

Empirical lower bounds on translation unit error rate for the full class of inversion transduction grammars

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Abstract

Empirical lower bounds studies in which the frequency of alignment configurations that cannot be induced by a particular formalism is estimated, have been important for the development of syntax-based machine translation formalisms. The formalism that has received most attention has been inversion transduction grammars (ITGs) (Wu, 1997). All previous work on the coverage of ITGs, however, concerns parse failure rates (PFRs) or sentence level coverage, which is not directly related to any of the evaluation measures used in machine translation. Søgaard and Kuhn (2009) induce lower bounds on translation unit error rates (TUERs) for a number of formalisms, incl. normal form ITGs, but not for the full class of ITGs. Many of the alignment configurations that cannot be induced by normal form ITGs can be induced by unrestricted ITGs, however. This paper estimates the difference and shows that the average reduction in lower bounds on TUER is 2.48 in absolute difference (16.01 in average parse failure rate).

1 Introduction

The first stage in training a machine translation system is typically that of aligning bilingual text. The quality of alignments is in that case of vital importance to the quality of the induced translation rules used by the system in subsequent stages. In string-based statistical machine translation, the alignment space is typically restricted by the n -grams considered in the underlying language model, but in syntax-based machine translation the alignment space is restricted by very different and less transparent structural constraints.

While it is easy to estimate the consequences of restrictions to n -grams of limited size, it is less trivial to estimate the consequences of the structural constraints imposed by syntax-based machine translation formalisms. Consequently, much work has been devoted to this task (Wu, 1997; Zens and Ney, 2003; Wellington et al., 2006; Macken, 2007; Søgaard and Kuhn, 2009).

The task of estimating the consequences of the structural constraints imposed by a particular syntax-based formalism consists in finding what is often called “empirical lower bounds” on the coverage of the formalism (Wellington et al., 2006; Søgaard and Kuhn, 2009). Gold standard alignments are constructed and queried in some way as to identify complex alignment configurations, or they are parsed by an all-accepting grammar such that a parse failure indicates that no alignment could be induced by the formalism.

The assumption in this and related work that enables us to introduce a meaningful notion of alignment capacity is that simultaneously recognized words are aligned (Wu, 1997; Zhang and Gildea, 2004; Wellington et al., 2006; Søgaard and Kuhn, 2009). As noted by Søgaard (2009), this definition of alignment has the advantageous consequence that candidate alignments can be singled out by mere inspection of the grammar rules. It also has the consequence that alignments are transitive (Goutte et al., 2004), since simultaneity is transitive.

While previous work (Søgaard and Kuhn, 2009) has estimated empirical lower bounds for normal form ITGs at the level of translation units (TUER), or cepts (Goutte et al., 2004), defined as maximally connected subgraphs in alignments, nobody has done this for the full class of ITGs. What is important to understand is that while normal form ITGs can induce the same class of translations as the full class of ITGs, they do *not* induce the same class of alignments. They do not, for ex-

ample, induce discontinuous translation units (see Sect. 3). Sect. 2 briefly presents some related results in the literature. Some knowledge about formalisms used in machine translation is assumed.

2 Related work

Aho and Ullman (1972) showed that 4-ary synchronous context-free grammars (SCFGs) could not be binarized, and Satta and Peserico (2005) showed that the hierarchy of SCFGs beyond ternary ones does not collapse; they also showed that the complexity of the universal recognition problem for SCFGs is NP-complete. ITGs on the other hand has a $\mathcal{O}(|G|n^6)$ solvable universal recognition problem, which coincides with the unrestricted alignment problem (Søgaard, 2009). The result extends to decoding in conjunction with a bigram language model (Huang et al., 2005).

Wu (1997) introduced ITGs and normal form ITGs. ITGs are a notational variant of the subclass of SCFGs such that all indexed nonterminals in the source side of the RHS occur in the same order or exactly in the inverse order in the target side of the RHS. It turns out that this subclass of SCFGs defines the same set of translations that can be defined by binary SCFGs. The different forms of production rules are listed below with the more restricted normal form production rules in the right column, with $\phi \in (N \cup \{e/f \mid e \in T^*, f \in T^*\})^*$ (N nonterminals and T terminals, as usual). The RHS operator $[]$ preserves source language constituent order in the target language, while $\langle \rangle$ reverses it.¹

$$\begin{array}{l} A \rightarrow [\phi] \\ A \rightarrow \langle \phi \rangle \end{array} \left| \begin{array}{l} A \rightarrow [BC] \\ A \rightarrow \langle BC \rangle \\ A \rightarrow e/f \end{array} \right.$$

Several studies have addressed the alignment capacity of ITGs and normal form ITGs. Zens and Ney (2003) induce lower bounds on PRFs for normal form ITGs. Wellington et al. (2006) induce lower bounds on PRFs for ITGs. Søgaard and Kuhn (2009) induce lower bounds on TUEP for normal form ITGs and more expressive formalisms for syntax-based machine translation. No one has, however, to the best of our knowledge induced lower bounds on TUEP for ITGs.

¹One reviewer argues that our definition of full ITGs is *not* equivalent to the definition in Wu (1997), which, in the reviewer’s words, allows “at most one lexical item from each language”. Sect. 6 of Wu (1997), however, explicitly encourages lexical elements in rules to have more than one lexical item in many cases.

3 Experiments

As already mentioned empirical lower bounds studies differ in four important respects, namely wrt.: (i) whether they use hand-aligned or automatically aligned gold standards, (ii) the level at which they count failures, e.g. sentence, alignment or translation unit level, (iii) whether they interpret translation units disjunctively or conjunctively, and (iv) whether they induce the lower bounds (a) by running an all-accepting grammar on the gold standard data, (b) by logical characterization of the structures that can be induced by a formalism, or (c) by counting the frequency of complex alignment configurations. The advantage of (a) and (b) is that they are guaranteed to find the highest possible lower bound on the gold standard data, whereas (c) is more modular (formalism-independent) and actually tells us what configurations cause trouble.

(i) In this study we use hand-aligned gold standard data. It should be obvious why this is preferable to automatically aligned data. The only reason that some previous studies used automatically aligned data is that hand-aligned data are hard to come by. This study uses the data also used by Søgaard and Kuhn (2009), which to the best of our knowledge uses the largest collection of hand-aligned parallel corpora used in any of these studies. (ii) Failures are counted at the level of translation units as argued for in the above, but supplemented by parse failure rates for completeness. (iii) Since we count failures at the level of translation units, it is natural to interpret them conjunctively. Otherwise we would in reality count failures at the level of alignments. (iv) We use (c).

The conjunctive interpretation of translation units was also adopted by Fox (2002) and is motivated by the importance of translation units and discontinuous ones in particular to machine translation in general (Simard and colleagues, 2005; Ayan and Dorr, 2006; Macken, 2007; Shieber, 2007). In brief,

$$\text{TUEP} = 1 - \frac{2|S_U \cap G_U|}{|S_U| + |G_U|}$$

where G_U are the translation units in the gold standard, and S_U the translation units produced by the system. This evaluation measure is related to consistent phrase error rate (CPER) introduced in Ayan and Dorr (2006), except that it does not only consider contiguous phrases.

	Snts	TUs	IOAs	DTUs	CDTUs	Bonbons	MIX-DTUs
Da-Sp	926	6441	0.56	9.16	0.81	0.16	0.23
En-Fr	100	869	0.23	2.99	0.12	0.23	0.23
En-Ge	987	17354	1.75	5.55	0.45	0.05	0.79
En-Po	100	783	0.26	2.17	0.00	0.00	0.38
En-Sp	100	831	0.48	1.32	0.00	0.00	0.36
Po-Fr	100	862	0.23	3.13	0.58	0.00	0.46
Po-Sp	100	882	0.11	0.90	0.00	0.00	0.00
Sp-Fr	100	914	0.11	2.95	0.55	0.00	0.22

Figure 1: Characteristics of the parallel corpora and frequency of configurations ($\frac{n}{TUs} \times 100$).

	ITGs				NF-ITGs			
	LB-TUER	LB-PFR	Ovlp(TUs)	Ovlp(Snts)	LB-TUER	PFR	Ovlp(TUs)	Ovlp(Snts)
Da-Sp	1.58	10.37	11	10	8.54	40.50	76	32
En-Fr	0.69	6.00	1	1	2.88	22.00	3	2
En-Ge	2.75	47.32	49	42	5.24	69.30	357	236
En-Po	0.64	5.00	0	0	2.43	19.00	0	0
En-Sp	0.84	7.00	0	0	1.80	15.00	0	0
Po-Fr	1.04	9.00	2	2	3.36	24.00	0	0
Po-Sp	0.11	1.00	1	1	0.90	8.00	1	1
Sp-Fr	0.77	7.00	1	1	3.06	23.00	0	0
AV	1.05	11.59			3.53	27.60		

Figure 2: Induced lower bounds for ITGs and normal form ITGs (NF-ITGs). LB-TUER lists the lower bounds on TUER. LB-PFR lists the lower bounds on parse failure rates. Finally, the third and fourth columns list configuration overlaps at the level of translation units, resp. sentences.

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