Semantically-Informed Syntactic Machine Translation: A Tree-Grafting Approach

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Abstract

We describe a unified and coherent syntactic framework for supporting a semantically-informed syntactic approach to statistical machine translation. Semantically enriched syntactic tags assigned to the target-language training texts improved translation quality. The resulting system significantly outperformed a linguistically naive baseline model (Hiero), and reached the highest scores yet reported on the NIST 2009 Urdu-English translation task. This finding supports the hypothesis (posed by many researchers in the MT community, e.g., in DARPA GALE) that both syntactic and semantic information are critical for improving translation quality—and further demonstrates that large gains can be achieved for low-resource languages with different word order than English.

1 Introduction

This paper describes a tree-grafting approach to incorporating named entities and modality into a unified and coherent syntactic framework, as a first step toward supporting Semantically-Informed Machine Translation (SIMT). The implementation of this approach was the result of a large effort undertaken in the summer of 2009. The most significant result of the SIMT effort was the integration of semantic knowledge into statistical machine translation in a unified and coherent syntactic framework. By augmenting hierarchical phrase-based translation rules with syntactic labels that were extracted from a parsed parallel corpus, and further augmenting the parse trees with semantic elements such as named-entity markers and modality (through a process we refer to as grafting), we produced a better model for translating Urdu and English. The resulting system significantly outperformed the linguistically naive baseline Hiero model, and reached the highest scores yet reported on the NIST 2009 Urdu-English translation task.

We note that, while our largest gains were from syntactic enrichments to the model, smaller (but significant) gains were achieved by injecting semantic knowledge into the syntactic paradigm. Of course, entities and modalities are only a small piece of the much larger semantic space, but demonstrating success on these new, unexplored semantic aspects of language bodes well for (larger) improvements based on the incorporation of other semantic aspects (e.g., relations and temporal knowledge). Moreover, we believe this syntactic framework to be well suited for further exploration of the impact of many different types of semantics on MT quality. Indeed, it would not have been possible to initiate the current study without the foundational work that gave rise to a syntactic paradigm that could support these semantic enrichments. We believe this framework will be especially useful for exploring other languages with few resources and different word order than English.

The semantic units that we examined in this effort were named entities (such as people or organizations) and modalities (indications that a statement represents something that has taken place or is a belief or an intention). Other semantic units such as relations between entities and events, were not part of this effort, but we believe they could be similarly incorporated into the framework. We chose to examine semantic units that canonically exhibit two different syntactic types: nominal, in the case of named entities, and verbal, in the case of modality.
Modality is an extra-propositional component of meaning. In *John may go to NY*, the basic proposition is *John go to NY* (epistemic necessity), *John might go to NY* (epistemic possibility), *John has to leave now* (deontic necessity) and *John may leave now* (deontic possibility). Many semanticists (Kratzer, 2009; von Fintel and Iatridou, 2009) define modality as quantification over possible worlds. *John might go* means that there exist some possible worlds in which John goes. Another view of modality relates more to a speaker’s attitude toward a proposition (Nirenburg and McShane, 2008; McShane et al., 2004). Modality resources built for this purpose have been described previously (Baker et al., 2010).

This paper will focus on a tree-grafting mechanism used to enrich the machine-translation output and on the resulting improvements to translation quality when the training process for the machine-translation systems included tagging of named entities and modality.

The next section provides the motivation behind the SIMT approach. Section 3 presents implementation details of the semantically-informed syntactic system. Section 4 describes the tree grafting algorithm. Section 5 provides the results of this work.
Figure 2: The evolution of a semantically informed approach to our synchronous context free grammars (SCFGs). At the start of summer the decoder used translation rules with a single generic non-terminal symbol, later syntactic categories were used, and by the end of the summer the translation rules included semantic elements such as named entities and modalities.

Following this, Section 6 examines work that is related to our approach. Finally, Section 7 presents conclusions and future work.

2 Motivation

The aim of the SIMT effort was to provide a generalized framework for representing structured semantic information, such as named entities and modality, and to investigate whether incorporating this sort of information into machine translation (MT) systems could produce better translations. The SIMT effort differs from other efforts in MT, most notably the DARPA Global Autonomous Language Exploitation (GALE) initiative, in at least two ways:

1. The SIMT effort worked on translation for a low-density language, with a minimal amount of bilingual training data. In GALE, hundreds of millions of words worth of bilingual texts are used to train statistical translation models. In the SIMT effort, only 1.7 million words of Urdu-English texts were available. Table 1 provides the data set sizes used in our experiments.
2. The SIMT effort showed significant improvements from incorporating syntax and semantics into machine translation, whereas syntactic translation models have not shown dramatic improvements in GALE’s Arabic-English translation task. The improvements for Urdu translation described here are probably due to the fact that it is a low-resource, verb-final language and so requires generalization beyond phrase-based or hierarchical phrase-based models.

These differences created novel research directions for our effort, and resulted in promising findings that suggest that both syntactic and semantic information are critical for improving translation quality.

It is informative to look at an example translation to understand the challenges of translating important semantic entities when working with a low-resource language pair. Figure 1 shows an example taken from the 2008 NIST Urdu-English translation task, and illustrates the translation quality of a state-of-the-art Urdu-English system (prior to the SIMT effort). The small amount of training data for this language pair (see Table 1) results in significantly degraded translation quality compared, e.g., to an Arabic-English system that has more than 100 times the amount of training data.

The machine translation output in Figure 1 was produced using Moses (Koehn et al., 2007), a state-of-the-art phrase-based machine translation system that by default does not incorporate any linguistic information (e.g., syntax or morphology or translit-
Figure 3: Workflow for producing semantically-grafted parse trees. The English side of the parallel corpus is automatically parsed, and also tagged with modality and named-entity markers. These tags are then grafted onto the syntactic parse trees. The relation finder was designed for additional tagging but was not implemented in the current work. (Future work will test relations as another component of meaning that may contribute toward improved MT output.)

As a result, words that were not directly observed in the bilingual training data were untranslatable. Names, in particular, are problematic. For example, the lack of translation for Nagaland and Nagas induces multiple omissions throughout the translated text. This is because out of vocabulary words are deleted from the Moses output.

We use modality and named-entity tags as higher-order symbols inside the translation rules used by the translation models. Generic symbols in translation rules (e.g., the non-terminal symbol “X”) were replaced with structured information at multiple levels of abstraction, using a tree-grafting approach, as described in more detail in the following sections.

We extracted SCFG grammar rules containing named entities and modality using an extraction procedure that requires parse trees for one side of the parallel corpus. While it is assumed that these trees are labeled and bracketed in a syntactically motivated fashion, the framework places no specific requirement on the label inventory. We take advantage of this characteristic by providing the rule extraction algorithm with augmented parse trees containing syntactic labels that have named entities and modalities grafted onto them so that they additionally express semantic information.

Our strategy for producing semantically-grafted parse trees involves three steps:

1. The English sentences in the parallel training data are parsed with a syntactic parser. In our work, we used the lexicalized probabilistic

| set       | lines | tokens | types | tokens | types |
|-----------|-------|--------|-------|--------|-------|
| training  | 202k  | 1.7M   | 56k   | 1.7M   | 51k   |
| dev       | 981   | 21k    | 4k    | 19k    | 4k    |
| devtest   | 883   | 22k    | 4k    | 19-20k | 4k    |
| test      | 1792  | 42k    | 6k    | 38-41k | 5k    |

Table 1: The size of the various data sets used for the experiments in this paper including the training, development (dev), incremental test set (devtest) and blind test set (test). The dev/devtest was a split of the NIST08 Urdu-English test set, and the blind test set was NIST09.

3 Tree-Grafting to refine translation grammars with semantic categories

We use synchronous context free grammars (SCFGs) as the underlying formalism for our statistical models of translation. SCFGs provide a convenient and theoretically grounded way of incorporating linguistic information into statistical models of translation, by specifying grammar rules with syntactic non-terminals in the source and target languages. We refine the set of non-terminal symbols so that they not only include syntactic categories, but also semantic categories.

Chiang (2005) re-popularized the use of SCFGs for machine translation, with the introduction of his hierarchical phrase-based machine translation system, Hiero. Hiero uses grammars with a single non-terminal symbol “X” rather than using linguistically informed non-terminal symbols. When moving to linguistic grammars, we use the Syntax Augmented Machine Translation (SAMT) developed by Venu-gopal et al. (2007). In SAMT the “X” symbols in translation grammars are replaced with nonterminal categories derived from parse trees that label the English side of the Urdu-English parallel corpus. We refine the syntactic categories by combining them with semantic categories. This progression is illustrated in Figure 2.

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\textsuperscript{1}For non-constituent phrases, composite CCG-style categories are used (Steedman, 1999).
context-free grammar parser provided by Basis Technology Corporation.

2. The English sentences are named-entity-tagged by the Phoenix tagger (Richman and Schone, 2008) and modality-tagged by the system described in (Baker et al., 2010).

3. The named entities and modalities are grafted onto the syntactic parse trees using a tree-grafting procedure. The grafting procedure was implemented as a part of the SIMT effort. Details are spelled out further in Section 4.

The workflow for producing semantically-grafted trees is illustrated in Figure 3. Figure 4 illustrates how named-entity tags are grafted onto a parse tree. We note that while our framework is general, we focus the discussion here on the particular semantic elements (named entities and modalities) that were incorporated during the SIMT effort.

Once the semantically-grafted trees have been produced for the parallel corpus, the trees are presented, along with word alignments (produced by an aligner such as GIZA++), to the rule extraction software to extract synchronous grammar rules that are both syntactically and semantically informed. These grammar rules are used by the decoder to produce translations. In our experiments, we used the Joshua decoder (Li et al., 2009), the SAMT grammar extraction software (Venugopal and Zollmann, 2009), and special purpose-built tree-grafting software.

Figure 5 shows example semantic rules that are used by the decoder. The noun-phrase rules are augmented with named entities, and the verb phrase rules are augmented with modalities. The semantic categories are listed in Table 2 and Table 3. Because these get marked on the Urdu source as well as the English translation, semantically enriched grammars also act as very simple named entity or modality taggers for Urdu. However, only entities and modalities that occurred in the parallel training corpus are marked in the output.

4 Tree-Grafting Algorithm

The overall scheme of our tree-grafting algorithm is to match semantic tags to syntactic categories. There are two inputs to the process. Each is derived from a common text file of sentences. The first input is a list of standoff annotations for the semantic units in the input sentences, indexed by sentence number. The second is a list of parse trees for the sentences in Penn Treebank format, indexed by sentence number.

Table 2 lists the entity types identified during the SIMT effort, with examples. Table 3 likewise lists the modality types that were produced by the modality tagger. Baker et al. (2010) described a system that automatically tags triggers and targets of modality. A trigger is a word with a modal meaning like believe, possible, or want. A target is a word in the scope of the trigger. For example, the sentence The students are able to swim is tagged as The students are ⟨TRIG-ABLE able⟩ to ⟨TARG-ABLE to swim⟩.

The tree-grafting algorithm proceeds as follows. For each sentence, we iterate over the list of semantic tags. For each semantic tag, we determine the
Figure 5: Example translation rules with named entity tags and modalities combined with syntactic categories.

Table 2: Named entity tags

| Named Entity | Example               |
|--------------|-----------------------|
| AGE          | 50 years old          |
| DATE         | September 26, 2009    |
| FACILITY     | Southwestern Medical Center |
| GPE (Geo-political entity) | New York |
| GPE-ite      | Australian            |
| LOCATION     | West Sea              |
| MONEY        | 15,000 pounds         |
| OCCUPATION   | governor              |
| ORGANIZATION | United Nations        |
| ORGANIZATION-ite | marines   |
| PERCENT      | 3.1 percent           |
| PERSON       | Tony Blair            |
| TIME         | 2030 GMT              |

Table 3: Modality tags with their negated versions

| Modality      | Example        |
|---------------|----------------|
| Require       | NOTPermit      |
| Permit        | NOTRequire     |
| Succeed       | NOTSucceed     |
| SucceedNegation | NOTSucceedNegation |
| Effort        | NOTEffort      |
| EffortNegation | NOTEffortNegation |
| Intend        | NOTIntend      |
| IntendNegation | NOTIntendNegation |
| Able          | NOTAble        |
| AbleNegation  | NOTAbleNegation |
| Want          | NOTWant        |
| Belief        | NOTBelief      |
| Firm_Belief   | NOTFirm_Belief |
| Negation      | NOTNegation    |

Note: In testing we found that grafting named entities first and modalities last yielded a slightly higher Bleu score than the reverse order.

2 In case a word was tagged both as
Figure 6: Results for a range of experiments conducted during the SIMT effort. Results show scores for baseline systems, which here include a phrase-based model (Moses) and a hierarchical phrase-based model (Hiero), neither of which make use of syntactic information. These also show the substantial improvements when syntax is introduced, along with different numbers of feature functions (FFs), and further improvements from semantic elements. The scores are lowercased Bleu calculated on the held-out devtest set.

A modality target and a modality trigger, we gave precedence to the target tag. This is because, while modality targets vary, modality triggers are generally identifiable with lexical items. Finally, we used a simplified specificity ordering of modality tags, borrowing from an approach described in [Baker et al., 2010], to ensure precedence of more specific tags over more general ones. Table 3 lists the modality types from highest (Require modality) to lowest (Negation modality) precedence.

5 Results

Figure 6 gives the results for a number of experiments conducted during the SIMT effort. The experiments are broken into three groups: baselines, syntax, and semantics. To contextualize our results we experimented with a number of different baselines that were composed from two different approaches to statistical machine translation—phrase-based and hierarchical phrase-based SMT—along with different combinations of language model sizes and word aligners. Our best performing baseline was a Hiero model with a 5-gram language model and word alignments produced using the Berkeley aligner. The Bleu score for this baseline on the development set was 23.1 Bleu points.

After experimenting with syntactically motivated grammar rules, we conducted three experiments on the effects of incorporating semantic elements (e.g., named entities and modality markers) into the translation grammars. In our devtest set our taggers tagged on average 3.5 named entities (NEs) per sentence and 0.35 modalities per sentence. These were included by grafting NEs and modality markers onto the parse trees. Individually, each of these made modest improvements over the syntactically-informed system alone. Grafting named entities onto the parse trees improved the Bleu score by 0.2 points. Modalities improved it by 0.3 points. Doing both simultaneously had an additive effect and resulted in a 0.5 Bleu score improvement over syntax alone. This improvement was the largest improvement that we got from anything other than the move from linguistically naive models to syntactically informed models.

Figure 7 shows example output from the final SIMT system. Notice that even in the title of the article, the SIMT system produces much more coherent English output than that of the linguistically naive system. The figure also shows improvements due to transliteration, which are described in [Irvine et al. 2010]. The scores reported in Figure 6 do not include transliteration improvements.

6 Related Work

This section describes related work in monolingual techniques for augmenting parsing, where parsing is applied to one language in the parallel text.

Our tree-grafting approach is related to a technique used for tree augmentation in [Miller et al., 2000], where parse-tree nodes are augmented with scores on the NIST 2009 test set.
semantic categories. Miller et al. augment tree nodes with named entities and relations, while we used named entities and modalities. The parser is subsequently retrained for both semantic and syntactic processing. The semantic annotations were done manually by students following a set of guidelines and then merged with the syntactic trees automatically. In our work we tagged our corpus with entities and modalities automatically and then grafted them onto the syntactic trees automatically, for the purpose of training a statistical machine translation system. An added benefit of the extracted translation rules is that they are capable of producing semantically-tagged Urdu parses, despite that the training data were processed by only an English parser and tagger.

Related work in syntax-based MT includes (Huang and Knight, 2006), where a series of syntax rules are applied to a source language string to produce a target language phrase structure tree. The Penn English Treebank (Marcus et al., 1993) is used as the source for the syntactic labels and syntax trees are relabeled to improve translation quality. In this work, node-internal and node-external information is used to relabel nodes, similar to earlier work where structural context was used to relabel nodes in the parsing domain (Klein and Manning, 2003). Klein and Manning’s methods include lexicalizing determiners and percent markers, making more fine-grained VP categories, and marking the properties of sister nodes on nodes. All of these labels are derivable from the trees themselves and not from an auxiliary source.

In the parsing domain, the work of (Petrov and Klein, 2007) is related to the current work. Petrov and Klein use a technique of rule splitting and rule merging in order to refine parse trees during machine learning. Hierarchical splitting leads to the creation of learned categories that have linguistic relevance, such as a breakdown of a determiner category into two subcategories of determiners by number, i.e., this and that group together as do some and these. We use rule splitting in cases where a semantic category is inserted as a node in a parse tree, after the English side of the corpus has been parsed by a statistical parser (as described in section 4).

7 Conclusions and Future Work

We have described a technique for translation that shows particular promise for low-resource languages. We have integrated linguistic knowledge into statistical machine translation in a unified and coherent framework. We demonstrated that augmenting hierarchical phrase-based translation rules with semantic labels (through “grafting”) resulted in a 0.5 Bleu score improvement over syntax alone.

Although our largest gains were from syntactic enrichments to the Hiero model, demonstrating success on the integration of new semantic aspects of language bodes well for future improvements based on the incorporation of other semantic aspects, e.g., relations and temporal knowledge, into the translation rules, would further improve the translations. The syntactic framework is unique in its ability to support the exploration of the impact of many different types of semantics on MT quality.

Our findings indicate that the use of syntactic and semantic information radically improves translation quality for low-resource languages with different word order than English. Urdu has SOV (subject, object, verb) word order compared to English SVO (subject, verb, object). Thus, our observed improvements are likely to be transferable to languages like Korean and Farsi, as well as a host of other low-resource languages with different word order.

The work presented here represents the first small steps toward a full integration of MT and semantics. Efforts underway in DARPA’s GALE program have already demonstrated the potential for combining MT and semantics (termed distillation) to answer the information needs of monolingual speakers using multilingual sources. In previous work, however, semantic processing proceeded largely independently of the MT system, operating only on the translated output. Our approach is significantly different in that it combines syntax, semantics, and MT into a single model, offering the potential advantages of joint modeling and joint decision-making. It would be interesting to explore whether the integration of MT with syntax and semantics can be extended to provide a single-model solution for tasks such as cross-language information extraction and question answering, and to evaluate our integrated approach, e.g., using GALE distillation metrics.
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Kai von Fintel and Sabine Iatridou. 2009. Morphology, syntax, and semantics of modals. Lecture notes for 2009 LSA Institute class.
Thomas red of the United States, the National Laboratory in designer are already working on the book of Los Alamos National Laboratory, former director of the technical intelligence, with the cooperation of Diana steelman wrote.

This book ‘nuclear express: political history and the explosion of bomb’ has been written, and the two writers have also claimed that the country has made nuclear bomb is he or any other country’s nuclear secrets to كوريا. He said that we may also presume that Israel, Korea nuclear secrets, or any of the other nuclear power cooperation.

Thomas Reid said in an interview to the news that Benazir Bhutto in 1990 in the era of China The first nuclear bomb test.

Thomas Reid said that on the basis of several reasons to believe that China has the first nuclear bomb test.

Reasons of this bomb design and China information obtained during the conversation with the scientists.

He further said that this was the reason that Pakistan only two weeks in 1998 and was able to nuclear experiment in response to India’s nuclear experiments within three days.

Thomas Reid had reminded that Russia has sudden nuclear experiment in 61 and in response to the United States to experiment in 17 days. Despite the fact that the United States had quite a long period from the bomb.

He further said that the experience of the atom bomb Pakistan in May 1998, he was to make very carefully and confidence on Pakistani scientists.

He said that he there is evidence that Dr. Abdul Qadeer Khan after the Chinese design. Apart from this, The The technicians obtained documents in Libya were also confirmed it from them.

To another question whether the joint nuclear tests is common, He said in دیوانی servents for Britain’s nuclear experiment.

He said that we are guesses also believed that Israel should also provide access to the results of this experience.

Thomas Reid and this question was also is China’s program of nuclear proliferation.

On this Thomas Reid said that in 1991 to set up in China’s city of Iran nuclear installation instructions for the raw material, and دیوانی is provided.

Besides this, China has provided enrichment plant in Iran also.

He said that China, North Korea, Iran, Syria, Pakistan, through Egypt. Libya and Yemen is to provide nuclear technology.