Shalt2 - a Symmetric Machine Translation System with Conceptual Transfer

Shalt2 is a knowledge-based machine translation system with a symmetric architecture. The grammar rules, mapping rules between syntactic and conceptual (semantic) representations, and transfer rules for conceptual paraphrasing are all bi-directional knowledge sources used by both a parser and a generator.

1. Introduction

Shalt2 is a research prototype of a knowledge-based, multi-domain/multi-lingual MT system. It has two predecessors, SHALT [31] (1982-90) and KBMT-89 [31] (1987-89), which brought us valuable lessons we reflected in the design and implementation of Shalt2. As a result, Shalt2 has been designed and implemented as a symmetric MT system with frame-based conceptual representation. The advantages of a symmetric architecture coupled with a conceptual representation are obvious. First, it allows us to maintain single knowledge sources for both parsing and generation. We can automatically control the coverage and reversibility of these processes. Second, conceptual structures are a desirable interface for representing the meaning of sentences, machine-generated output (such as diagnosis by an expert system), and expressions in graphical languages. AI-based approaches can provide powerful inference methods for identification of a (semi-)equivalent class of conceptual representations, which corresponds to a paraphrasing capability. Unlike interlingual MT systems, our approach relieves the parser of the burden of generating a unique meaning representation of all equivalent sentences, which becomes harder in proportion to the number of languages the system has to translate.

2. Shalt2 Architecture and Knowledge Sources

Shalt2 has five types of knowledge sources: a set \( G \) of syntactic grammar rules (including dictionaries), a set \( C \) of hierarchically defined conceptual primitives called concept definitions, a set \( M \) of mapping rules between syntactic and conceptual structures, a set \( P \) of conceptual paraphrasing rules, and a set \( E \) of cases (a structurally and conceptually disambiguated set of sample sentences). These knowledge sources are shared by three major processes: a parser, a concept mapper, and a generator. \( G \) should be provided for each language, whereas the set \( C \) should be defined for each application domain. \( M, P, \) and \( E \) should be provided for each pair of a language and a domain. Figure 1 shows an overview of the Shalt2 architecture.

2.1 Syntactic Grammar

Shalt2 currently has two English grammars (PEG and a less competent English grammar) and a Japanese grammar. The last two grammars are bi-directional grammars written in an LFG-like formalism called a pseudo-unification grammar (PUG) [16], and were originally employed in KBMT-89.\(^\dagger\) PEG is not bi-directional, since it has too many destructive operations to build or encode record structures, but it is our primary English grammar for three reasons: (1) broad coverage, (2) ability to encapsulate structural ambiguities in a compact parse tree, and (3) compatibility with other NLP programs that use PEG to analyze English sentences. Our bi-directional English grammar is following up PEG and will be able to replace it. The symmetric architecture of Shalt2, however, allows uni-directional knowledge sources and processes to be hooked into the system. Their coverage and ability to parse or generate sentences can be measured in terms of a set of conceptual representations that they can relate to syntactic structures.

Although the syntactic structures of PEG and PUG grammars differ, they are integrated into a single syntactic representation called Dependency Structures (DSs) [6]. Roughly speaking, a DS is a tree-like structure with a set of nodes and a set of arcs, which correspond to maximal projections of syntactic constituents and grammaticality.

\(^\dagger\)The English version was originally written by Gates et al. [2] but was not bi-directional. The Japanese grammar was originally written by Mitamura and Takeda [2]. The Shalt2 versions of these PUG grammars have been modified considerably to allow them to handle coordinations, comparatives, and so on.
defines a class *insert with an is-a link to a class *action.

The reader may notice that the above sentence should really have ambiguities in prepositional phrase attachment, which result in two conflicting dependencies “insert -PPADJUNCT- drive” and “diskette -PPADJUNCT- drive” in a single DS. We will discuss the handling of such ambiguities in Section 3.

2.2 Concept Definitions

A set of conceptual primitives is called a Natural Language (NL) class system [11], and is maintained as an object-oriented knowledge base under FrameKit [10]. The NL class system consists of a set of constant classes, three meta-classes, and virtual classes, with an exclusive inheritance mechanism discussed below.

Each class represents a concept in the real world. A class has zero or more slots, which describe the fillers it may use to represent a compound concept. NL objects are particular instances of NL classes. There are is-a and part-of relationships defined over the NL classes. For example,

(defclass *option
  (def (*math-coprocessor
          *hard-disk *software))

(defclass *male-thing
  (def (equal :sex *male)))

shows two types of virtual class: *option and *male-thing. The *option consists of the classes *math-coprocessor, *hard-disk, and *software. The *male-thing is a class that includes instances of any class with the sex slot filled with *male. Note that the maintainability of a class hierarchy drastically declines if we allow classes such as *option to be “actual” rather than virtual, as we will have many is-a links from anything that could be an option. The second type of virtual class helps incorporate so-called semantic features into the NL class system. Existing machine-readable dictionaries (for example, LDOCE [8]) often have entries with semantic features such as HUMAN, LIQUID, and VEHICLES that may not fit into a given ontological class hierarchy. A virtual class definition
2.3 Mapping Rules

Mapping rules define lexical and structural correspondences between syntactic and conceptual representations. A lexical mapping rule has the form

\[
\text{emap } \star\text{insert}
\]

\[
\langle \text{v} \rangle \quad \text{insert} \quad ((\text{CAT } v) \quad \text{(SUBCAT trans)})
\]

\[
\quad \text{(role } \quad \text{=sem } \star\text{physical-action})
\]

\[
\quad \text{(:agent } \quad \text{=syn (SUBJECT)})
\]

\[
\quad \text{(:goal } \quad \text{=syn (PPADJUNCT))}
\]

\[
\quad ((\text{PREP into}) \quad \text{(CAT n)})
\]

where a transitive verb "insert" maps to or from an instance of "insert" with its exclusive superclass "physical-action." The three slots for structural mapping between concepts (agent, theme, and goal) and grammatical roles (SUBJECT, DOBJECT, and PPADJUNCT) are also defined in this rule. The agent filler, for example, should be an instance that is mapped from a syntactic SUBJECT of the verb "insert." The goal filler must be a prepositional phrase consisting of a noun with the preposition "into." The fragments of syntactic feature structures following a lexical word or a grammatical function in a mapping rule specify the minimum structures that subsume feature structures of candidate syntactic counterparts. These structural mappings are specific to this instance.

The structural mapping rule

\[
\text{emap } \star\text{physical-action} \leftarrow \star = \star
\]

\[
\quad \text{(:mood } \quad \text{=syn (MOOD)})
\]

\[
\quad \text{(:time } \quad \text{=syn (TENSE)})
\]

specifies that the conceptual slots :mood and :time map to or from the grammatical roles MOOD and TENSE, respectively. Unlike the structural mapping in a lexical mapping rule, these slot mappings can be inherited by any instance of a subclass of "physical-action." The "insert" instance defined above, for example, can inherit these mood and :time mappings. Given a dependency structure (DS), mapping rules work as distributed constraints on the nodes and arcs in the DS in such a way that a conceptual representation R is an image of the DS iff R is the minimal representation satisfying all the lexical and structural mappings associated with each node and arc. On the other hand, given a conceptual representation R, mapping rules work inversely as constraints on R to define a minimal DS that can be mapped to R. Thus, assuming that lexical mapping rules are similarly provided for nouns (diskette and drive) and feature values (imp, pres, and so on), we will have the conceptual representation of a sentence consists of instances of classes. We use a hyphen and a number following a class name (*insert-1, *imp-1, ...) when it is necessary to show instances explicitly. Otherwise, we identify class names and instance names.
Computing[1]. Selected sentences in the LDOCE have also been added to the case base. The sentences in the LDOCE define word senses or show sample usages of each entry. Though composed of a limited vocabulary, they are often syntactically/semantically ambiguous and it is time-consuming for users to build the case base completely manually. Therefore, the Shalt2 parser is used to develop the case base. Starting with a small, manually crafted "core" case base, each new sentence is analyzed and disambiguated by the parser to generate a DS, which is corrected or modified by the user and then added to the case base. As the size of the case base grows, the proportion of human corrections/modifications decreases, since the output of the parser becomes more and more accurate. The process is called knowledge bootstrapping and is discussed by Nagao[9] in more detail. Mapping constraints, however, are associated with only a part of the case base, because the NL class system and the mapping rules are not yet complete.

3. Parser

The Shalt2 parser first generates a DS with packed structural ambiguities for a given input sentence. It actually calls a PEG parser or Tomita's LR-parser[12] for PUG, and then calls a DS converter to map a PEG parse tree or a PUG feature structure[1] to a DS. Next, mapping rules are applied to the DS so that lexical and structural mappings are associated with each node and arc in the DS. Figure 2 shows a DS with mapping constraints for the sentence "Keep the diskette in the drive," where the verb "keep" has five word senses: *execute, *guard, *hold, *employ, and *own. It is clear that we will end up with ten distinct conceptual representations if we evaluate all the mapping rules, and in general, combinatorial explosion could easily make the parser impractical. Viewing the mapping rules as constraints rather than procedural rules is the key to our parser, and is called delayed composition of conceptual representation.

A sentence analyzer called SENA[14] disambiguates the DS by using a constraint solver JAUNT[8] and a case base. JAUNT applies grammatical constraints (for instance, modifier-modifiee links between nodes do not cross one another) and semantic constraints (such as selectional restrictions," functional control, and other NL object identity constraints detected by the context analyzer) uniformly to a DS that has ambiguities, and calculates pairwise consistency efficiently for each combination of nodes. Finally, the case base provides preferential knowledge to favor one pair of nodes over all other consistent pairs. The disambiguation process can be summarized as follows:

1. For each conflicting arc in the DS, calculate the "distance"[6] between the two nodes in the arc by using a case base.
2. Leave the arc with the minimal distance and eliminate all the other conflicting arcs. Each NL object associated with a matching node in the case base also gives a higher preference to the same class of instance over the other instances in a node.
3. Propagate the deletion of arcs to other nodes and arcs in the DS. Eliminate nodes and arcs that are no longer valid in the DS.
4. Apply the above steps until there are no conflicting arcs in the DS.

The resulting DS has no structural ambiguity. Remaining lexical ambiguities are similarly resolved, because we can also determine which pair of NL objects connected with an arc has the minimal distance in the case base. Our case base for computer manuals would support the "diskette -PPADJUNCT- drive" arc and the "hold-1 instance with diskette" as its DOBJECT. Therefore, the parser will eventually return (*hold-1 (:theme (*diskette (:location-in (*drive))))) as a disambiguated result. Nagao[6] discusses more sophisticated techniques such as scheduling sets of arcs to be disambiguated, backtracking, and relaxation of case base matching by means of an is-a hierarchy.

Finally, a context analyzer is called to resolve anaphora, identity of definite nouns, and implicit identity between NL objects. It stores the DS in the working space, where references to preceding instances are represented by the links between instances in the DS. These inter-sentential links are used to determine the scopes of adverbs such as "also" and "only".

For example, if the phrase "role of an operator" appears in a text, the word "operator" could be a person who operates a machine or a logical operator for computation, but no sufficient information is available to resolve this ambiguity at this moment. In such cases, creating referential links in a forest of DSs could lead us to find evidence for disambiguating these two meanings. The scope of an adverb, such as "also," is determined by identifying repeated NL objects and newly introduced NL objects, where the latter are more likely to fall within the scope of the adverb.

The context analyzer uses a similar method to determine lexical ambiguities that were not resolved by the sentence analyzer when the case base failed to provide enough information.

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1. Tomita's local ambiguity packing[12] is used to obtain a feature structure with packed structural ambiguities.
2. We use about 20 of the semantic features described in the LDOCE. The restrictions imposed by the features are rather "loose," and are used to eliminate only unlikely combinations of word senses.
4. Concept Mapper

Given a conceptual representation, which is an output from the parser, and a target language, the concept mapper tries to discover another conceptual representation that has a well-defined mapping to a DS while keeping the semantic content as intact as possible. This process is called conceptual transfer. If the given conceptual representation already has a well-defined mapping to a DS, the concept mapper does nothing and Shail2 works like an interlingual MT system. It is important that conceptual transfer should be related with the mapping to a DS, because there are generally many conceptual representations with a similar semantic content. The existence of well-defined mapping not only guarantees that the generator can produce a sentence in the target language, but also effectively eliminates unsuccessful paraphrasing.

In addition to the paraphrasing rules mentioned earlier, the concept mapper uses the following general rules for conceptual transfer.† The paraphrasing rules are composed to make a complex mapping.

- Projection: Map an NL object with a filled slot s to an instance of the same class with the unfilled slot s. Projection corresponds to deletion of a slot s.
- Generalization: Map an NL object of a class X to an instance of one of the subclasses of X.
- Specialization: Map an NL object of a class X to an instance of one of the subclasses of X.

As an example, a projection rule is frequently used when we translate English nouns into Japanese ones, as in the following exampl:

```
diskette  (diskette (:num (*sg)))
diskettes (diskette (:num (*pl)))
a diskette  (diskette (:num (*sg)))
the diskettes (diskette (:num (*pl)))
```

Here, the four English noun phrases above are usually translated by the same Japanese noun phrase† (the fifth one), which does not carry any information on :num and :def. We provide a paraphrasing rule for translation in the opposite direction such that for any instance of the *object can obtain appropriate :sum and :def fillers. The parser, however, is responsible for determining these fillers in most cases. In general, the designer of semi-equivalent rules for translation in one direction has to provide a way of inferring missing information for translation in the opposite direction. Generalization and specialization rules are complementary and can be paired to become equivalent rules when a specialization rule for any instance of a class x is unambiguous. That is, without losing any fillers, one can always choose an instance of a subclass y to which x can be uniquely mapped. A generalization from each y to z provides the opposite mapping.

†These are semi-equivalent rules. Equivalent rules have higher priority when the rules are to be applied.

‡One exception is that deictic noun phrases are translated when we use the Japanese counterpart "the".

5. Grammar-Based Sentence Generator

Recent investigation of unification grammars and their bi-directionality [8, 9, 10] has enabled us to design and implement a grammar-based generator. Our generator uses a PUG grammar, which is also used by the parser, to traverse or decompose a feature structure obtained from a DS in order to find a sequence of grammar rule applications, which eventually lead to lexicalized rules for generating a sentence. The generation algorithm is based primarily on Wedekind's algorithm, but is modified for PUG.

The current implementation of our generator lacks subtle control of word ordering, honorific expressions, and style preference. We are developing a set of discourse parameters to associate preferences with grammar rules to be tried, so that specific expressions are favored by the parameter settings.

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