Automation of Database Design through Semantic Analysis

NAZLIA OMAR¹, ROSILAH HASSAN¹, HASLINA ARSHAD², SHAHNORBANUN SAHRAN²
Department of Computer Science¹
Department of Industrial Computing²
Faculty of Information Science and Technology
Universiti Kebangsaan Malaysia
43600 Bangi, Malaysia
no@ftsm.ukm.my http://www.ftsm.ukm.my

Abstract: - This paper presents the use of heuristics gained from the syntactic and semantic knowledge for the creation of database design in terms of the Entity-Relationship(ER) model through natural language processing. The application of both syntactic and semantic heuristics is used as the strategy to obtain the relevant ER elements such as entities, attributes and relationships from the specifications. Results on the use of the semantic heuristics show that these may help to further improve the results in the automatic detection of the ER elements.

Key-Words: - heuristics, semantic, natural language processing, database design

1 Introduction
Database design is a process of producing a logical data model for a specific database. Entity-relationship(ER) modelling, which is a high level conceptual model designed to facilitate database design, can be a daunting task to both students and designers alike due to its abstract nature and technicality. Much research has attempted to apply natural language processing in extracting knowledge from requirements specifications with the aim to design databases. However, research on the formation and use of heuristics to aid the construction of logical databases from natural language has been scarce.

This paper proposes the use of semantic heuristics, in addition to syntactic heuristics, in the generation of ER models from natural language specifications. The semantic heuristics are utilised to identify the semantic roles of potential candidates that may determine the relevant ER elements such as entities, attributes and relationships from the database specifications. Syntactic heuristics have been developed and implemented in tool called ER-Converter (12,13). ER-Converter has been evaluated against a set of database problems and achieved 90% recall and 85% precision. In order to further improve the accuracy of the results, semantic heuristics are proposed.

2 Background and Previous Work
Much work (2,5,6,15) has attempted to apply natural language in extracting knowledge from requirements specifications or dialogue sessions with designers with the aim to design databases. Dialogue tool (2) is a knowledge-based tool applied to the German language for producing a skeleton diagram of an Enhanced Entity-Relationship (EER) model. This tool is part of a larger database design system known as RADD (Rapid Application and Database Development) which consists of other components that form a complex tool. In order to obtain knowledge from the designer, a moderated dialogue is established during the design process. The transformation of the structure of natural language sentences into EER model structures is a process which is based on heuristic assumptions and pragmatic interpretation. The aim of the pragmatic interpretation is the mapping of the natural language input onto EER model structures using the results of the syntactic and semantic analyses. One major limitation in this system is that the accuracy of the EER model produced depends on the size and complexity of the grammar used and the scope of lexicon.

ANNAPURNA (5) is project aimed to provide a computerized environment for semi-automatic database design from knowledge acquisition up to generating an optimal database schema for a given database management system. ANNPURNA concentrated on the phases concerned with acquiring the terminological rules. The first step in acquisition of the terminological knowledge involves extracting the knowledge from queries and rules that have the form of natural language expressions. The knowledge obtained would then be put into the form of S-diagrams. An S-diagram is a graphical data model which can be used to specify classes (for example room and door), subclass connections
between classes (for example rooms and doors are physical objects) and attributes. The limitation of the above work is that the use of S-diagrams performs best when the complexity is small.

DMG (15) is a rule based design tool which maintains rules and heuristics in several knowledge bases. A parsing algorithm which accesses information of a grammar and a lexicon is designed to meet the requirements of the tool. During the parsing phase, the sentence is parsed by retrieving necessary information from the grammar, represented by syntactic rules and the lexicon. The parsing results are processed further on by rules and heuristics which set up a relationship between linguistic and design knowledge. The DMG has to interact with the user if a word does not exist in the lexicon or the input of the mapping rules is ambiguous. The linguistic structures are then transformed by heuristics into EER concepts. Though DMG proposed a large number of heuristics to be used in the transformation from natural language to EER models, the tool has not yet been developed into a practical system.

E-R generator (6) is another rule-based system that generates E-R models from natural language specifications. The E-R generator consists of two kinds of rules: specific rules linked to semantics of some words in sentences, and generic rules that identify entities and relationships on the basis of the logical form of the sentence and on the basis of the entities and relationships under construction. The knowledge representation structures are constructed by a natural language understander (NLU) system which uses a semantic interpretation approach. There are situations in which the system needs assistance from the user in order to resolve ambiguities such as the attachment of attributes and resolving anaphoric references.

CM-Builder (9) is a natural language based CASE tool which aims at supporting the analysis stage of software development in an object-oriented framework. The tool uses natural language processing techniques to analyse software requirements documents and produces initial conceptual models represented in Unified Modelling Language. The system uses discourse interpretation and frequency analysis in producing the conceptual models. CM-Builder still has some limitation in the linguistic analysis. For example, attachment of postmodifiers such as prepositional phrases and relative clauses is limited. Other shortcomings include the state of the knowledge bases which are static and not easily updateable nor adaptive.

Heuristics, based on linguistic rules, are reported to be utilized in many of the systems like ANNAPURNA (5), DMG (15) and RADD (2). However, only DMG (15) presents a precise set of heuristics used in deriving an EER model. The heuristics presented, however, are mainly based on syntax. This research aims to fill in the gap by proposing a new set of semantic heuristics.

3 Syntactic Heuristics to Identify ER Elements

Heuristics represent an indefinite assumption (15), often guided by common sense, to provide good but not necessarily optimal solutions to difficult problems, easily and quickly (16). Research on the formation and use of heuristics to aid the construction of logical database structures from natural language has been scarce. The only existing work that proposes a large number of heuristics to be used in the transformation from natural language to ER models is DMG (15). However the work has not been implemented. The authors of DMG proposed both syntactic and semantic heuristics to be applied in extracting knowledge from requirements specifications. Although E-R Generator (6) and RADD (2) utilized heuristics in their work, they do not detail a precise set of heuristics in their approach. Chen (3) suggested that the basic constructs of English sentences could be mapped into ER schemas in a natural way and presented a set of rules to put forward the ideas. Though the set are referred to as “rules”, Chen mentioned that they are better viewed as “guidelines” as it is possible to find counter examples to them. Here we regard Chen’s “rules” as heuristics as they are largely “rules-of-thumb” based on observations rather than theoretically derived. Only heuristics for language syntax are considered and proposed at this stage.

Here, a selection of the syntactic heuristics applied in the transformation from database specifications to the data modeling constructs is presented. These heuristics are gathered from past work (3,14,15) and some are newly formed (12,13). A complete set of these heuristics can be found in (13). Some examples in terms of sentences are provided to illustrate the application of heuristics which are context dependent.

Heuristics to determine entities:
1. Heuristic HE2: A common noun may indicate an entity type (3,15).
2. Heuristic HE3: A proper noun may indicate an entity (3,15).
3. Heuristic HE7: If consecutive nouns are present, check the last noun. If it is not one of the words in set S where \( S = \{\text{number, no, code, date, type, volume, birth, id, address, name}\} \), most likely it is an entity type. Else it may indicate an attribute type.

Heuristics to exclude non-potential entity types candidates:
1. Heuristic HEX: A noun such as “record”, “database”, “company”, “system”, “information” and “organization” may not be a suitable candidate for an entity type. For example, “company” may indicate the business environment and should not be included as part of the entity types. Examples:
   a. “An insurance company wishes to create a database to keep track of its operations.”
   b. “An organization purchases item from a number of suppliers.”

Heuristics to determine attributes:
1. Heuristic HA6: Genitive case in the noun phrase may indicate an attributive function (15).
2. Heuristic HA8: If a noun is followed directly by another noun and the latter belongs to set \( S = \{\text{number, no, code, date, type, volume, birth, id, address, name}\} \), this may indicate that both words are an attribute. Else it is most likely to be an entity.

Heuristics to determine relationships:
1. Heuristic HR1: An adverb can indicate an attribute for relationship (3).
2. Heuristic HR4: A verb followed by a preposition such as “on”, “in”, “by” and “to” may indicate a relationship type. For example: “Persons work on projects.” Other examples include “assigned to” and “managed by”.

Heuristics to determine cardinalities:
1. Heuristic HC2: The adjective “many” or “any” may suggest a maximum cardinality. For example:
   a. “A surgeon can perform many operations.”
   b. “Each diet may be made of any number of servings.”
2. Heuristic HC3: A comparative adjective “more” followed by the preposition “than” and a cardinal number may indicate the degree of the cardinality between two entities. For example: “Each patient could have more than one operation.” The syntactic heuristics were tested through the implementation of ER-Converter (12,13). The approach in the evaluation uses methods for evaluating Information Extraction systems, primarily Message Understanding Conferences (MUC) (8) evaluations i.e. recall and precision. Recall is percentage of all the possible correct answers produced by the system. Precision is the percentage of answers that are correctly identified by the system. In any system, both precision and recall should be as close to 100% as possible. However, in general, an increase in precision tends to decrease recall and vice versa. In the context of this research, the definition of recall and precision below are adopted as used by CM-Builder (9) and new measures are defined. The evaluation results obtained from applying the syntactic heuristics in ER-Converter is 90% recall and 85% precision. In order to improve the accuracy of the results, semantic analysis of the natural language specifications is deemed as a promising approach.

4 Semantic Heuristics
In order to resolve a wider range of problems related to ambiguities in requirements’ specifications such as anaphoric references or nominalization, without pre-processing text or using restricted language, semantic analysis of the sentences may be necessary to handle such issues. Semantic analysis involves a process whereby meaning representations are created and assigned to linguistic inputs (10). The ‘understanding’ of the results of the parsing, lexical information, context and common sense reasoning is referred to as the semantic interpretation of the text. More expressive power can be added when semantic interpretation is used.

Semantic roles in objects like agent, instrument, source and location (7) may be helpful in interpreting possible elements of the ER model. Semantic roles or sometimes known as thematic roles are conceptual notions which provide a shallow semantic language for characterizing certain arguments of verbs (10). Table 1 shows some commonly used semantic roles and their definitions.

<table>
<thead>
<tr>
<th>Table 1. Semantic Roles and Their Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semantic role</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>AGENT</td>
</tr>
<tr>
<td>EXPERIENCER</td>
</tr>
<tr>
<td>FORCE</td>
</tr>
<tr>
<td>THEME</td>
</tr>
<tr>
<td>RESULT</td>
</tr>
<tr>
<td>CONTENT</td>
</tr>
<tr>
<td>INSTRUMENT</td>
</tr>
<tr>
<td>BENEFICIARY</td>
</tr>
<tr>
<td>SOURCE</td>
</tr>
</tbody>
</table>

ISSN: 1790-5117
The following example illustrates the concept of semantic roles:
“The purchaser (AGENT) sends an order form (THEME) to the supplier (GOAL).”

From the example, the subject, i.e. ‘the purchaser’ acts as an agent as the causer of the event. The object, ‘order form’, has the semantic role ‘THEME’ as it is directly affected by the event. ‘Supplier’ represents the GOAL where it is the destination of the transfer event. Other examples are as follows:
1. They (AGENT) may send their good (THEME) to market (GOAL) through suppliers (INSTRUMENT)
2. The goods (THEME) are sent by truck (INSTRUMENT) to collection centres (GOAL) in larger cities (LOCATION)

In example (1) and (2), different roles are assigned to the subject and object of the sentences depending on the context and the semantic cues. These semantic roles may assist in the pragmatic interpretation of the natural language input to an ER model. For example, the semantic roles agent, goal and instrument may indicate entity types, depending on the context. By deriving suitable heuristics for the identification of the semantic roles, it is envisaged that these could assist in deriving ER elements which syntactic heuristics fail to identify. In addition, the semantic heuristics may also add extra evidence on some of the elements that has been identified through syntactic clues.

A tool called SRL-Tool [18] to label the semantic roles is developed to assist in the semantic analysis. The following subsection presents a selection of the heuristics to determine some of the semantic roles.

4.1 Heuristics to determine Agent’s Role

HA1: Agent’s role occurs when a noun phrase appear and followed by a verb phrase that does not belongs to “BE”(VerbBe).

Example of Agent’s role:
1) The boy ran down the street
   The boy = Agent and ran = verb phrase not belonging to “BE”(VerbBe)
2) Micheal swam
   Micheal = Agent and swam = verb phrase not belonging to “BE”(VerbBe)

4.2 Heuristics to determine Theme’s Role

HT1: If an Agent role occur at HA1 but appear in an inanimate group, then it may indicate a Theme role.

Example of Theme’s role:
1) The rock rolled
   rock = Theme and rock is an Inanimate

2) The ship sank
   ship = Theme and ship is an Inanimate

HT2: If an Agent role occur at HA1 but exist before the verb “BE” (Verb BE), then it may indicate a Theme role.

Example of Theme’s role:
1) He was chased
   He = Theme and was is the phrase “BE”(VerbBe)

2) The goods are sent
   goods = Theme and are is a verb phrase “BE”(VerbBe)

HT3: If a preposition such as ‘of’ and ‘about’ does not occur in a sentence, then it may indicate the Theme role exists before the verb phrase.

Example of Theme’s role:
1) Cut the cake
   cake = Theme and the preposition “of” or “about” does not occur in that sentence.

Once the relevant semantic roles are determined for a given natural language text or specification, the next step is to determine the semantic heuristics to identify the relevant ER elements. In this research, a manual investigation is carried out in the process of developing the semantic heuristics. This involves the use a training set which consists of 21 database problems. The problems are tagged with semantic roles prior to the semantic analysis. Below is some example of the relevant semantic heuristics:

Semantic heuristics to determine entity types:
1. SHE1: A theme can be an entity type.
   For example:
   A library (THEME) can hold many copies of a book (THEME).
2. SHE2: An agent can be an entity type.
   For example:
   Each hire (THEME) is made by a group (AGENT) in the organization.
Semantic heuristics to determine attributes:
1. SHA1: A theme can be an attribute type if the theme occurs after the verb phrase “has” or “have”. For example:
   Each building (THEME) in an organization has a different building name (THEME).
2. SHA2: An instrument occurring after a preposition such as “with” and “by” can be an attribute type. For example:
   Each car (THEME) is made up with parts of iron bars (INSTRUMENT).

Once an optimal set of the heuristics are determined and selected, they will be implemented as part of an extension to the existing tool, ER-Converter[12]. The process begins by reading a plain input text file containing a requirements specification of a database problem in English. For this purpose, a parser is required to parse the English sentences to obtain their part-of-speech (POS) tags before further processing. Part of speech tagging assigns each word in an input sentence its proper part of speech such as noun, verb and determiner to reflect the word’s syntactic category [1]. The parser used here is Memory-Based Shallow Parser (MBSP) [4,17]. The results produced is then parsed through SRL-Tool[18] for the semantic analysis. The parsed text is then be fed into ER-Converter to identify suitable data modeling elements from the specification. The task requires several steps to be carried out in order to achieve the desired ER model from the natural language input, each of which is listed as follows:
- Step 1: Part of speech tagging using Memory-based Shallow Parser
- Step 2: Semantic roles assignment using SRL-Tool
- Step 3: Read natural language input text into system
- Step 4: Apply syntactic and semantic heuristics and assign weights
- Step 5: Human intervention
- Step 6: Attachment of attributes to their corresponding entity
- Step 7: Attachment of entities to their corresponding relationship
- Step 8: Attachment of entities to their corresponding cardinality
- Step 9: Produce final result

5 Conclusion
This paper describes an approach of generating ER elements automatically from natural language specifications using heuristics. Semantic heuristics are proposed to be utilized in conjunction with the syntactic heuristics to improve the accuracy of the results in producing the ER elements from natural language specifications. The contribution made can be applied in areas such as part of the domain model of an intelligent tutoring system, designed to assist in the learning and teaching of databases and other applications of NLP for database design.

References:

ISSN: 1790-5117


