight.getIndexString();

boolean changed =

myQueue.addOrUpdateCheckToDelete(conceptRight, 11);

if(changed)

update(myQueue);

String indexSem = sem.getIndexString();

if(hsAllIndexedSemanticRelations.contains(indexSem) ==
false)

{
hsAllIndexedSemanticRelations.add(indexSem);

insert(sem);

}

end

Table 9 gives examples of the semantic relations which can be identified in a text by the OSA based on the ontology.

EXAMPLES OF THE SEMANTIC RELATIONS

The analyzed text	Semantic relations
В это хмурое утро Алиса пошла в свой университет в теплом вязаном свитере. [In the morning, Alice came to the University in her warm sweater]	Time(пойти [come], в утро [in morning]) Place(пойти [come], в университет [to University]) Cloth(пойти [come], в свитер [in sweater])
Из-за угла дома выбежал мальчик в драной куртке. [A boy in a ragged coat ran from behind the corner]	Where from(выбежать [run], из-за угол [from behind corner]) Cloth(мальчик [boy], в куртка [coat])
Этот скорый поезд едет от Москвы до Санкт-Петербурга за 4 часа. [This train goes from Moscow to St Petersburg in four hours.]	Where from(ехать [go], от Москва [from Moscow]) Where to(ехать [go], до Санкт-Петербург [to St Petersburg]) Time(ехать [go], за 4 час [in four hours])

It should be mentioned that implementation of the BOSRs, uncovering meaning of prepositions in “master” – preposition – “slave” constructions, into the OSA does not guarantee absolute success since the immediate context these BOSRs analyze does not always include the information needed to grasp the meaning. The OSA can be improved by implementing technologies of wider context analyzing.

VI.CONCLUSIONS

We have developed and described the interpreter uncovering prepositional meanings in “master” – preposition – “slave” constructions. 290 manually-built rules were implemented in the interpreter. These rules contains semantic,

lexical and morphological markers defined by analyzing the Syntactic Dictionary by Galina Zolotova. The average percentage of successful outcomes is 82,6%. These rules can be transformed into BOSRs and implemented into the onto-semantic analyzer. Performance of the OSA can be improved by implementing new BOSRs based on other rules uncovering prepositional meaning in “master” – preposition – “slave” constructions. The OSA can be used in different natural language processing systems (for example, the question-answering systems documented in the papers [13], [14]). The interpreter of the meanings of Russian prepositions, that has been developed and implemented in software in the course of this work, does not have any analogues at the present time.

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