Constraints on the Space of MT Divergences*

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1 Introduction

This abstract addresses two questions with respect to the role of the lexicon in a machine translation (MT) system:

1. What types of MT divergences are appropriately characterized in the lexicon?
2. What are the principles governing the structures and processes of the lexicon that constrain the space of MT divergences?

We start our discussion with the following definitions:

MT Divergences: all source-language (SL), target-language (TL) sentence translation pairs, where the SL and TL sentences have different structures or convey different information.[1]

Language-to-Language (L-L) Divergences: the characterization or formalization of MT divergences in terms of a mapping between SL-specific and TL-specific structures or information.

Language-to-Interlingua (L-IL) Divergences: the characterization or formalization of MT divergences in terms of mappings between the SL-specific or TL-specific structures or information and the Interlingua.

We assume that the set of MT divergences (*i.e.*, the first definition) documented in the research literature is the equivalent of a "black box" input-output specification of sentence pairs that all MT systems must eventually account for. This level of definition is independent of theoretical and implementational issues.

By contrast, we take the divergences specified as formal mappings between representations (*i.e.*, the last two definitions) to reflect implicit hypotheses or theory-internal principles of natural language representations; this is the equivalent of a "glass box" input-output specification.

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[1] We take this definition to cover both the categories of divergence and mismatch as defined in Barnett *et al.* (1991).

2 Background

Developing a computational theory of lexical representations is an inherently iterative process. We take, as a starting point, the lexical representations proposed in the work of Jackendoff (1983, 1990). Dorr (1993) proposes that the lexicon serve as a repository for information based on these representations coupled with parametric switches to capture cross-linguistic variation. With parameterization, these representations have served as the basis of an interlingua (IL) for a machine translation system called UNITRAN. This system is currently capable of resolving MT divergences as shown in figure 1.[2,3]

The representations, called Lexical Conceptual Structures (LCS), are used to define a large range of lexical items in the lexicon. These structures contain a semantic or conceptual predicate-argument structure that is linked via coindexation to a syntactic head-argument structure that is also part of the LCS.[4] It should be noted that other interlingual MT systems have also been implemented with a semantic formalism developed outside the MT framework (see Barnett *et al.* (1991) on the use of Discourse Representation Theory by Heim (1982), Kamp (1984), also Appelo and Landsbergen (1986) on the use of Montague Grammar (see Dowty *et al.* (1981)).

We define two constraints on the lexical representations of our MT system. The first identifies key syntactic relations encoded indirectly in IL structures. This is assumed in order to meet translation requirements of structural parity when possible, and to cover systematically L-IL divergence classes, as in figure 1.[5] The second constraint states that IL primitives are not constrained by the knowledge base, but rather the other way around, *i.e.*, that they are taken as evidence for categories that must exist in the knowledge base ontology. These two constraints are stated as follows:

Divergence Type	**Translation Example**
Conflational	E: I stabbed John ⇕ S: Yo le di puñaladas a Juan 'I gave knife-wounds to John'
Structural	E: John entered the house ⇕ S: Juan entró en la casa 'John entered into the house'
Thematic	E: I like Mary ⇕ S: Me gusta María 'Mary pleases me'
Categorial	E: I am hungry ⇕ G: Ich habe Hunger 'I have hunger'
Demotional	E: I like to eat ⇕ G: Ich esse gern 'I eat likingly'
Promotional	E: John usually goes home ⇕ G: Juan suele ir a casa 'John tends to go (to) home'
Lexical	E: John broke into the room ⇕ S: Juan forzó la entrada al cuarto 'John forced entry to the room'

Figure 1: An L-L characterization of L-IL divergences accounted for by parameterization of the lexicon.

[2] Dorr (1990) presents an analysis of these as L-IL divergences, demonstrating that, given the syntactic and interlingual structures Dorr assumes, this categorization covers the complete set of possible syntactic-interlingual mappings.

[3] Throughout this abstract, the abbreviations B, E, Es, F, G, H, R, S, and T will be used to stand for Bantu, English, Estonian, French, German, Hungarian, Russian, Spanish, and Turkish, respectively.

[4] In Jackendoff (1990), the LCS also contains other structures that will not be described here.

[5] An example of meeting structural parity requirements is when the same subject and object from the SL sentence are retained as such in the TL sentence.

Syntax-IL Correspondence Constraint: The structural relations in IL representations are constrained as follows:

(a) canonically in terms of a language-independent mapping between syntactic structure and IL structure.[6]

(b) by language-specific IL parameter values that override the mapping in (a).

IL-Ontology Correspondence Constraint: The primitives of the IL representations (*i.e.*, the interpretation of the IL nodes) are taken to be conceptual kinds and so must exist as categories in the knowledge base ontology.

This abstract will focus on problems relevant to the first of these two constraints, but see Dorr and Voss (1992) for a discussion about the implications of the second constraint.[7]

Taken together, these constraints guide the MT system designer's selection of possible IL representations to be used in the lexicon. For example, we will argue later that an implicitly defined argument of a syntactic head must be mapped into an explicit IL constituent, in keeping with the first constraint, and that the type for that IL constituent must be formulated as a conceptual kind that can map into an ontological category in the knowledge base, in keeping with the second constraint. IL representations meeting these constraints, in turn, limit the space of possible L-IL divergences (as a restricted set of structures over which the divergences may occur.) The general approach we take involves refining different aspects of the lexical representations (the structures, the parameters, and the model or interpretation for the structures and parameters) consistent with these constraints.

Earlier work on UNITRAN demonstrated that the lexical representations were adequately expressive for handling divergences arising from verbal predicates.[8] This result leaves open the possibility that MT divergences arising from other types of predicates could also be handled effectively in this model. In particular, we will examine MT divergences grounded in a semantic domain, namely those arising from spatial predicates (*i.e.*, predicates representing a relation in physical space.)

3 L-IL Divergences in Spatial Expressions

The current work focuses on the development of a computational theory of lexical representations for spatial predicates. The MT system in which this theory is embedded is based on the framework of Dorr (1993) and allows for the interpretation and generation of spatial expressions. The new model, called LEXITRAN, adopts a modified LCS for a specific class of lexical entries, with the following properties:

1. their lexical-semantic representation contains a *spatial predicate*.[9]

2. their lexical-syntactic representation conveys the spatial relation or operator (*e.g.*, a di-

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[6] The canonical mapping that is assumed maps between the syntactic structure and the interlingual representation as follows:

(a)	syntactic head ↔ IL root
(b)	syntactic argument ↔ IL argument
(c)	syntactic adjunct ↔ IL modifier

More details about this mapping are provided in Dorr (1990).

[7] The knowledge representation system discussed in Dorr and Voss (1992) is the PARKA system of Spector *et al.* (1990, 1992).

[8] Notice that, with one exception, in figure 1 the main verb in the English sentences translates into "more" than just another verb.

[9] A *predicate* here refers to the logical or mathematical sense of the word in that it is a structure (composed of a predicate-relation and arguments) that exists at the interpreted or semantic level of representation. It may at times correspond to an explicit word or a phrase in a natural language expression, or it may have no *overt* or *lexicalized* manifestation.

rection "south," "left," "down," a geometric configuration "around," a physical relation "against," a distance "near"); these may be realized as as a verb, verbal affix (prefix, suffix), verbal particle, or adposition (preposition, postposition).

In particular, we propose to address the L-IL divergences shown in figure 2.

The focus here on representing spatial predicates is motivated by several issues. First, spatial relations are central to a debate on the formalisms of semantic structure and its primitives. Proponents of a *localist hypothesis* argue that spatial expressions are linguistically more basic than other kinds of expressions and serve as structural templates for the latter (see Lagnacker (1987) and Jackendoff (1983) for two forms of the hypothesis). By contrast, Heine *et al.* (1991) argue that "spatial concepts tend to be derived from concepts representing activities." We do not attempt to resolve this, but to contribute to the debate by clarifying the representational formalisms, *i.e.*, the syntax and semantics of the IL and the composition and decomposition operations on the IL.

Second, although spatial predicates are defined as theoretical constructs within a lexical-semantic level, they are linked to constructs of syntax and knowledge representation systems, making them an excellent domain in which to test those constructs of syntax that are defined in terms of ontological categories and those constructs in knowledge-representation systems that are said to preserve the semantically significant structural relations of natural-language expressions.

A third reason for looking at spatial predicates is that there now exists a research literature on spatial terms in languages from all over the world and on the acquisition of spatial terms by children. This literature provides a valuable range of data on which to refine the

Figure 2: An L-IL characterization of divergences in spatial expressions. The five classes of lexicalization patterns reflect the divergence in the mapping between IL spatial predicates and syntactic structure.

Figure 3: English and German Lexical Entries for *under*

theory and test predictions.

4 Approach

Consider the translation of the following English sentence into German:

(1) E: The mouse ran under the table

The English and German lexical entries for the word *under* are shown in figure 3 using the representation adopted by UNITRAN.[10]

The sequence of diagrams in figures 4–6 provide a schematic trace of UNITRAN's translation of this example. The trace shows how the analysis of the English sentence maps into three German sentences, each of which captures one of the three distinct meanings of the English sentence:

(2) G: Die Maus ist unter dem Tisch gelaufen
'The mouse ran (about in the area) under the table'

(3) G: Die Maus ist unter den Tisch gelaufen
'The mouse ran (to a place somewhere) under the table'

[10]The asterisk (∗ in figure 3 is the star marker parameter defined by Dorr (1993). The nodes at which an asterisk appears are the sites at which another LCS structure must be attached.

Figure 4: Translation of *The mouse ran under the table* with *under* phrase as UNDER modifier.

(4) G: Die Maus ist unter den Tisch durch gelaufen
'The mouse ran (past a place somewhere) under the table'

At the parse step, the analysis of the sentence creates two syntactic structures (capturing the fact that syntactically a PP can attach either as an adjunct (figure 4) or as an argument (figures 5 and 6) to the verb). At the semantic interpretation step, the analysis creates another split in the interpretation (capturing the fact that semantically the PP "path" argument has two possible interpretations). Then in the generation stage, each of the three sentence interpretations (in the IL) are generated into a distinct German sentence.

This example shows that the Jackendoff-Dorr LCSs are expressively adequate to handle the interpretation of the spatial predicates

Figure 5: Translation of *The mouse ran under the table* with *under* phrase as TO argument.

Figure 6: Translation of *The mouse ran under the table* with *under* phrase as VIA argument.

contained in the English word *under*, when *under* appears syntactically in the fourth and fifth categories of figure 2. The representation is also able to handle the generation from these spatial predicates into the German words *unter* and *durch*, where *unter* appears syntactically in the fourth category and *durch* in the second category.

Consider now the following two sentences:

(5) Susan lives to the south of Colorado
'Susan lives in the southern part of Colorado' (*e.g.*, La Junta)
'Susan lives south of Colorado' (*e.g.*, New Mexico)

(6) Daniel drove to the south of Colorado
'Daniel drove to a place in the southern part of Colorado'
'Daniel drove to a place south of Colorado'
'Daniel drove on a path heading toward the southern part of Colorado'
'Daniel drove on a path heading south of Colorado'
'Daniel drove on a path going via the southern part of Colorado'
'Daniel drove on a path going south of Colorado'

The Jackendoff-Dorr primitives are unable to support the range of interpretations in these sentences. First, sentence (5) refers to a place where Susan lives that, in English, is ambiguous with respect to being in or out of Colorado. In order to translate the phrase *to the south of* adequately for variants of (5) such as *Susan lives to the south of England* and *Susan lives to the south of Lake Erie*, the two interpretations need to be distinguished. So the *granularity* of the place representation needed to identify where Susan lives must be increased to capture the internal/external contrast.

A second limitation appears in sentence (6) when interpreting the particular path that Daniel took on his drive. Although a path may be identified by specific places along its extent (*i.e.*, "path-internal" places such as its starting point, its endpoint or some intermediate location), the path may also be identified by a place it avoids (*i.e.*, "path-external" places).

Suppose, for example, that the path in sentence (6) heads from east to west and that in order to avoid the Rockies in Colorado, it changes directions and veers south, avoiding Colorado which otherwise would have been in its path. The path goes to the south of Colorado.

Note that this "avoided location" or "path-external" place interpretation is the only type feasible when the reference object is an area one does not enter by car, as in: *Daniel drove to the south of the bog.*[11] Conversely, the "path-internal" place interpretation is the only type available when it is impossible to drive to the area immediately surrounding the reference object, as in: *Daniel drove to the south of England.* The internal-external ambiguity of the *to the south of* construction is ruled out in these two cases as long as the interpreter knows the relevant properties of the reference objects. In (6) where the reference object and its surrounding area are passable by car, the ambiguity remains and so the path may be in or out of Colorado.

These observations may be summarized as follows. In sentence (5), the conceptual distinction between locations internal and external to a place is not lexicalized. In sentence (6), the conceptual distinction between locations internal and external to a path is not lexicalized. An IL theory must specify the formal principles for representing these observations.

[11] The reference object is the argument of the spatial predicate whose location is known, *i.e.*, is a point of reference.

At the level of IL semantic analysis, a sequence of decisions must be made:

- Does the internal-external distinction belong in the IL for (5) or (6)?
- If so, should the internal-external distinction be encoded implicitly or explicitly in the IL?
- If not, what is the IL for a sentence where the internal-external distinction is lexicalized? (Consider the sentence *She lives outside the city.*)
- If encoded implicitly, what part of the IL is used by the system's spatial reasoner to infer the internal-external distinction?
- If encoded explicitly, what part of the IL identifies that the distinction is not lexicalized?

At the level of IL syntactic analysis, we can ask:

- If the semantics of this distinction is explicit, how is this information to be encoded syntactically? For example, should it be in the form of distinct node labels, distinct node types, or distinct substructures in an IL?

Finally, in coordinating these two levels of analysis, an IL theory must define how the syntactic operations of composition and decomposition affect the semantics of the IL for spatial predicates. For example, the theory must be able to determine whether the semantics is "monotonically non-decreasing" (in the sense that the semantic structure of each constituent in the sentence is composed intact into the semantic structure of the full sentence), or whether there is some "coercion" involved where the semantics of one substructure changes the semantics of another substructure for the sentence.

Our solution to some of these issues entails three changes to the Jackendoff-Dorr representations in order to capture the internal-external distinction in paths and places.

Figure 7: Comparison of lexical representations for *in Texas* and *to the town*.

4.1 Explicit Constituent for Place/Path

The first set of changes redefines the Place and Path structures, guaranteeing a root node for the semantics of a place and a path.

Jackendoff (1983, 1990) treats the Place and Path primitives as one-argument functions that return a place and a path, respectively (see figure 7(a)). In the UNITRAN model, the Place primitive has another argument position for the "subject" of the spatial relation (see figure 7(b)). The "subject" (*i.e.* item or event being located) is syntactically external to the phrase, but semantically this constituent is internal to the Place primitive (denoted *EXT* in the figure). We can think of Jackendoff's Place primitive as a "grammatical predicate" containing the internal argument to the spatial relation, whereas Dorr's Place representation is a "logical predicate" that contains both the internal and external arguments.

The structures in the current LEXITRAN model (see figure 7(c)) have a distinct root node in each of the Place and Path constituents that corresponds to the "some place" implicit in (7)(i) and the "some path" implicit in (7)(ii):

(7) (i) The man lives in Texas

(ii) She hiked to the town

The revised representation provides the same two-argument structure for both Paths and Places. The root nodes may be tagged (*e.g.*, via Dorr's $*$ mechanism) and then lexicalized, as needed to represent sentences such as *he lives some place in Texas* and *she hiked some path to the town*.

4.2 Granularity of Place in a Path

The second change refines the Place node labels in a Path constituent. Sentences such as (8) and (9) contain paths with an explicit direction, *west*. Implicit in the phrase *west of Detroit* is also the meaning "external" to Detroit.

(8) Gertrude lives west of Detroit

(9) The bus drove west of Detroit

The representation issue is what to do with this implicit information. A Jackendoff approach would not encode this sense (see figure 8(a)). Another option would be to treat the phrase *west of Detroit* as having two types of directions, a "west" and a "from." This would capture the meaning of a path going "from" Detroit, as in figure 8(b).

The IL representation used in LEXITRAN differs from these approaches in that it encodes the information implicitly in the node label for the reference object, "Detroit" (see figure 8(c)). By treating Detroit as a Source-Place, we can let a spatial reasoner infer that

Figure 8: Comparison of lexical representations for *west of Detroit*.

Detroit must be a place treated as a point internal to the path. Note that other directions, such as *left* and *right* also behave like the compass adverbs:

(10) (i) They stood left of the guardhouse

(ii) The car veered right of the driveway

The proposed representation change applies to these sentences as well.

4.3 Part-of Relation for a Place

The third change creates a different Place structure, in order to represent a part-of a place, rather than the whole place. For example, a region that is designated "south Texas" is a place that may be represented either as a part of Texas or as any position identified as south within Texas. The alternative structures corresponding to these two interpretations are in figures 9(a) and 9(b).

In (11), both the part-whole relation and compass direction are explicit. In (12)(i)–(iii), only the direction is explicit:

Figure 9: Comparison of lexical representations for *south Texas* and *the south of Texas*.

(11) He lives in the southern part of Texas

(12) (i) He lives in southern Texas

(ii) He lives in south Texas

(iii) He lives in the south of Texas

However, since the part-whole relation may appear without direction but some other modifier, as in *He lives in the part of Texas called Texarkana* or *They drove through the Texas panhandle*, the representation that has been adopted in LEXITRAN is the one that encodes the part-whole relation in its own constituent structure, as shown in figure 9(b). This approach is consistent with the structure changes proposed above. The guiding principle has been: for each place or a path in an IL representation, there must exist a corresponding constituent structure. We define "constituent structure" as either a node with the structure it dominates or a leaf node.

5 Conclusion

In conclusion, the focus of this work on the MT lexicon has been on lexical-semantic representations as constrained by the need for a mapping to and from syntactic structures as well as by the need to share conceptual kind terms with a knowledge base ontology. Within this framework, we have specified the divergences of interest in terms of an L-L characterization for general ease of reading; however, we make clear that our formal approach relies on L-IL.

In developing a computational theory of lexical representations that adequately covers MT divergences in the research literature, we have:

1. shifted from a syntactic basis for scoping the MT divergences to a semantic one (from verbal predicates to spatial predicates).

2. shifted from characterizing the divergences generally to a set of definitions that differentiates between ways of formulating divergences.

In addition, we have begun to clarify the role of KB information in constraining lexical representations; space limitations do not allow us to elaborate on this point.

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