Spatial Information Challenges in English to Portuguese Machine Translation

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Abstract

Neural Machine Translation (NMT) systems, the current leading approach in Machine Translation, still face difficulties when translating spatial language. In this paper, we use Qualitative Spatial Reasoning (QSR) to represent spatial information in English-Portuguese automatic translations. We identify causes of unnatural translations by translating 145 sentences from CAM and COCA using Google Translate and DeepL. Applying QSR, we logically represent meaning differences. Our results show that despite good overall performance, NMT engines struggle with specific spatial meanings, resulting in a 10.6% sense error rate and a 12.0% error in syntactic projections. This work addresses practical and theoretical MT challenges.

keywords: Neural Machine Translation; English-Portuguese Machine Translation; Qualitative Spatial Reasoning; Google Translate; DeepL.

1 Introduction

Neural Machine Translation (NMT) has emerged as the dominant paradigm in Machine Translation (MT) both in academia and real-world applications (Dabre et al., 2020). This success can be partly attributed to the improved ability of deep learning models to capture long dependencies in sentences (Vaswani et al., 2017; Yang et al., 2020).

Although very effective, some NMT tools still fall short of capturing the nuances of spatial information, such as preposition polysemy, and the idiosyncratic projection of manner in verbs or in adjuncts (McCleary and Viotti, 2004). For instance, Example (1), extracted from the Cambridge Online Dictionary (CAM), was translated from English (EN) to Portuguese (PT) using Google Translate (GT) and DeepL (DL).

(1) He swam *across* the river. (CAM)

a. ? Ele nadou do outro lado do rio.
3SG.M swam from-the other side of-the river
(GT)

b. Ele atravessou o rio a nado. (DL)
3SG.M crossed the river by swimming

GT's translation of Example (1), while grammatically correct, misses the mark when it comes to capturing the most natural PT expression for the EN sentence. DL, on the other hand, nails it.

The reason behind this mistranslation lies in the polysemy of the preposition *across*, which can signify both a *fixed opposite location to the point of reference* and *movement from one side of a space to the other*. In this particular case, the intended meaning is clearly the latter. To illustrate this, let's consider Figures 1 and 2.

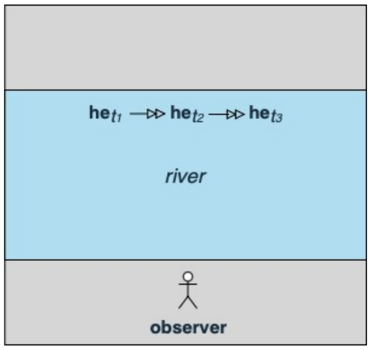

Figure 1: Semantic diagram of (1)-a.

Figure 1, representing the GT output, indicates motion within a specific location (an opposite bank of the river). However, Figure 2, representing the DL output, conveys the meaning of crossing from one river bank to the other, thus capturing the dynamic nature implied in the original EN sentence.

That said, this paper explores the automatic translation of EN sentences involving spatial information (topology or movement) into PT using GT and DL. Our goal is twofold: first, we draw on the work of Spranger et al. (2016), Freksa and Kreutzmann (2016) and Randell et al. (1992) to formalize

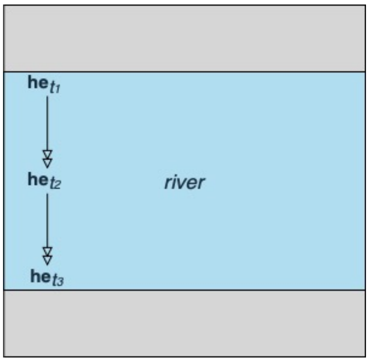

Figure 2: Semantic diagram of (1)-b.

samples of sentences in both source and target languages. Then, we categorize the translations to identify common mistakes made by the NMT tools. Rather than focusing on the NMT process itself, we aim to discuss the spatial meanings that these tools struggle to capture, illuminating practical and theoretical research directions in spatial language and MT. Our results show that, despite their generally good performance, MT engines are still prone to some more or less systematically categorical mistakes when translating EN texts to PT.

The rest of this paper is organized as follows. Section 2 offers a brief overview on spatial language research and related work. Section 3 details our methodology, Section 4 presents our study's findings, and Section 5 concludes the paper and discusses potential directions for future work.

2 Background and Related Work

The study of spatial language has become a significant area of investigation (Levinson and Wilkins, 2006). The use of linguistic expressions to describe spatial relationships constitutes a central point across various disciplines, including Cognitive Linguistics (Lakoff and Johnson, 2008; Talmy, 1985, 2000a; Oliveira and Fernandes, 2022), Cognitive Psychology (Taylor and Tversky, 1996; Tversky, 2003; Slobin, 1996; Oliveira, 2021), Semantics (Zwarts and Basso, 2016), Natural Language Processing (NLP) (Kelleher and Dobnik, 2022; Dobnik et al., 2018, 2022; Ghanimifard and Dobnik, 2019), and Artificial Intelligence (AI) (Zang et al., 2018; Gotts et al., 1996; Ligozat et al., 2007).

Spatial language research has focused on the different linguistic components that convey spatial information, such as verbs (Mani and Pustejovsky, 2012) and prepositions (Coventry and Garrod, 2004; Herskovits, 1985). Despite progress, prepositional semantics remains relatively challenging for NLP due to issues involving ambiguity caused by polysemy (Herskovits, 1986; Rodrigues et al., 2020, 2017), as illustrated in Example (1). One particular issue that arises is how typologically different languages express spatial information. For instance, in languages like EN, the meanings typically conveyed by spatial prepositions may be expressed in different parts of speech in PT, such as in verb roots: (e.g.: "The pencil rolled *off* the table" and "O lápis *saiu* rolando da mesa".) (Talmy, 2000b; Oliveira and Fernandes, 2022).

For our research purposes, we will focus on a short literature review on Qualitative Spatial Reasoning (QSR) (Cohn and Hazarika, 2001; Chen et al., 2015; Rodrigues et al., 2020). QSR is a subfield of AI that allows for the formal representation of human knowledge about physical objects in the world (Cohn et al., 1997). Through QSR methods, we can formally represent the qualitative static and dynamic spatial information found in our corpus. The Region Connection Calculus (RCC-8) (Randell et al., 1992; Cohn et al., 1997) is a QSR that establishes eight mereotopological relations that serve as a framework for representing static information about space. Mani and Pustejovsky (2012) proposed a formalization based on Dynamic Interval Temporal Logic (DITL) to model motion-related information expressed through EN verbs. Freksa and Kreutzmann (2016) and Freksa (1992, 1991) presented Conceptual Neighborhoods, which allow for the representation of discrete transitions between temporal or spatial relations in dynamic terms. Lastly, Spranger et al. (2016) introduced a system based on RCC-8 and Allen's Interval Algebra (Allen, 1983) to generate both dynamic and static spatial relations for robotic interaction.

These works provide tools for modeling different types of spatial information. Among them, the papers from Freksa and Kreutzmann (2016) and Spranger et al. (2016) are particularly relevant for us since they present formal ways to model motion in order to represent spatial configurations that may continuously change over time,

3 Methods

In this section, we describe our methodology step-by-step, briefly comprising data collection, preposition classification, translation process, spatial formalization, and translation categorization.

3.1 Data Collection

We compiled 145 sentences containing five EN prepositions that convey spatial knowledge: *across*, *into*, *onto*, *through*, and *via*. These sentences were sourced from the Cambridge Online Dictionary (CAM)[1] and the Corpus of Contemporary American English (COCA)[2]. We manually labeled each sample according to their contents regarding prepositions, spatial meaning, and an identifier for sentence number. In (2), we show one such example from the corpus (sample `Through-CAM-1-2`).

(2) He struggled through the crowd till he reached the front. (CAM)

a. ? Ele lutou no meio da multidão até chegar à frente. (GT)
3SG.M fought in-the middle of-the crowd until reach to-the front

b. ? Ele se debateu entre a multidão até chegar à frente. (DL)
3SG.M REFL struggled amongst the crowd until reach to-the front

3.2 Categorization by Meanings

We systematically categorized each sentence based on spatial meanings aligned with entries found in CAM for each preposition, as shown in Table 1.

EN Preposition	Spatial Meaning(s)
Across	(1) perpendicular position (2) movement of crossing (3) opposite location (4) in all parts of
Into	(1) movement to unspecified point of an area or container (2) movement up to point of contact with an obstacle
Onto	(1) movement over a surface without leaving the delimited area
Through	(1) movement traversing an area from one extremity to the other (2) movement past or penetrating a barrier
Via	(1) part of a route

Table 1: Categorization of *across*, *into*, *onto*, *through*, and *via* based on definitions from CAM.

3.3 Translation Process

We translated the sentences into PT with Google Translate (GT)[3] and DeepL (DL)[4] using their versions publicly available online in August-September 2023. Additionally, to facilitate comparison, we provided professional human-translated references for all samples.

3.4 Spatial Knowledge Formalization

To formalize the sentences, we based our analysis on Freksa and Kreutzmann (2016) and Spranger et al. (2016). For representing time, we defined each time interval t as a set of time points, and we used the predicate *occurs_in*$(\theta,\ t)$ to denote that an event θ occurs during time interval t. Events θ were defined based on the thirteen spatio-temporal qualitative relations as shown in Figure 3.

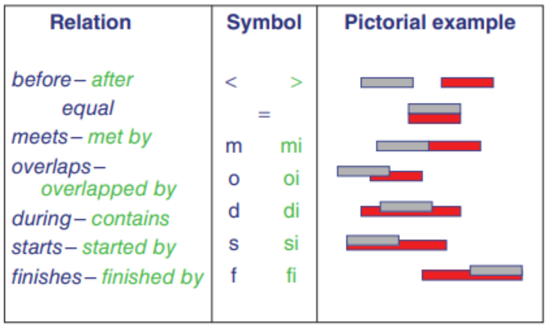

Figure 3: The thirteen qualitative relations between two linear extended objects on a directed line (Freksa and Kreutzmann, 2016).

Figure 3 shows the thirteen jointly-exhaustive and pairwise-disjoint relations based on Allen's Interval Calculus (Allen, 1983). These relations can be described by the following set of functions: {*before, after, equal, meets, met by, overlaps, overlapped by, during, contains, starts, started by, finishes, finished by*}. With this set of relations, we can represent transitions relative to moving objects that take part in an event. For example, an event in which an object F (the Figure) moves across a surface R (Region or Ground) can be defined by the following relations: $\langle F\ starts\ R,\ R\ contains\ F,\ F\ finishes\ R\rangle$. In this scenario, the Figure is a moving or conceptually movable point, and the Ground is a reference point (Talmy, 1985, 2000a).

We assume by default a 3D space for all objects in our motion scenes. To represent spatial information in sentences like Example (1), where the preposition *across* denotes movement traversing a surface, we define the function *surface(r)*. This function maps a relation like *during* or *contains* to its surface by projecting a surface object onto 2D.

Mereotopological relations were modeled using RCC-8 (Randell et al., 1992): {*dc, ec, po, eq, tpp,*

[1] https://dictionary.cambridge.org/
[2] https://www.english-corpora.org/coca/
[3] https://translate.google.com
[4] https://www.deepl.com/translator

ntpp, *tpp*$^{-1}$, *ntpp*$^{-1}$}. To represent a sentence like the GT output in Example (1), we posit a Reference Region (*RR*) which is a portion of some region *R*, or Ground, situated apart from the place where the action carried out by object *F*, the Figure, occurs. The Reference Region is separated from the rest of *R* by a cross-cut line (we call it *meridian*), which connects with *R* in two distant (non-consecutive) points and does not touch $F : R_{op} = ntpp(F, R)$.

In order to express the relation between the predicate *occurs_in(θ, t)* and the qualitative relations shown in Figure 3, we used the $\leftsquigarrow$ connective, which signifies a *defeasible implication*, i.e., a form of reasoning that is rationally persuasive but lacks deductive validity. In this context, the premises of the argument offer rational support for the conclusion, but there remains the possibility that the premises are true while the conclusion is false. Simply put, the connection between the premises and the conclusion is provisional and could be overridden by supplementary information.

3.5 Categorization of MT Translations

We categorized the 145 sentences translated by both GT and DL (i.e., 290 in total) by comparing each preposition translation with the meanings presented in Table 1. To achieve this, we utilized the following categories: (C)orrect translation, mistaken (S)ense translation, and mistaken (P)rojection translation. The latter primarily involves the improper incorporation of manner into the verb of the Portuguese-translated sentences, instead of representing manner with adjuncts (see, for instance, 3).

4 Results and Discussion

To summarize our formal analysis, we will discuss in detail the formalizations for the sentences in Examples (1) and (2). The formulas depict qualitative spatial relations between the original sentences and their respective translations. In both formalizations, time intervals were represented by t_1, t_2, t_3, where t_1 and t_3 correspond to the initial and final intervals, respectively. On the other hand, t_2 represents a time interval between t_1 and t_3. Table 2 shows the formulas representing Example (1).

Original text: He swam across the river.
$\forall t \in \{t_1, t_2, t_3\}, t_1 < t_2 < t_3$ $occurs\_in(moves\_across(he, river), t) \leftsquigarrow$ $river' = surface(river) \wedge$ $starts(he, river', t_1) \wedge$ $during(he, river', t_2) \wedge$ $finishes(he, river', t_3)$
GT: Ele nadou do outro lado do rio.
$\forall t \in \{t_1, t_2, t_3\}, t_1 < t_2 < t_3$ $occurs\_in(moves\_on\_opposite\_side(he, river_{op}), t) \leftsquigarrow$ $river' = surface(river_{op}) \wedge$ $starts(he, river', t_1) \wedge$ $during(he, river', t_2) \wedge$ $finishes(he, river', t_3)$
DL: Ele atravessou o rio a nado.
$\forall t \in \{t_1, t_2, t_3\}, t_1 < t_2 < t_3$ $occurs\_in(moves\_across(he, river_{op}), t) \leftsquigarrow$ $river' = surface(river_{op}) \wedge$ $starts(he, river', t_1) \wedge$ $during(he, river', t_2) \wedge$ $finishes(he, river', t_3)$

Table 2: Formalizations for sentences in Example (1).

The formalization in Table 2 enables us to represent the lexical difference mentioned in Section 1. In the original sentence, the preposition *across* is categorized as sense (2) according to CAM (Table 1). However, the GT translation opts for sense (3). The expression "do outro lado" conveys the meaning that the action carried out by *he* occurred in a portion of the *river* that is separate from *RR*, differing from the region where the action occurred in the original sentence, and aligning with the DL translation.

Qualitative differences are also evident in the formalization of Example (2) in Table 3, where *through* is employed in sense (1) (from Table 1).

Original text: He struggled through the crowd till he reached the front.
$\forall t \in \{t_1, t_2, t_3\}, t_1 < t_2 < t_3$ $occurs\_in(arduously(moves\_through(he, crowd), t)) \leftsquigarrow$ $starts(he, crowd, t_1) \wedge$ $during(he, crowd, t_2) \wedge$ $finishes(he, crowd, t_3)$
GT: Ele lutou no meio da multidão até chegar à frente.
$\forall t \in \{t_1, t_2, t_3\}, t_1 < t_2 < t_3$ $occurs\_in(fights(he, crowd) \wedge moves\_to(he, crowd), t) \leftsquigarrow$ $starts(he, crowd, t_1) \wedge$ $during(he, crowd, t_2) \wedge$ $finishes(he, crowd, t_3)$
DL: Ele se debateu entre a multidão até chegar à frente.
$\forall t \in \{t_1, t_2, t_3\}, t_1 < t_2 < t_3$ $occurs\_in(flounder(he, crowd) \wedge moves\_to(he, crowd), t) \leftsquigarrow$ $starts(he, crowd, t_1) \wedge$ $during(he, crowd, t_2) \wedge$ $finishes(he, crowd, t_3)$

Table 3: Formalizations for sentences in Example (2).

The triplet $\langle starts, during, finishes \rangle$ was applied to all sentences in Table 3. This choice reflects that the action initiated at one entrance point of the *crowd* and concluded at an exit point. The distinctions among the sentences lie in the manner in which the action occurred.

The original sentence in Example (2) describes the Figure's challenging motion event from a point inside or beyond the crowd to a "forward" extremity (ultimately reaching the *front*) undertaken with difficulty. This difficulty is seamlessly integrated into the EN verb *to struggle*. Similarly, GT and DL attempt to convey the same idea using PT verbs like "lutar" (*to fight*) and "se debater" (*to flounder*), respectively, resulting in translations that sound excessively hyperbolic. A more accurate rendition would be "Ele atravessou a multidão *com dificuldade* até chegar à frente." In this version, the act of crossing is expressed by "atravessar," while the difficulty is conveyed by "com dificuldade".

To represent this distinction in the formalizations, we introduced a second-order predicate (*arduously*). In Table 3, the effort involved in executing the action linked to the verb *to struggle* is expressed by the predicate *arduously*. In contrast, the verbal phrases "lutou no meio de" ((*he*) *fought in the middle of*) and "se debateu entre" ((*he*) *floundered among* (*the crowd*)) denote individualized events.

The formalizations in Table 3 reveal the challenges GT and DL face when translating manner, leading to translation errors. Table 4 summarizes the evaluation for each category found in our analysis: **Correct** translation; mistaken **Sense** translation, and mistaken **Projection** translation.

	Correct	Sense	Projection
GT	106 (73.1%)	19 (13.1%)	20 (13.8%)
DL	118 (81.4%)	12 (8.3%)	15 (10.3%)
Total	**224 (77.2%)**	**31 (10.6%)**	**35 (12.0%)**

Table 4: Categorization of GT and DL performance.

Table 4 reveals that DL outperformed GT in generating correct translations. DL correctly translated 118 sentences (81.4%), while GT achieved 106 (73.1%). DL also exhibited fewer Sense errors (8.3%) and Projection errors (10.3%) compared to GT, which had 19 (13.1%) and 20 (13.8%) respectively. Sense errors refer to situations where the MT engine generates a grammatically correct sentence that does not convey the original meaning. E.g., when translating *across*, regardless of its meaning, GT predominantly chose the translation "do outro lado". Projection errors are influenced by the distinct lexicalization of spatial information in EN and PT as described in Talmy (1985, 2000a).

5 Conclusion and Future Directions

In this paper, we analyzed 145 sentences translated from EN to PT by Google Translate and DeepL from the CAM and COCA corpora describing spatial relations. Using QSR methods, we formalized the spatial information to highlight the differences in qualitative relations between source and target sentences. We also analyzed the translations for all sentences and found that polysemy-related sense errors and syntactic projection errors challenge MT.

To strengthen our findings, it would be interesting to (i) formalize more examples; (ii) computationally test the formalizations; and (iii) analyze automatic translations of other target languages. One obvious limitation of these extensions is that they are extremely time-consuming, since all formalizations must be done by hand. Additionally, we acknowledge the difficulty of developing automatic methods to logically represent spatial language and to incorporate formal layers into NMT models. Overall, we hope that this work highlights practical and theoretical issues in MT.

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