Prepositional Phrase Attachment and Interlingua

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Abstract. In this paper, we present our work on the classical problem of *prepositional phrase attachment.* This forms part of an interlingua based machine translation system, in which the semantics of the source language sentences is captured in the form of *Universal Networking Language (UNL)* expressions. We begin with a thorough linguistic analysis of six common prepositions in English, namely, *for, from, in, on, to* and *with.* The insights obtained are used to enrich a *lexicon* and a *rule base*, which guide the search for the correct attachment site for the prepositional phrase and the subsequent generation of accurate semantic relations. The system has been tested on British National Corpus, and the accuracy of the results establishes the effectiveness of our approach.

Keywords: PP-attachment, Predicate-Argument Structure, Universal Networking Language, the syntactic frame [*V-N_1-P-N_2*].

1. Introduction

No natural language processing system can do a meaningful job of analyzing the text, without resolving the prepositional phrase (PP) attachment. There are two fundamental questions related to this problem:

(1) *Given a sentence containing the frame*
[V-NP_1-P- NP_2]
does NP_2 attach to V or to NP_1?
(2) *What should be the semantic relation that*
links the PP with the rest of the concept graph of the sentence?

Our work is motivated by seeking answers to these questions. We focus our attention on six most common prepositions of English, *viz., for, from, in, on, to* and *with* (for the motivation, please see Table 5 in section 5).

In order to resolve these issues, we have taken linguistic insights from the following works: [1], [2], [3] and [4]. Other related and motivating works specific to the PP-attachment problem are: [5], [6], [7], [8] and [9].

The roadmap of the paper is as follows: Section 2 provides a linguistic analysis of the six prepositions in question. The UNL system is introduced in Section 3. Section 4

discusses the design and implementation of the system. Evaluation results are given in Section 5. Section 6 concludes the paper and is followed by the references.

2. Linguistic Analysis

Prepositions are often termed as syntactic connecting words. However, they have syntactic as well as semantic specifications that are unique to them. The *selection* of a preposition is decided by the meaning of the syntactic elements that determine it, and the *meaning* depends partly on the preceding syntactic elements and partly on the ones that follow. We now provide a detailed linguistic study of six prepositions in English.

2.1 Syntactic Environments

A preposition can occur in different syntactic environments. For instance, the preposition *for* participates in eight different sequential environments. In each environment, it refers to a specific *thematic role*[1] depending on the semantics of the preceding and the immediately following lexical heads. Table 1 illustrates these environments.

Possible Frames	Examples
[NP–for-NP-V]	The search for the policy is going on.
[NP–for–V_{-ing}–NP-V]	The main channel for breaking the deadlock is the Airport Committee.
[V-for–NP]	He applied for a certificate.
[V-NP_1-for-NP_2]	He is reading this book for his exam.
[V-NP-for-V_{-ing}]	The Court jailed him for possessing a loaded gun.
[V-AP-for-NP]	She is famous for her painting.
[V-AP-for-V_{-ing}]	They are responsible for providing services in such fields.
[V_{-pass}-for-V_{-ing}]	They have been prosecuted for allowing underage children into the theatre.

Table 1: Syntactic environments of *for*

In this table, the first column gives the environments (henceforth, *frames*), and the second column gives the relevant examples. In fact, for each frame a preposition can have different senses depending on the *thematic role* of the NP which the preposition licenses[2] to.

[1] In linguistic theory, *thematic roles* are broad classes of participants in events.

[2] By *licensing* we mean that in a PP the preposition governs and assigns *case* to the NP. (cf. *Governing Theory* and *Case Theory* [1])

The assumption is that thematic roles are closely related to the argument structure of particular lexical items (*viz*., verbs and complex event nominals). Each argument is assigned one and only one theta role. Each theta role is assigned one and only one argument. The relationship between the thematic properties of lexical items and their syntactic representations is mediated by a syntactic principle called the *theta-criterion* [1]. On the basis of the above assumption, Table 2 provides a brief analysis of six prepositions and the related verb types [4]. The first column provides the thematic roles. The rest of the columns show the *verb types* [4] that assign the thematic roles to the *P-NP*$_2$.

Thematic Roles	**For**	**from**	**In**	**On**	**To**	**With**
Benefactive	Build, Create, Prepare Verbs	-	-	-	-	-
Goal	Spend Verbs	-	Put Verbs	Put, Spend Verbs	Send Verbs	-
Instrumental	-	Build, Create, Prepare Verbs	-	-	-	Spray Verbs
Source	-	Send Verbs	-	-	-	-

Table 2: Thematic roles for [V-N_1–P-N_2] (*not exhaustive*)

2.2 Conditions for Attachment Sites

We focus our attention on the particular frame [V-NP_1–P-NP_2], for which the prepositional phrase attachment sites under various conditions are enumerated, as shown in Table 3. The descriptions are self explanatory.

Conditions	**Sub-conditions**	**Attachment Point**
[NP_2] is subcategorized by the verb [V]	[NP_2] is licensed by a preposition [P]	[NP_2] is attached to the verb [V] *(e.g., He forwarded the mail to John)*
[NP_2] is subcategorized by the noun in [NP_1]	[NP_2] is licensed by a preposition [P]	[NP_2] is attached to the noun in [NP_1] *(e.g. She had no answer to the accusations)*
[NP_2] is neither subcategorized by the verb [V] nor by the noun in [NP_1]	[NP_2] refers to [PLACE] *feature*	[NP_2] is attached to the verb [V] *(e.g., I met him in his office; The girls met him on different days)*
	[NP_2] refers to [TIME] *feature*	

Table 3: PP-attachment conditions for the *frame* [V-NP_1-P-NP_2]

3. The UNL System

UNL is an electronic language for computers to express and exchange information [10]. UNL consists of *Universal words (UW), relations, attributes*, and the *UNL knowledge base (KB)*. The UWs constitute the vocabulary of UNL, relations and attributes the syntax and the UNL KB the semantics of the framework. UNL represents information sentence by sentence as a hyper-graph with concepts as nodes and relations as arcs. Figure 1 represents the UNL graph for the sentence (4).

(4) The boy went to school.

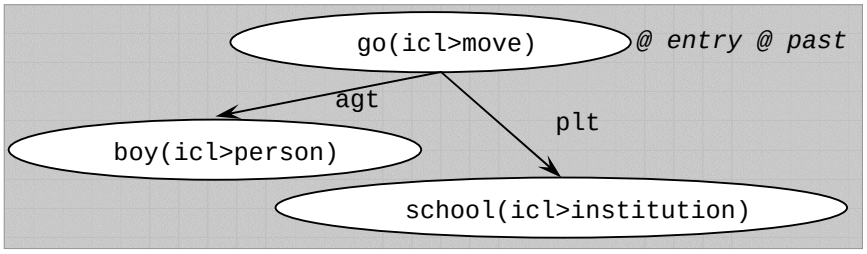

Figure 1: UNL graph for the sentence *'The boy went to school'*.

In *figure 1*, the arcs labeled with *agt* (agent) and *plt* (destination) are the relation labels. The nodes *go(icl>move)*, *boy(icl>person)*, *school(icl>institution)* are the *Universal Words* (*UW*). These are words with *restrictions* in parentheses for denoting unique sense. UWs can be annotated with attributes like *number*, *tense etc.*, which provide further information about how the concept is being used in the specific sentence. Any of the three restriction labels- *icl(inclusion of)*, *iof (instance of)* and *equ* (*used for abbreviations*)- can be attached to an UW for restricting its sense. For (4), the UNL expressions are as follows:

(5) agt(go(icl>move).@entry.@past, boy(icl>person))
plt(go(icl>move).@entry.@past, school(icl>institution))

The most recent specfication of the UNL contains 41 relation labels and 67 attribute labels [11].

3.1 The Analyzer Machine

The analysis of the source language sentences into UNL is carried out using a language independent analyzer called *EnConverter* [12], which does morphological, syntactic and semantic analysis sentence by sentence, accessing a knowledge rich **Lexicon** and interpreting the **Analysis Rules**. The *EnConverter (henceforth, EnCo)* is essentially a multi headed Turing Machine which has two kinds of heads: *processing heads* and *context heads*. The processing heads are also called *Analysis Windows* and are *two* in number: the *left analysis window (LAW)* and the *right analysis window (RAW)*. The context heads are also called *condition windows* of which there can be many.

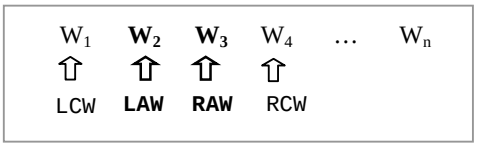

Figure 2. EnCo analyses a sentence by placing *windows* on the constituent words

The nodes under the analysis windows (Figure 2) are processed for linking by a UNL relation label and/or for attaching UNL attributes to. The contents of a node are the Head Words (HWs), the Universal Words (UWs), and the lexical and the UNL attributes. The context heads are located on either side of the processing heads and are used for look-ahead and look-back. The machine has functions like *shifting the windows right or left by one node, adding a node to the node-list* (tape of the machine), *deleting a node, exchange of nodes under processing heads, copying a node* and *changing the attributes of the nodes*. During the analysis, whenever a UNL relation is produced between two nodes, one of these nodes is deleted from the tape and is added as a child of another node in the tree. Forming the analysis rules for EnCo is equivalent to programming a sophisticated symbol processing machine.

3.2 The English Analyzer

The English Analyzer makes use of the *EnCo*, the *English-UW dictionary* and the *rule base* for English Analysis. At every step of the analysis, the rule base drives the EnCo to perform tasks like

a. completing the morphological analysis (*e.g.,* combine *Boy and 's*),
b. combining two grammatical entities (*e.g., is* and *working*) and
c. generating a UNL relation (*e.g., agt* relation between *he* and *is working)*.

Many rules are formed using Context Free (CFG)-like grammar segments, the productions of which help in clause delimitation, prepositional phrase attachment, part of speech (POS) disambiguation and so on. This is illustrated with the example of noun clause handling:

(6) The boy who works here went to school.

The processing proceeds as follows:

a. The clause *who works here* starts with a relative pronoun and its end is decided by the system using the grammar. The system does not include *went* in the subordinate clause, since there is no rule like

*CL*AUSE-> WH-Word V ADV V

b. The system detects *here* as an adverb of place from the lexical attributes and generates *plc* (place relation) with the verb *work* of the subordinate clause. At this point *here* is deleted. After that, *work* is related with *boy* (which is modified by the relative clause and coindexed with the relative pronoun *who*)

through the *agt* relation and gets deleted. At this point the analysis of the clause finishes.

c. *boy* is now linked with the main verb *went* of the main clause. Here too the *agt* relation is generated after deleting *boy*.

d. The main verb is then related with the prepositional phrase to generate *plt* (indicating *destination)*, taking into consideration the preposition *to* and the noun *school* (which has *PLACE* as a semantic attribute in the lexicon). *to* and *school* again are deleted. From *went*, *go(icl>move)* is generated with the *@entry* attribute- which indicates the main predicate of the sentence- and the analysis process ends.

The final set of UNL expressions for the sentence in (6) is given in (7)[3].

```
(7) agt(go(icl>move).@entry.@past, boy(icl>person))
    plt(go(icl>move).@entry.@past, school(icl>institution))
    agt(work(icl>do),boy(icl>person))
    plc(work(icl>do),here))
```

The English analysis system currently has close to 5000 analysis rules and approximately 70,000 entries in the lexicon.

4. Design and Implementation of the PP-Attachment System

The system is implemented using an enriched lexicon and a rule base that guide the operation of the English analyzer (*cf.* Section 3.2). We first describe the enrichment of the *lexicon.* This is followed by the *core strategy* of analysis, which is heavily lexicon dependent. The strategy is translated into the *rule base.*

4.1 The Lexicon

The lexicon is the heart of the UNL system. Lexical knowledge consists of lines of entries describing the *headword (HW)*, the *Universal Word (UW)* and the *properties* of *HW*. For example, the lexical entries for (8a) are given in (8b):

```
(8)a. John ate rice with a spoon
   b. [John] "John(iof>person)" (N,MALE,PROPER,ANIMATE)
      [eat] "eat(icl>do)" (V,VoI)
      [rice] "rice(icl>food)" (N,FOOD)
     [spoon] "spoon(icl>artifact)" (N,INSTR)
```

The HWs are enclosed in square brackets, the UWs in quotes and the properties of the *HWs* in parentheses. The properties are fairly obvious except possibly for *VoI* which means *verb of ingestion* and *INSTR* which means *instrument.*

As discussed in Section 2, the arguments of *V* and *N* are lexically specified. For example, consider the entry for *give* in the lexicon:

[3] The adverb *here* does not need a disambiguating restriction.

(9)[gave] "give(icl>do)"(*VRB,VOA,VOA-PHSL,PAST*)<E,0,0>;

The attributes are shown within parentheses. These attributes specify that *give* is a *verb (VRB), verb of action (VOA), physical-action verb (VOA-PHSL),* and is in *past* tense *(PAST)*. Now, consider the sentence

(10) *He gave a gift to her*

in which *give* takes one NP as its first argument and a PP as its second argument. This is specified in the lexicon through the attribute #_TO_A2. Additionally, the UNL relation is specified (*#_TO_A2_GOL*). This leads to

(11)[gave] "give(icl>do)" (*VRB,VOA,VOA-PHSL,#_TO_A2, #_TO_A2_GOL,PAST*) <E,0,0>;

The entries for nouns and adjectives are enriched in a similar manner.

4.2 Strategy of Analysis: Exploiting the Lexical Attributes

To determine the attachment site of NP_2, four cases of different attribute combinations are considered, as shown in Table 4. *#<P>* indicates that preposition *P* is part of the attribute list of *V* or N_1 and *Not#<P>* suggests the absence from the attribute list.

	Conditions in lexicon			**Action**	
	Attributes of *V*	**Attributes of NP_1**	**Attributes of NP_2**	**Attachment of NP_2**	**Examples**
1	#<P>	#<P>	_	N_1	…paid a visit to the museum. …imposed a law on food hygiene.
2	#<P>	Not#<P>	_	V	...passed the ball to Bill. …imposed heavy penalties on fuel dealers.
3	Not#<P>	Not#<P>	_	N_1	…saw the trap in question.
			#<PLACE>	V	…met him in his office.
			#<TIME>		…met him in the afternoon.
4	Not#<P>	#<P>		N_1	…supplied plans for projects.

Table 4: Lexical conditions for *P-NP_2 -attachment*

The explanation of Table 4 is as follows:

A. NP_2 is attached to *V*, only when
(*V* has *#P* attribute) **AND** (N_1 does not have it); see *row 2*,

Otherwise

B. NP_2 is attached to N_1 when
(both *V* and N_1 have *#<P>* attribute); see *row 1*

OR

(V does not have #<P>) **AND** (N_1 has it); see *row 4*

Otherwise

C. (Neither V nor N_1 has #<P>, in which case combinations of attributes of V, N_1 *or* N_2 determine the attachment site); see *row 3*

The strategy enumerated produces UNL relations corresponding to the six prepositions under consideration. These relations and the various attributes that are called into play appear in Appendix A.

4.3 The Rule Base

The strategy illustrated through Table 4 is converted into a set of rules which guides the analysis process. There are two types of rules, specific to PP-attachment:

Type I: Rules *using the argument structure information* provided in the lexicon.

Type II: Rules *identifying the noun with spatial/temporal feature* and attaching it to the verb or to the nearest complex event nominal.

Let us consider an example of a Type I rule. The rule r_1 in (12) decides when to shift right to take care of case 1 in Table 4.

```
(12) ;Right shift to affect noun attachment
     r1. R{VRB,#_FOR_AR2:::}{N,#_FOR:::}(PRE,#FOR)P60;
```

This states that

IF

the left analysis window is on a *verb* which takes a *for-pp* as the *second* argument (indicated by *#_FOR_AR2*)

AND

the right analysis window is on a *noun* which takes a *for-pp* as an argument (indicated by `#_FOR`)

AND

the preposition *for* follows the *noun* (indicated by `(PRE,#FOR)`)

THEN

Shift right (indicated by *R* at the start of the rule) (anticipating *noun attachment for the pp*).

The priority of this rule is 60 which should be between 0 (lowest) and 255 (highest). The priority is used in case of *rule conflict*.

Taking another example, where a UNL relation is created, the rule r_2 in (13) sets up *rsn* (standing for *reason)* relation between V and NP_2 and deletes the node corresponding to NP_2

```
(13)  ; Create relation between V and N2, after resolving the
        preposition preceding N2
      r2. <{VRB,#_FOR_AR2,#_FOR_AR2_rsn:::}{N,FORRES,PRERES::rsn:}P25;
```

This states that

IF

the left analysis window is on a *verb* which takes a *for-pp* as the *second* argument which should be linked with the *rsn* relation (indicated by `#_FOR_AR2_rsn`)

AND

the right analysis window is on a *noun* for which the preceding preposition has been processed and deleted

THEN

set up the *rsn* relation between *V* and N_2.

The above is relation-setting rule as indicated by < at the start of the rule. The priority is 25.

Now we consider an example of Type II rules (r_3 and r_4), where *tim* relation is set up between *V* and N_2 with the help of the attributes of N_2.

```
(14) r3. DL(VRB,EVENT,VOA){PRE,#ON:::}
                          {N,UNIT,TIME,DAY:+ONRES,+PRERES::}P27;
     r4. <{VRB,EVENT,VOA:::}{N,TIME,UNIT,ONRES,PRERES::tim:}P20;
```

The rules are added to the existing rule base so that they can work in conjunction with the basic rules of the analyzer machine (*shifting, relation-setting, node-deleting, node-inserting, attribute-changing* and so on and so forth). The new rules use the new set of attributes to resolve the PP.

5. Evaluation

In this section, the preparation of the test data and the experiments conducted thereon, are reported.

5.1 Creation of Test Data

For the linguistic analysis, we relied on the data from Oxford genie [13], Web Concordancer [14], Wordnet 2.0 [15], and [16]. The obvious reason is the availability of a number of sentence structures with a variety of semantic information. The relevant sentences were collected, and segmented into sequential frames, each frame containing a preposition.

5.2 Experiments and Top Level Statistics

The experiment of generating UNL expressions has been performed on the British National Corpus [15]. We have chosen the BNC corpus mainly because of its wide domain coverage. The only hindrance to using it is that the sentences are too long to

be easily processed. Hence a word limit of 12-15 words per sentence was imposed on the test sentences. The steps in the evaluation are as follows:

a. Sentences with various patterns are extracted. Care is taken to exclude frames with phrasal verbs and compound nouns (which are not in the scope of the current work).
b. These are processed by the EnCo to generate UNL expressions.
c. The correctness of the UNL expressions is manually ascertained. A correct UNL *entails that attachment problems have been already solved.*

One sentence from each *sentence type* for six prepositions was tested (*cf. Table 5* and *6*). The result shows 100% accuracy. The UNL expressions for six representative sentences for the six prepositions under study are given in Appendix B.

For	From	In	on	To	With
0.7 million	0.35 million	1.4 million	0.5 million	0.8 million	0.6 million

Table 5: statistics of the participation of six prepositions in BNC; these six account for about 45% of the total 11 millions PPs in the corpus.

Prepositions in the frame [V-NP_1-P-NP_2]	Total no. of Sentence Types	Examples
For	6	He carved a toy for the baby. The Court jailed him for 8 years. He is the Commissioner for Inland Revenue. He is reading this book for his exam. They selected him for his honesty. This is the train for Delhi.
From	3	This is a proposal from a group. They make a small income from fishing. They are starting their project from next Sunday.
In	8	I have confidence in him. I deposited the money in my bank account. He revealed this fact in a short statement. He delivered his speech in English. He lost his arm in an accident. I met him in his office. I meet him in the evening. The council recorded 12 complaints in two weeks.
On	5	I put the book on the table. He commissioned John on personal basis. I can picture a farmer on a picnic. I met him on the road. The girls met him on different days.
To	4	They served a wonderful meal to fifty delegates. He forwarded the mail to the minister. We received an invitation to the wedding. Ambulances rushed the injured to the hospital.
With	8	He cancelled a meeting with his students.

		She wore a green skirt with a blouse. They equated the railways with progress. He covered the baby with a blanket. He started the event with a hectic schedule. I bother her with my problems. That provides him with a living. He is playing chess with his friend.

Table 6: Statistics of sentence types for six prepositions in the frame [V-NP_1-P-NP_2]

We obtained correct UNL relations for all the sentence types (Table 6 above) involving the six prepositions under study.

6. Conclusion and Future Work

In this paper we have investigated the problem of PP-attachment in the context of interlingua based MT systems. Our work reinforces the belief that an in-depth linguistic analysis of sentence phenomena not only leads to the design of accurate systems, but also makes the task of evaluation simpler, in that only a set of *sentence types* need to be tested and not millions of sentences. The investigation also underlines the importance of designing rich and high-quality lexicons and integrating these with comprehensive rules of analysis. The future work consists in extending the approach to the complete set of English prepositions and the post positions for Indian languages.

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Appendix A

Prepositions and their UNL Relations

By applying the strategy specified in the previous section, we have generated the UNL relations for the six prepositions under consideration. Lexical attributes have been used in most cases. These facts are presented in the following Table.

	UNL Relations	Attributes of [V]	Attributes of [N_1]	Attributes of [N_2]
For	*ben*	[#_FOR_A2_ben]	-	[N,ANIMATE]
	dur	[VRB]	-	[TIME,UNIT, PL]
	mod	[BE]	-	[^PLACE]
	pur	[#_FOR_A2_rsn]	-	-
	rsn	[#_FOR_A2_rsn]	-	[ABS]
	to	[BE]	-	[PLACE]
From	*frm*	[BE]or [HAVE]	[N]	[N]
	src	[#_FROM_A2_src]	-	-
	tmf	[VRB]	-	[TIME,UNIT]
In	*aoj*	[HAVE]	[ABS]	[ANIMATE]
	gol	[#_IN_A2_gol]	-	-
	man	[VOA-COMM]	-	[PSYFTR,ABS]
	met	[VOA-COMM]	-	[PSYFTR,ABS, LANG]
	scn	[VRB]	-	[EVENT,ABS]
	plc	[VRB]	[EVENT]	[PLACE]
	tim	[VRB]	[EVENT]	[TIME]
	dur	[VRB]	[EVENT]	[TIME,UNIT,PL]
On	*gol*	[#_IN_A2_gol]	-	-
	man	[VRB]	-	[PSYFTR,ABS]
	scn	[VRB]	-	[ABS]
	plc	[VRB]	[EVENT]	[PLACE]
	tim	[VRB]	[EVENT]	[TIME]
To	*ben*	[#_TO_A2_ben]	-	
	gol	[#_TO_A2_gol]	-	[PLACE]
	obj	[V,^VOA-MOTN]	-	[EVENT,ABS]
	plt	[V,VOA-MOTN, TO_plt]	-	[PLACE]
With	*cag*	[VOA]	-	[ANIMATE]
	cao	[BE]		[ABS]
	cob	[#_WITH_A2_cao]	-	-
	ins	[#_WITH_A2_ins]	-	[^ABS]
	man	[VOA]	-	[PSYFTR,ABS]
	met	[#_WITH_A2_met]	-	[ABS]

	obj	[#_WITH_A1_obj]	[ANIMT]	-
	Ptn	[#_WITH_A2_ptn]		[ANIMT]

Table 7: UNL Relation Inventory for Six Prepositions in the frame [V-NP_1-P_1-NP_2]

Appendix B

Out of 34 tested sentences, six sentences with UNL expressions are given in the following Table.

	Sentences with UNL Expressions
For	He carved a toy for the baby. {unl} ben(carve(icl>cut):03.@entry.@past,baby(icl>child):0O.@def) obj(carve(icl>cut):03.@entry.@past, toy(icl>plaything):0C.@indef) agt(carve(icl>cut):03.@entry.@past, he:00) {/unl}
From	They make a small income from fishing. {unl} src(make(icl>do):05.@entry.@present,fishing(icl>business):0U) obj(make(icl>do):05.@entry.@present,income(icl>gain):0I.@indef) agt(make(icl>do):05.@entry.@present, they(icl>persons):00) mod(income(icl>gain):0I.@indef,small(aoj>thing):0C) {/unl}
In	I deposited my money in my bank account. {unl} gol(deposit(icl>put):02.@entry.@past,account(icl>statement):0W) obj(deposit(icl>put):02.@entry.@past,money(icl>currency):0F) agt(deposit(icl>fasten):02.@entry.@past, I:0C) mod(money(icl>currency):0F, I:0C) mod(account(icl> statement):0W,bank(icl>possession):0R) mod(account(icl> statement):0W, I:0O) {/unl}
On	I put the book on the table. {unl} gol(put(icl>move):02.@present.@entry,table(icl>object):0M.@def) obj(put(icl>move):02.@present.@entry, book(pof>publication):0A.@def) agt(put(icl>move):02.@present.@entry,I:00) {/unl}
To	They served a wonderful meal to fifty delegates. {unl} gol(serve(icl>provide):05.@entry.@past, delegate(icl>person):12.@pl) obj(serve(icl>provide):05.@entry.@past, meal(icl>food):0O.@indef) agt(serve(icl>provide):05.@entry.@past, they(icl>thing):00) mod(meal(icl>food):0O.@indef, wonderful(mod<thing):0E) qua(delegate(icl>person):12.@pl, fifty(icl>number):0W) {/unl}
With	John covered the baby with a blanket. {unl} ins(cover(icl>do):05.@entry.@past, blanket(icl>object):0T.@indef)

	obj(cover(icl>do):05.@entry.@past,baby(icl>child):0H.@def) agt(cover(icl>do):05.@entry.@past,john(iof>person):00) {/unl}

Table 8: UNL Expressions for six representative sentences for the six prepositions under study