

## Improving the Quality of Solutions by Automated Database Design Systems with the Provision of Real World Knowledge – An Evaluation

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### ABSTRAK

Sistem pengautomasian reka bentuk pangkalan data berkemampuan untuk membantu pereka bentuk dalam proses analisis dan reka bentuk sebuah sistem pangkalan data. Walau bagaimanapun, kemampuan sistem seumpama ini menjanakan model yang berkualiti setanding dengan pakar pangkalan data masih lagi menjadi persoalan. Sehubungan dengan itu, beberapa sistem yang bukan sahaja berpengetahuan dalam proses reka bentuk pangkalan data tetapi juga berkemampuan untuk menggunakan pengetahuan tentang dunia sebenar telah dibangunkan. Sungguhpun begitu, penggunaan pengetahuan dunia sebenar dikatakan mampu untuk meningkatkan kualiti model pangkalan data, satu kajian tentang keberkesanan kaedah ini masih lagi belum dilakukan. Kertas kerja ini membincangkan penilaian tiga pendekatan dalam perwakilan pengetahuan yang dicadangkan untuk pengetahuan dunia sebenar iaitu *dictionary*, *thesaurus*, dan *knowledge reconciliation*. Hasil kajian menunjukkan bahawa sistem yang dilengkapi dengan pengetahuan dunia sebenar mampu menjanakan model reka bentuk yang lebih berkualiti berbanding sistem yang tidak dilengkapi dengan pengetahuan dunia sebenar. Walau bagaimanapun, bagi sistem yang dilengkapi dengan pengetahuan sebenar untuk mencapai kualiti reka bentuk yang setanding dengan reka bentuk yang dihasilkan oleh pakar pereka bentuk pangkalan data masih lagi belum terjawab melalui kajian ini.

### ABSTRACT

Automated database design systems have the capability of assisting human designers in the process of database analysis and design. However, the capacity of these systems to produce quality solutions which are similar to expert human designers remains largely unresolved. Therefore, in recent years there have been a number of attempts to develop systems that are not only "knowledgeable" about database design process but also have the capability of exploiting knowledge of the real world. Although such use of real world knowledge was claimed capable of increasing the quality of design models, there is currently little, if any, formal evaluation that this claim has taken place. This paper presents such an evaluation of three existing approaches proposed to facilitate system-storage and exploitation of real world knowledge; the dictionary approach, the thesaurus approach, and the knowledge reconciliation approach. Results obtained have indicated that some of the approaches under examination in

this study are capable of producing higher quality design models compared to when no such knowledge is in use. However, the ability of such representations of real world knowledge to achieve the standard quality of human generated design models remains unanswered.

**Keywords:** Database design, automated database design, system evaluation, artificial intelligence

## INTRODUCTION

Automated database design systems are mainly concerned in assisting novice human designers in producing high quality of data models (Vessey and Sravanapudi 1995). This aspect was claimed to be achieved from the capability of such systems to provide intelligent assistance in the form of advice, suggesting alternative solutions, helping to investigate the consequences of design decisions, and maintaining the availability of the design knowledge by providing information should a decision be questioned or require explanation in retrospect (Lloyd-Williams 1994). However, it was realised that expert human designers contribute far more than database design expertise to the design process (Storey *et al.* 1993). Expert human designers, even when working in an unfamiliar domain, are able to make use of their knowledge of the real world in order to interact with users, make helpful suggestions and inferences, and identify potential errors and inconsistencies (Storey 1992; Storey and Goldstein 1993). This situation has resulted in numerous calls for the representation of real world knowledge within such systems, coupled with the ability to reason with and make use of this knowledge.

Although it has been claimed that the use and exploitation of real world knowledge is capable of improving the quality of designs produced by an automated database design system, little or no attention has been directed to provide decisive evidence regarding this claim. This fundamental issue has not yet been fully explored possibly due to the lack of a rigorous and unified framework and methodology in providing such evidence. This paper presents the testing and evaluation of three approaches proposed to facilitate the system-storage and exploitation of real world knowledge; the dictionary approach (Kawaguchi *et al.* 1986), the thesaurus approach (Lloyd-Williams 1994, 1997), and the knowledge reconciliation approach (Storey *et al.* 1993; Storey *et al.* 1997), the intention being to initiate the gathering of evidence to support the claim previously stated or otherwise.

This paper is organised into the following topics. In the next section we provide a brief overview of the existing approaches to representing real-world knowledge. We then discuss the research methodology employed in this evaluative experiment, and present the results of our empirical investigation. Finally we present the conclusions that may be drawn from our work.

### *Brief Overview of Existing Approaches to Representing Real-World Knowledge*

The following provides a brief overview of the methods of knowledge representation employed by the dictionary, thesaurus and knowledge reconciliation approaches. Those interested in detailed discussions of each approach, along with the claimed benefits associated with their use, are referred to the relevant source literature (Lloyd-Williams 1994; Storey *et al.* 1993; Kawaguchi *et al.* 1986).

The dictionary approach to representing and exploiting real-world knowledge by an automated database design system is illustrated by the Intelligent Interview System (I<sup>2</sup>S) of Kawaguchi *et al.* (1986). The I<sup>2</sup>S approach organises the encapsulated real-world knowledge into a series of domain specific dictionaries, each dictionary comprising verb information with both past and present forms of each verb being presented. During a design session, I<sup>2</sup>S makes use of the dictionary in an attempt to "interview" the user, extracting a series of simple queries that the eventual database will be expected to satisfy. These queries are analysed by the system and used in the generation of a logical structure representing the target database.

The thesaurus approach is illustrated by the Object Design Assistant (ODA) system of Lloyd-Williams (1993). Knowledge is represented within the thesaurus structure by making use of series of concepts and associated synonyms, linked together via abstraction mechanisms, categorised according to those recognised by the system (aggregation, association and generalisation). During a design session, the ODA system attempts to make use of the thesaurus in order to obviate the need to ask what may be viewed as being trivial questions of the user.

The knowledge reconciliation approach is illustrated by the Common Sense Business Reasoner (CSBR) system of Storey *et al.* (1993, 1997). The approach is similar to the thesaurus in that it organises domain knowledge into a collection of domain specific concepts and relationships between these concepts. Synonyms, however, are not represented by this approach. During a design session the system attempts to reason with this knowledge in order to reconcile it with the user-specified application domain, the intention being to provide the user with meaningful suggestions of concepts and relationships missing from the evolving database design, and to augment the contents of the domain knowledge after the completion of each design session.

## **MATERIAL AND METHODS**

In order to conduct the evaluative experiments on the use of the dictionary, thesaurus and knowledge reconciliation approaches, a prototype automated database design system, the *Intelligent Object Analyser* (IOA), was developed. IOA provides support for the conceptual design of databases. As IOA was used as a research vehicle to this study, it has the capability of operating in four different modes; either using real-world knowledge provided by the thesaurus, dictionary or knowledge reconciliation approaches (throughout this paper, processing

associated with these approaches are respectively referred to as the thesaurus mode, the dictionary mode and the knowledge reconciliation mode) or without the use of real-world knowledge (basic mode). In each real-world knowledge assisted modes of processing, the information provided is exploited throughout the design process wherever possible in order to improve the completeness and consistency of the evolving design model. A brief outline of the method and process employed by the system is discussed in the following subsection to facilitate the understanding on how the real-world knowledge may be represented and exploited during design processing.

*The Intelligent Object Analyser*

As illustrated in Fig. 1, the structure of IOA comprises three main components: the user interface, the inference engine and the knowledge bases, plus a pluggable component, consisting of real world knowledge structures respectively represented using the dictionary, thesaurus and knowledge reconciliation approaches.

The *user interface* is a medium for communication between the user and the IOA. The IOA system employs an interactive window system interface which includes the use of pull down menus and a natural language interface. The system contains multiple menus for controlling a design session, viewing an evolving design model and saving and loading a design model.

The inference engine of the IOA system acts as a controller that controls the interaction between the user and the system. It directs any part of the user input to the correct processor for processing and decides which rules to trigger. The domain selection engine, which is part of the inference engine, is used to control the use of selected domain representation structures. The domain selection engine was specifically incorporated in IOA to assist during the course of testing and evaluation of the three approaches in representing real world knowledge structures.

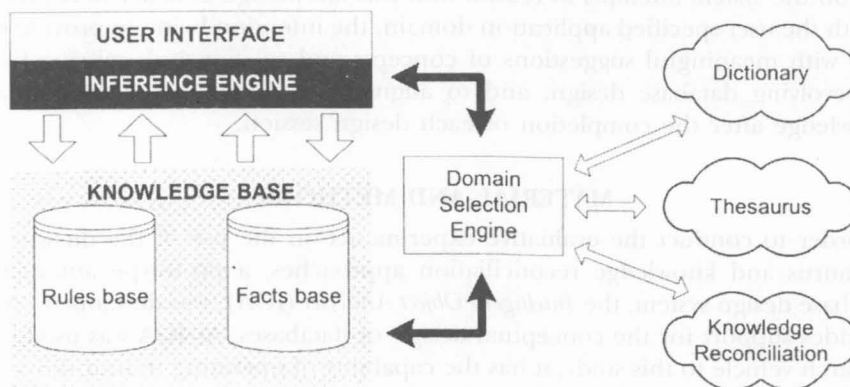


Fig. 1: The IOA architecture

The IOA knowledge-base contains a mixture of rules and facts. Rules correspond to knowledge of how to perform the design task (the order in which design activities take place), detecting and resolving ambiguities, redundancies and inconsistencies within an evolving design, and handling the gradual augmentation of an evolving design as a design session progresses. Facts are used to represent two views of the application domain; an initial representation (the problem domain model) as provided by the user, and the object-oriented design generated from this initial representation. During a design session, IOA follows a two-step procedure.

- The first step involves creating an initial representation of the application domain (known as the problem domain model) and the subsequent refinement of this model.
- The second step involves the refinement of the problem domain model by detecting and resolving any inconsistencies that may exist, and the transformation of the model into object-oriented form.

The first stage of processing requires a set of declarative statements that describe the application domain to be submitted to IOA. These statements are a variation of the method of interactive schema specification described by Baldiserra *et al.* (1979), being based upon the binary model described by Bracchi *et al.* (1976). Each statement links together two concepts (taking the form *A verb-phrase B*), and falls into one of three classes of construct, corresponding directly to the structural abstractions of association, generalization, and aggregation. The statements are used to construct a problem domain model representing the application domain. Once constructed, IOA attempts to confirm its *understanding* of the semantic aspects of the problem domain model; that is, whether each structure within the model represents generalization, aggregation or association.

Once constructed, the problem domain model is submitted to a series of refinement procedures in order to detect and resolve any inconsistencies (such as redundancies that may be present within generalization hierarchies) that may exist. These procedures are performed both with and without the requirement of user input (sometimes referred to as *external* and *internal* validation respectively). Once such inconsistencies have been resolved, IOA makes use of the problem domain model in order to generate a conceptual model.

Although the basic approach represented by the IOA is seen capable of producing reliable design solutions, there are avenues whereby relying on the basic approach alone fails to produce high quality design solutions. For example, the basic approach is incapable of providing suggestions to the user of any important elements found missing from the design model since the system does not have any forms of domain knowledge. The IOA system's inability to identify inconsistencies arises as a result of synonyms and verbs represented by different forms of tenses. Therefore, the provision of real world knowledge as represented by the thesaurus, dictionary and knowledge

reconciliation approaches is seen by many as one of the solutions to overcome this ineffectiveness. It is however beyond the scope of this paper to discuss the technical details of how such representations are being exploited within the IOA system. Interested readers may want to refer to the following articles for further details (Noah and Lloyd-Williams 1998a; 1998b; Noah and Williams 2000; 2001). For instance Noah & Lloyd-Williams (1998a) have discussed in detail the potentiality of the dictionary approach to improve the quality of design solutions particularly within the aspects of design consistency. Noah and Williams (2000 and 2001), on the other hand, have discussed in great detail the exploration of the thesaurus and the knowledge reconciliation approaches in improving the performance of automated database design systems.

#### *Testing and Evaluation Framework*

The testing and evaluation framework designed for this study consists of the following aspects.

- Setting up the performance-related criteria, and particularly the accepted level of performance, i.e. the level of performance that the system must perform or produce.
- Conducting the testing activity involving the generation and execution of a series of test cases in various modes of system processing under a prototype automated database design system.
- Analysing the observed results produced from the execution of test cases in (2), in order to assess the achievement of the accepted performance level previously set up in (1).

The aforementioned framework is now being discussed.

#### *Setting up an Accepted Level of System's Performance*

In any artificial intelligence (AI) based systems, the performance is usually judged from the ability of the systems to perform at levels equivalent to human expertise or any simulated models (such as the regression model) (Moody and Shanks 1994). For example, diagnosis made by an expert cardiac diagnostic system should be similar or comparable to the diagnosis made by a cardiologist. Therefore in the case of this study, the model produced as an output by an automated database design system should be comparable to the quality of design models produced by human experts.

Although elements that relate to the quality of data models have always been a subjective issue, many researchers agree that they can be judged from the aspects of completeness and consistency. This indication was derived from the opinions of (Moody and Shanks 1994; Kesh 1995; Teuw and Van Den Berg 1997; Moody 1998) that a good quality conceptual model must be complete and consistent (free from any redundancy and inconsistency). According to Moody (1998) completeness relates to whether a data model contains all information required to meet user requirements. If a model is incomplete, the resulting database system will not satisfy users. Consistency, on the other hand,

refers to whether a data model contains any forms of redundancies and incorrectness in data modelling conforming to a set of rules. Inconsistent models may result in the database system being developed containing redundant information, and aspects of information anomalies.

In this study, as our intention was to ascertain whether the use and exploitation of real world knowledge make a significant contribution towards enhancing the quality of designs solution, the acceptable level of performance being set-up are twofold. The design solutions provided by the knowledge-assisted modes of processing should be: 1) comparable and equivalent to those of human design solutions (either actual or simulated); and 2) of higher quality as compared to those design solutions produced when no such knowledge was in use.

In the case where actual human outputs are not easily available, simulated human output can be used (O'Keefe and O'Leary 1993).

#### *Testing Activity*

This stage involved generating a representative set of test cases and the subsequent execution of these test cases. These intentionally synthesised test cases were generated from a set of design problems which were primarily extracted from the available literature. The advantage is that the accompanying solution could be used as a benchmark and compared to the system-suggested solution in order to confirm the appropriateness or otherwise of the designs produced. Although actual test cases are ideal sources in performing this test, such test cases that guaranteed to expose all the aspects required under the prescribed input domain considered in this study are very difficult to find (Chandrasekaran 1983). As a result, intentionally synthesised test cases are generally acceptable (O'Keefe and O'Leary 1993).

To assess whether the use and exploitation of the dictionary, thesaurus and knowledge reconciliation approaches can achieve the required performance level previously described in terms of its completeness and consistency, two types of tests have been implemented. The first test involved the generation and execution of a set of test cases with varying degrees of complexity (Test A), whereas the second test involved the execution of a set of test cases with a different number and combination of type of errors (Test B).

In Test A, each of the initial design problems (extracted from the available literature) was systematically altered by dividing them into multiple test cases with varying degrees of complexity as illustrated in *Fig. 2*. The intention is to assess whether the information and reasoning associated with the use of real-world knowledge are capable of increasing the completeness (measured in terms of the number of missing elements) of the designs produced up to an acceptable performance range specified.

During the execution of these test cases, in certain instances the user may be provided with a number of suggestive design elements which were previously detected by IOA as being missing from the test case. The decision for the inclusion of such design elements refers to the example design problem used

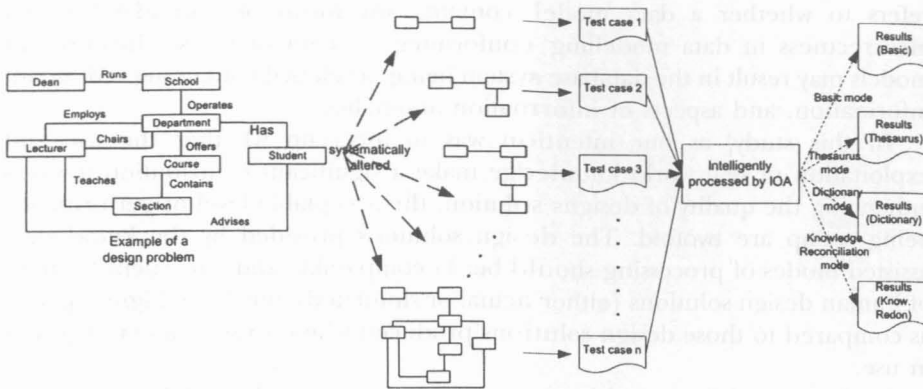


Fig. 2: Approach in case testing of Test A

to generate the test case. The suggested missing design elements are only included in the evolving design model if it is also represented by the design problem in use.

As previously mentioned, Test B involved the generation and execution of a series of test cases with a combination of different types and numbers of synthesised errors. The purpose is to evaluate whether designing using the real-world knowledge-assisted modes of processing are capable of increasing the consistency in the designs produced (measured in terms of the number of errors introduced of the final design output) within the performance range specified. As illustrated in Fig. 3, the approach taken firstly requires the production of a number of synthesised errors. The errors introduced included synonymous concept(s), synonymous or related relationship(s) and a combination of both. Secondly, each of these synthesised errors and combination of them were then systematically embedded into the corresponding design problem to generate the set of test cases.

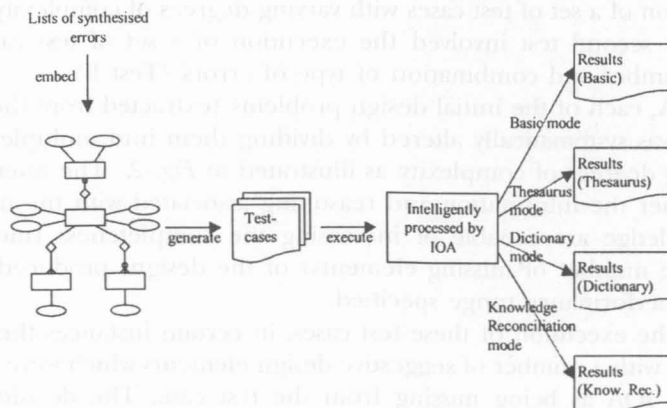


Fig. 3: Approach in case testing of Test B



As illustrated in *Figs. 2 and 3*, both sets of test cases were then executed within the four modes of processing (basic, dictionary, thesaurus and knowledge reconciliation). Results produced from the execution of the dictionary, thesaurus and knowledge reconciliation modes are compared to the solutions provided by the design problem in use and are also compared to those results produced when no such knowledge was in use. As human expert outputs are not easily available, this study assumed that the accompanying solutions associated with each design problem in use act as the human expert solutions. This paper refers to these type of solutions as human-simulated solutions.

#### *Analysis of the Observed Results*

As completeness and consistency defined in this study are measured in terms of the number of required missing design elements and the number of errors introduced within the designs output, respectively, the quantitative method of analysis was employed. In this evaluation, the hypothetical test with a 5% significance level was used to compare the differences between the real-world knowledge-assisted modes of processing solutions with those of human-simulated solutions and the basic mode processing solutions.

Although there are several recommended statistical methods available to test such hypotheses, the paired t-test method is highly appropriate in such circumstances as those prevailing in this study (O'Keefe and O'Leary 1993; O'Keefe *et al.* 1987). The paired t-test method is a form of *repeated measures design*, where the same variable (observed criterion) is measured on several occasions (processing modes) for each subject (test case).

## RESULTS AND DISCUSSION

The results presented here emanate from a series of tests performed on university domain problem found in the general literature (Rob and Rob 1993; Batini *et al.* 1992; Bowers 1993; Elmasri and Navathe 1989). A total of 24 and 84 test cases were generated from these initial problems for Test A and Test B respectively. The real-world knowledge structure (thesaurus, dictionary and knowledge reconciliation) used was constructed as the result of a series of interviews with researchers, the results of the interviews being integrated in order to form a single representative of the domain. This was a deliberate attempt to minimise any bias that might be introduced by taking the content of the test material into account. It is not claimed that these representations portray the definitive knowledge of the university domain, but it does provide an illustration of the way in which such knowledge may be stored and exploited by an automated database design system. Examples of fragments of the real world knowledge structure constructed according to the three approaches are illustrated in Appendix A.

*Completeness (Test A)*

The main purpose in this test is to assess whether the real-world knowledge-assisted solutions are comparable (similar) to the expected solutions provided by human designers; and better (improved) to the solutions provided when processing using the basic approach. The hypotheses for these tests are:

- H<sub>0</sub>: the output produced from the exploitation of the thesaurus, dictionary and knowledge reconciliation approaches are comparable to those of simulated models (there are no significant differences between the two outputs in terms of the number of required missing design elements).
- H<sub>1</sub>: the output produced from the exploitation of the thesaurus, dictionary and knowledge reconciliation approaches are of higher quality compared to those solutions produced using the basic approach (the output from real-world knowledge assisted modes of processing contains less number of missing design elements compared to the output produced from the basic mode of processing).

The completeness of the design solutions is measured by the number of missing design elements of the design problem in use. This was achieved by comparing the output complexity from the execution of the initial (unaltered) design problem and that from the execution of the generated test-case (altered design problem).

Table 1 illustrates the statistical paired t-test results of this study, whereby  $n$  is the degree of freedom,  $t$  is the value which is derived from the following equation:

$$t = \frac{d}{S_d / \sqrt{n}}$$

where  $d$  is the mean difference,  $S_d$  is the standard deviation and  $n$  is the degrees of freedom. Using statistical software packages such as the *Statistical Package for Social Science* (SPSS), the values of  $t$  and the  $P$  value illustrating the probability for accepting the null hypothesis can be obtained. The null hypothesis is rejected and the research hypothesis is accepted if  $P < \text{significance level}$  (0.05). As the objective of the statistical analysis was to validate whether the approaches taken to representing domain knowledge significantly reduced or increased any of the evaluation criteria, referring to  $P$  alone will not provide a sufficient result as it only shows whether there is any significant difference between the observed results. In this case, the value of  $t$  can be used (Rees 1995), where a negative  $t$  value implies that the observed criterion is significantly reduced by the use of real world knowledge and a positive  $t$  value implies otherwise.

As can be seen in Table 1, there have been significant differences between the output produced from the dictionary, thesaurus and knowledge reconciliation approaches compared to those of human-simulated solutions. The corresponding negative  $t$  values indicate that exploiting such approaches does not achieve the

required performance level specified in terms of the completeness of the designs produced. In this case, the outputs produced from the real-world knowledge-assisted modes of processing contain a high number of missing design elements as compared to the simulated human output. In other words, the approaches under testing are incapable of suggesting the required missing design elements that will eventually improve the quality of data models (in terms of completeness) as compared to the human simulated models.

The paired t-test results presented in Table 2, however, indicate that, when comparing with the solutions provided using the basic approach, the knowledge reconciliation approach has the capacity of improving the completeness of the designs produced. This conclusion ensued as the result of the significant P value and the corresponding positive t value. The dictionary and thesaurus approaches, however, are incapable of achieving the required performance range specified. In this case, the statistical tests were invalid as the dictionary and thesaurus approaches do not provide suggestions for missing information. Therefore, both approaches result in similar numbers of required missing design elements within the resulting design output.

*Consistency (Test B)*

In this test, the main concern is to investigate if the solutions provided by the IOA system when using the dictionary, thesaurus and knowledge reconciliation approaches are comparable (similar) to the expected solutions provided by human designers; and better (improved) to the solutions provided when processing using the basic approach. The hypotheses for this test are as follows:

TABLE 1

The paired t-test results between real-world knowledge-assisted solution processing and human simulated solution in terms of completeness

Approaches	<i>n</i>	<i>t</i>	<i>P</i>
Dictionary	23	-5.456	0.000
Thesaurus	23	-5.456	0.000
Knowledge Reconciliation	23	-4.175	0.000

TABLE 2

The paired t-test results between the real-world knowledge-assisted processing solutions and the basic processing solution in terms of completeness

Approaches	<i>n</i>	<i>t</i>	<i>P</i>
Dictionary	N/A	N/A	N/A
Thesaurus	N/A	N/A	N/A
Knowledge Reconciliation	23	6.091	0.000

- H<sub>1</sub>: the output produced from the exploitation of the thesaurus, dictionary and knowledge reconciliation approaches are comparable to those of simulated models (there are no significant differences between the two outputs in terms of the number of elements of redundancies and inconsistencies).
- H<sub>2</sub>: the output produced from the exploitation of the thesaurus, dictionary and knowledge reconciliation approaches are of higher quality compared to those solutions produced using the basic approach (the output from real-world knowledge assisted modes of processing contains a lesser number of elements of redundancies and inconsistencies compared to those outputs produced from the basic mode of processing).

Based upon the paired t-test results presented in Table 3, although it is apparent that there are significant differences between the solutions provided by the IOA when using the dictionary, thesaurus and knowledge reconciliation approaches as compared to those of human-simulated solutions; the positive t-values associated with each approach show that the outputs produced from the real world knowledge assisted modes of processing still contain high numbers of redundancies and inconsistencies. Therefore, no real world knowledge-assisted modes of processing are capable of qualifying for the acceptable performance range specified in this study.

The paired t-test results presented in Table 4, on the other hand, suggest that compared to the solutions provided when processing using the basic approach, the solutions provided by IOA when processing using the real world knowledge-assisted modes are more consistent. These conclusions are evidenced by the significant values of P and the corresponding negative t-Values.

TABLE 3

The paired t-test results between real-world knowledge-assisted solutions processing and human simulated solutions in terms of design consistency

Approaches	<i>n</i>	<i>t</i>	<i>P</i>
Dictionary	83	10.674	0.000
Thesaurus	83	8.370	0.000
Knowledge Reconciliation	83	8.433	0.000

TABLE 4

The paired t-test results between the real-world knowledge-assisted processing solutions and the basic processing solution in terms of design consistency

Approaches	<i>n</i>	<i>t</i>	<i>P</i>
Dictionary	83	-4.547	0.000
Thesaurus	83	-9.735	0.000
Knowledge Reconciliation	83	-4.684	0.000

**DISCUSSION AND CONCLUSION**

Tables 5 and 6 present a summary of conclusions reached for the dictionary, thesaurus and knowledge reconciliation approaches.

**TABLE 5**  
Design completeness – summary

Performance Level	Dictionary	Thesaurus	Knowledge Reconciliation
Solutions are similar to those of human-simulated solutions	No	No	No
Solutions are better than those of basic mode solutions	No	No	Yes

**TABLE 6**  
Design consistency – summary

Performance Level	Dictionary	Thesaurus	Knowledge Reconciliation
Solutions are similar to those of human-simulated solutions	No	No	No
Solutions are better than those of basic mode solutions	Yes	Yes	Yes

Both tables suggest that the possibility of automated database design systems to provide quality solutions similar to those of human experts are far from reach even with the provision of real-world knowledge models. All the approaches proposed to facilitate the use and exploitation of real-world knowledge under investigation in this study are incapable of achieving the required performance range specified neither in the form of design completeness nor design consistency.

However, providing real-world knowledge within automated database design systems at least makes it capable of enhancing the systems' performance compared to when no such knowledge is in use. The knowledge reconciliation approach, for instance, based on its understanding from the reconciliation of knowledge process was seen capable of improving the completeness and consistency of the designs produced compared to the basic approach. Verbs and synonym-related information provided by the dictionaries and the thesaurus-type structure respectively, on the other hand, were seen capable of improving the consistency of the designs output. The incapability of both approaches to increase the completeness of the resulting designs output was due to the fact that both approaches proved incapable of suggesting any missing design element.

Although this evaluation study has produced satisfying results, it is recognised that consideration must be given to a number of practical issues. Firstly, the effectiveness of the system depends greatly on the accuracy and completeness of the system-held real world knowledge, and the results obtained from the testing may be influenced to a certain extent by the variety and coverage of the generated test cases used during the testing.

Secondly, the use and exploitation of the thesaurus, dictionary and knowledge reconciliation approaches to representing real world knowledge rely on the aspects of processing employed by the IOA system, which may be viewed by some as misleading from the original proposal of representation and usage of such approaches. For instance, the VCS system and the I<sup>2</sup>S system have dissimilar approaches to design processing as compared with the IOA system. Therefore, the approaches to representing real-world knowledge by both systems might be intended to address other aspects of systems performance criteria and characteristics.

#### SUMMARY AND IMPLICATIONS FOR FUTURE RESEARCH

This paper has presented the findings of the performance evaluation of the dictionary, thesaurus and knowledge reconciliation approaches to representing and exploiting real world knowledge by an automated database design system. In this evaluation, we specified performance as the quality of solutions provided by the system from exploiting the represented real world knowledge in terms of design completeness and design consistency. We have compared the solutions produced from the real world knowledge modes of processing with the simulated human models (the accompanying solutions of design problem example used) and the solutions from processing using the basic mode.

The results show that although the represented real world knowledge provide significant contribution in enhancing the quality of designs output as compared to the basic mode (particularly within the aspect of design consistency), such representations of real world knowledge are still incapable of meeting the standard quality of human simulated designs output. This may due to the incapability of the automated database design system to cumulatively augment the system-held domain knowledge from one application domain encountered to the next application domain encountered.

Therefore, it is recommended that future research propose a method of how previous design knowledge could be reused for other design sessions. This seems to be a straightforward process. However, a few feasibility studies should be taken into account and the following questions should be answered first (Vanwelkenhuysen 1995):

- How can design knowledge be modified to provide new insights into the problem or to remove undesired contents of the knowledge?
- How should implications of a change in the design knowledge be perceived?
- How can users be persuaded to participate in the augmentation of the design knowledge?

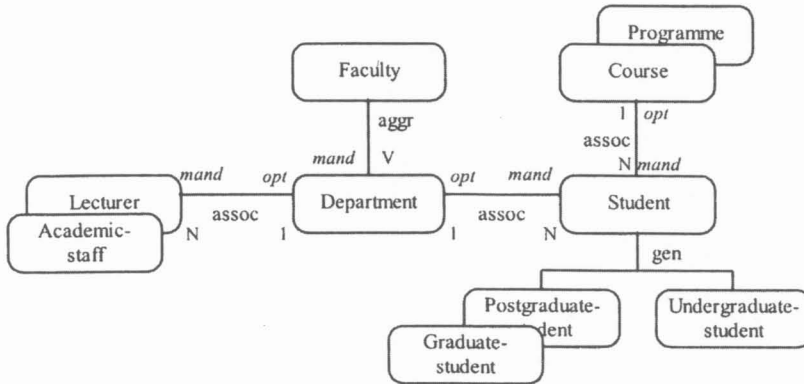
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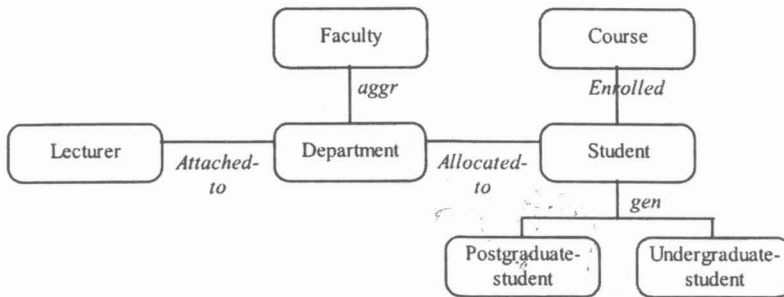
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APPENDIX A



Fragment of real-world knowledge represented as the thesaurus approach



Fragment of real-world knowledge represented as the knowledge reconciliation approach

- verb-phrase (enrol, enrolled)
- verb-phrase (teach, taught)
- verb-phrase (allocate, allocated)
- verb-phrase (run, ran)
- verb-phrase (supervise, supervised)
- .....
- .....
- .....

Fragment of real-world knowledge represented as the dictionary approach.