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Pacific Rim Knowledge Acquisition Workshop, PKAW 2006
Guilin, China, August 2006
Revised Selected Papers

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Preface

Since knowledge was recognized as a crucial part of intelligent systems in the 1970s and early 1980s, the problem of the systematic and efficient acquisition of knowledge was an important research problem. In the early days of expert systems, the focus of knowledge acquisition was to design a suitable knowledge base for the problem domain by eliciting the knowledge from available experts before the system was completed and deployed. Over the years, alternative approaches were developed, such as incremental approaches which would build a provisional knowledge base initially and would improve the knowledge base while the system was used in practice. Other approaches sought to build knowledge bases fully automatically by employing machine-learning methods. In recent years, a significant interest developed regarding the problem of constructing ontologies. Of particular interest have been ontologies that could be re-used in a number of ways and could possibly be shared across different users as well as domains.

The Pacific Knowledge Acquisition Workshops (PKAW) have a long tradition in providing a forum for researchers to exchange the latest ideas on the topic. Participants come from all over the world but with a focus on the Pacific Rim region. PKAW is one of three international knowledge acquisition workshop series held in the Pacific-Rim, Canada and Europe over the last two decades. The previous Pacific Knowledge Acquisition Workshop, PKAW 2004, had a strong emphasis on incremental knowledge acquisition, machine learning, neural networks and data mining.

This volume contains the post-proceedings of the Pacific Knowledge Acquisition Workshop 2006 (PKAW 2006) held in Guilin, China. The workshop received 81 submissions from 12 countries. All papers were refereed in full length by the members of the International Program Committee. A very rigorous selection process resulted in the acceptance of only 21 long papers (26%) and 6 short papers (7.5%). Revised versions of these papers which took the discussions at the workshop into account are included in this post-workshop volume. The selected papers show how the latest international research made progress in the above-mentioned aspects of knowledge acquisition. A number of papers also demonstrate practical applications of developed techniques.

The success of a workshop depends on the support of all the people involved. Therefore, the workshop Co-chairs would like to thank all the people who contributed to the success of PKAW 2006. First of all, we would like to take this opportunity to thank authors and participants. We wish to thank the Program Committee members who reviewed the papers and the volunteer student Yangsok Kim at The University of Tasmania for the administration of the workshop.

Auguest 2006

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Visual Knowledge Annotation and Management by Using Qualitative Spatial Information

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Abstract. The wide use of the Internet and the increasingly improvement of communication technologies have led users to need to manage multimedia information. In particular, there is an ample consensus about the necessity of new computational systems capable of processing images and "understand" what they contain. Such systems would ideally allow to retrieve multimedia content, to improve the way of storing it or to process the images to get some information interesting for the user. This paper presents a methodology for semi-automatically extracting knowledge from 2D still visual multimedia content, that is, images. The knowledge is acquired through the combination of several approaches: computer vision (to get and to analyse low level features), qualitative spatial analysis (to obtain high level information from low level features), ontologies (to represent knowledge), and MPEG-7 (to describe the information in a standard-way and make the system capable of performing queries and retrieve multimedia content).

1 Introduction

An incommensurable amount of visual information is becoming available in digital form, in digital archives, on the World Wide Web, in broadcast data streams and in personal and professional databases, and this kind of information is increasing.

Nowadays, it is common to have access to powerful computers capable of executing complex processes and despite that, there is no efficient approach to process multimedia content to extract high-level features (as knowledge) from them. Moreover, a lot of processes use multimedia contents as their primary data source in critical domains.

It is clear new computational systems capable of processing and "understanding" multimedia content are needed. So, different processes can be performed more efficiently: multimedia content retrieval, storage and processing. In this way, images can be processed to get interesting information for the user, who is not interested in low-level features of multimedia information but in high-level ones (i.e., the content meaning). This is the so-called semantic gap: how to bridge the low-level features and high-level features. It refers to the cognitive distance between the analysis results delivered by state-of-art image-analysis tools and the concepts human look for in images [4].

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Traditionally, textual features such as filenames, captions, and keywords have been used to annotate and retrieve images [7]. Research on intelligent systems for extracting knowledge or meta-information directly from multimedia content has increased in the last years. For example, systems which usually work with sport videos, recognising some kinds of events as a function of audio comments [12,13,14]. But this is not enough to get meta information about the image content. Many content-based image retrieval systems have been proposed in literature [1,2,3]. Most of them try to get more information by analysing the image to work out low-level features such as colours, textures, and shapes of objects, but this is not sufficient to get real information about what an image contents [11].

In this work, an approach to obtain high-level features from images using ontologies and qualitative spatial representation and reasoning is presented. This approach extracts relationships between the regions of the image by using their low-level features obtained in the segmentation step. Then, it creates a content representation where the regions are concepts, the low-level features their attributes and the relationships are inferred knowledge. This information is then used to compare this structure to ontologies stored in libraries so that the system can guess what each region really is and perhaps, what the image represents. An advantage of using semantic approaches is the fact that they do not require to re-design the framework for different domains. It provides a new layer that is completely independent of the methods and techniques used to process the image.

Finally, the structure of this paper is the following. In section 2, the technical background of this methodology is discussed. An overview of the methodology proposed for this work is described in section 3. Section 4 describes the processes for extracting high-level information from images. An example of the methodology is shown in section 5. Finally, some conclusions are put forward in section 6.

2 Technical Background

Along this section the basic methodological components of our approach are briefly explained.

2.1 Image Segmentation

Image segmentation is a challenging and important issue in image processing and computer vision. It tries to extract the objects an observer may find conceptually coherent by themselves, so that the extracted objects (i.e., regions) are distinct from each other. However, segmentation has access only to the descriptions of pixels (i.e., colour), and their spatial relationships, while a human observer always uses a higher level of knowledge (e.g., object recognition) to segment the image objects.

There are many segmentation algorithms, which are usually specialized in extracting specific types of regions (i.e., the background) [16]. Moreover, some can be used together to get different kind of information and then try to merge it.

To us, segmentation will provide a set of regions that will be used to get high-level information. So, after segmentation, an image is decomposed into a set of regions for which the system must try to find out their real meaning. Once segmentation has been performed, a set of low-level features are obtained for each region.

2.2 Qualitative Spatial Reasoning

According to [5], Qualitative Reasoning deals with capturing the knowledge of physical world while creating quantitative models. The ultimate objective of Qualitative Reasoning is to make this knowledge explicit, so that from appropriate reasoning techniques, a computer might predict, diagnose and explain the behaviour of physical systems in a qualitative manner.

Qualitative spatial representations address many different aspects of space including topology, orientation, shape, size and distance, so it has already been used in computer vision for visual object recognition at a higher level, including the interpretation and integration of visual information. It has been used to interpret the results of low-level computations as higher level descriptions of the scene or video input [10]. The use of qualitative predicates helps to ensure that semantically similar scenes have identical or at least very similar descriptions.

2.3 Ontologies

An ontology is viewed in this work as a formal specification of a domain knowledge conceptualization [15]. In this sense, ontologies provide a formal, structured knowledge representation, having the advantage of being reusable and shareable. Furthermore, an ontology can be seen as a semantic model containing concepts, their properties, interconceptual relations, and axioms related to the previous elements. For our purpose, ontologies can represent topological information of different domains, so this knowledge is used to infer the meaning of an image. This usage is discussed in [5], where the authors state that there are strong reasons for taking regions as the ontological primitive.

2.4 MPEG-7

MPEG-7, formally named "Multimedia Content Description Interface", is a ISO/IEC standard developed by MPEG for describing multimedia content data that supports some degree of interpretation of the information meaning, which can be passed onto, or accessed by, a device or a computer code [8].

MPEG-7 offers a comprehensive set of audiovisual Description Tools (the metadata elements and their structure and relationships, that are defined by the standard in the form of Descriptors and Description Schemes) to create descriptions. These descriptions are a set of instantiated Description Schemes and their corresponding Descriptors at the users will form the basis for applications enabling the needed effective and efficient access (search, filtering and browsing) to multimedia content. This is a challenging task given the broad spectrum of requirements and targeted multimedia applications, and the broad number of audiovisual features of importance in such context.

3 Overview of the Methodology

The methodology proposed here can be visualised through a framework comprised of three main modules, namely, image processing and low level features extraction, qualitative spatial information extraction and ontology library sub-system.

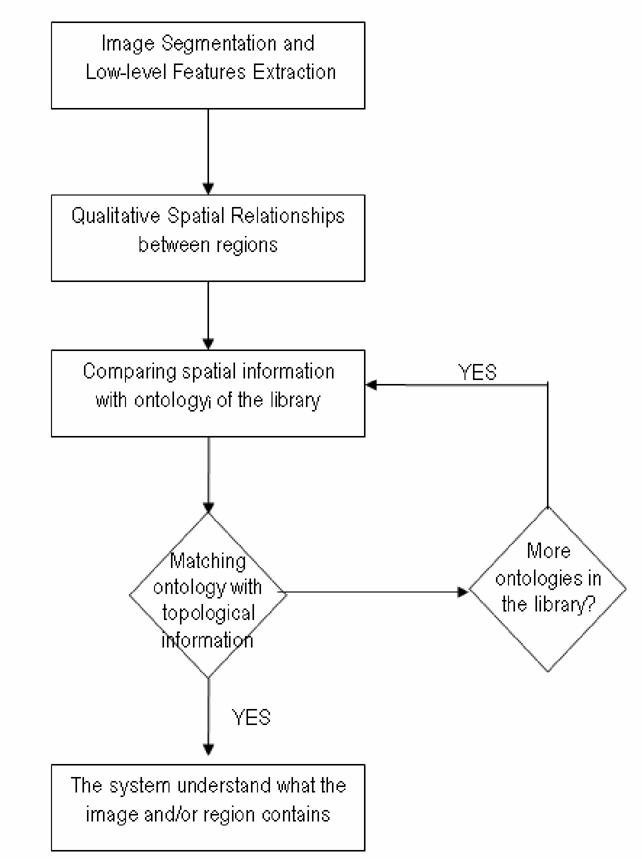

Fig. 1. Methodology schema

The goal of the framework is to get high level information from an input image. This process may be supported by an expert during the image processing task to extract the image segments.

At the beginning, some filters and techniques are applied to the input image to determine the segments. This step may be done by an expert if the content of the image is not previously known. This may be done (semi) automatically if the system has analysed similar images (the same domain) before, so it knows which algorithms and techniques to apply. After that, the system knows every segment that composes the whole image; so, it is possible to extract low level features for each segment and for the whole image in general (e.g. the background dominant colour). Once segmentation has been performed, a set of low-level features are obtained for each segment. This process will be explained in the next section.

Another sub-system will be able to get qualitative spatial information between segments so a structure of topological relationships between concepts will be obtained (e.g. "A is left of B", "C is similar size to D"…)

Once the structure is obtained, it can be compared with all the ontologies with topological information stored in our library subsystem to match the structure with an ontology. In this case, the system is able to interpret the image in the context of a particular domain.

4 High-Level Information Extraction Process

After describing the framework, the focus of this section is the knowledge extraction processes carried out. For each image, the system performs three sequential phases: image segmentation and low level features extraction, qualitative spatial relationships extraction and inference.

4.1 Image Processing and Low Level Features Extraction

As it has been abovementioned, the input is an image. The system processes each image to obtain the elements that appear in the image, using several techniques based on segmentation, which is the process that partitions the spatial domain of an image or other raster datasets like digital elevation models into mutually exclusive parts, called regions. After that, the system gets several quantitative features [6] for each element found. Theses features are enumerated in the following list:

Table 1. Features description

Features Description	
Position	It is defined as the portion of space that is occupied by the object.
Orientation	Where the object is pointing to.
Location	refers to the location of the object in the image (e.g. far north)
Size	The area of the segment.
Compactness	Represents the density of an object.
Dimension	It is composed by two properties: width and height.
Perimeter	It represents the distance around a figure.
Shape	It represents the visual appearance of a region.
Colour	The visual attribute of the region that results from the light they emit or transmit or reflect.
Texture	The tactile quality of a surface or the representation or invention of the appearance of such a surface quality.

Once all this information has been obtained, it may be represented in MPEG-7 because it has descriptors to represent general information about the image and for each region. Some of them are to define basic structures like colour, texture, shape, localization and others for another kind of multimedia contents such us video or sounds.

4.2 Qualitative Spatial Information Extraction

Qualitative representation has already been used in computer vision for visual object recognition at a higher level, which includes the interpretation and integration of visual information. The use of qualitative spatial information helps to ensure that semantically close scenes have highly similar descriptions. Hence, it is possible to recognise images that represent the same content. Our approach uses ontologies to define topologically a scenario. So, the system can compare the information obtained from the image with the ontologies in order to infer the content of an image. So, in this way, the system is able to interpret the results of low-level computations as higher level scene descriptions.

In order to achieve our objective, the system must find out all the spatial relationships existing between all the regions detected in the image through the previous phase. These relationships will give us information about how the regions are spatially 'related', that is, how the scenario is configured. The result of this process is a 'graph' where the nodes or concepts (regions) are related to each other by using different kinds of spatial relationships. The spatial relationships the system can work with are explained below.

4.2.1 Location Relationships

The location of one object is relative to another object. The first one is called the 'target' object and the second is the 'reference' object. Generally, this location has two components, a distance and a direction, so the system gets relations such as "A is north of B" and "A is far from B".

The system is able to work out the following location (cardinal) relationships: east, west, north, south, south-west, north-west, south-east, north-east and a special case called central area, in which other relations between two objects cannot be applied [9]. On the other hand, the system can also calculate some relations related to distance between objects: near, mid and far which may be obtained using fuzzy logic [10].

4.2.2 Orientation Relationships

The system can handle one orientation relationship, "pointing to". This relationship is not easy to get in an isolated image. Sometimes it is necessary to notice the movement of an element in a sequence of images to determine its orientation [6].

4.2.3 Dimension Relationships

By using this attribute, the system is able to get relationships about the height and width differences between objects, such as "A is similar height to B".

4.2.4 Size Relationships

In contrast to dimension relationships, where the system may obtain relations of height and width, size relationships compare the area of the elements (the system only can only work with 2D images). So, comparing objects using the 'size' property makes the system get relationships such as 'X is similar size to Y', where X and Y are elements of the image.

4.2.5 Connectivity Relationships

Connectivity relationships define the degree of connectedness of two elements of the image. The topological definition of connectedness is that a point-set is connected if, and only if, whenever it is contained in the union of two disjoint open sets, it is wholly contained in just one of those sets [6].

The system is capable of working with the following relations: part of, overlap, and partially overlap. An example of these relationships could be: “Iris overlaps pupil”, in an eye.

4.2.6 Shape Relationships

Shape is a complex property of the image elements. The spatial relationships between two regions of the image represent that some objects have a similar shape.

4.2.7 Colour Relationships

Although colour is not a spatial or a geometric property, it is interesting to find some similarities between objects in an image. It is possible to use fuzzy logic to say that an object (X) has similar colour to another (Y), trying to get similarities between them.

As it has been described before, once all the spatial information has been obtained, it is possible to represent all this information in MPEG-7. Although there are no descriptors to represent spatial relationships, new descriptors may be created to store the information obtained in MPEG-7, so that higher level information of the image is also stored in the same description.

4.3 Ontology Library Sub-system

Let us suppose that the system has obtained concept instances of an ontology with topological information. In this case, it would be possible to compare this ontology to all the ontologies of a library with the purpose of matching one of these ones with the concept instances the system has (checking if all the axioms are fulfilled). In this way, the system would be capable of inferring what an image contains.

Let us suppose an image of a human face as the system input. The system would be able to get some information about the concepts (elements) that appear in the image (e.g. “A has a similar shape to B”). However, the system does not know what each element is. So, the system compares the information obtained with the structure and axioms of an ontology, trying to infer whether the elements of the image are instances of the ontology concepts. In this case, the system could interpret the element and, eventually, the whole image (or part of it) with respect to that domain ontology. The result of this last process is real high-level information of the image, i.e. the human interpretation of the image, that is, information interesting for a human being.

As it has been pointed out before, once it is known what an image contains it can also be stored using MPEG-7 descriptions, so that high-level information is available for future searches.

5 Example

Let us illustrate how the methodology works through a very simple example. Let us suppose that the system must analyse the following image of a head. It should be noted that the system does not know what it is.

Fig. 2. Sample image

In this case, a human being can easily see a mouth, two eyes, a nose and two ears, that is, a head. Let us see step by step how the system might come to the same conclusion.

Step 1: Image segmentation

As it has been described before, the segmentation process is a difficult task. It usually needs the support of an expert (at least once for each kind of image/domain) to get all the regions. In this example, the image to process is already segmented (notice that each region is of a colour different from the around regions). So, the result of the segmentation is shown in figure 3:

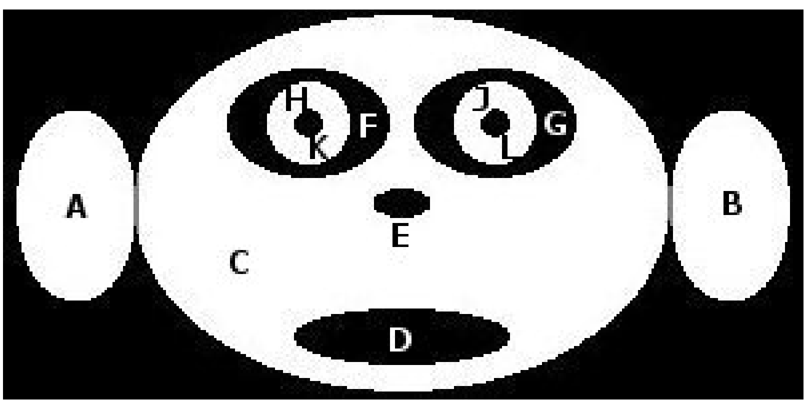

Fig. 3. Labeled image

Each region has been labeled so a human being would say that A and B are ears, C is the whole face, D is the mouth, E is the nose, and F and G are the eyes.

For each region, the system obtains all the (qualitative or quantitative) attributes we mentioned before: position, size, etc so that the next step can be performed.

Step 2: Qualitative Spatial Information Extraction

Once the segmentation task has been performed, the system uses the information obtained in the previous step to get qualitative spatial relationships between all the regions of the image. In our example, some of the relationships the system may get are shown in the following table:

Table 2. Some spatial relationships obtained for the example image

LEFT(A,B) LEFT(A,C) LEFT(A,D) LEFT(A,E) LEFT(A,F) LEFT(A,G)	SIM_SIZE(A,B) SIM_SIZE(F,G)	ABOVE(E,D) ABOVE(A,D) ABOVE(B,D) ABOVE(F,D) ABOVE(G,D) ABOVE(F,E)	SIM_SHAPE(A,B) SIM_SHAPE(F,G)	PART_OF(C,D) PART_OF(C,E) PART_OF(C,F) PART_OF(C,G)

Where SIM_SIZE(x,y) means "x has a similar size to y" and SIM_SHAPE(x,y) means "x has a similar shape to y", both are symmetric relationships. LEFT and ABOVE functions have inverse relationships (i.e., RIGHT and BELOW, respectively).

Step 3: Comparing the structure obtained with the ontologies in the library

Once the system has found all the regions and the relationships between them, it will be capable of comparing the structure obtained with the ontologies of the library in order to determine whether the image represents something described in an ontology.

In our knowledge base, a head is described by using the ontology shown below.

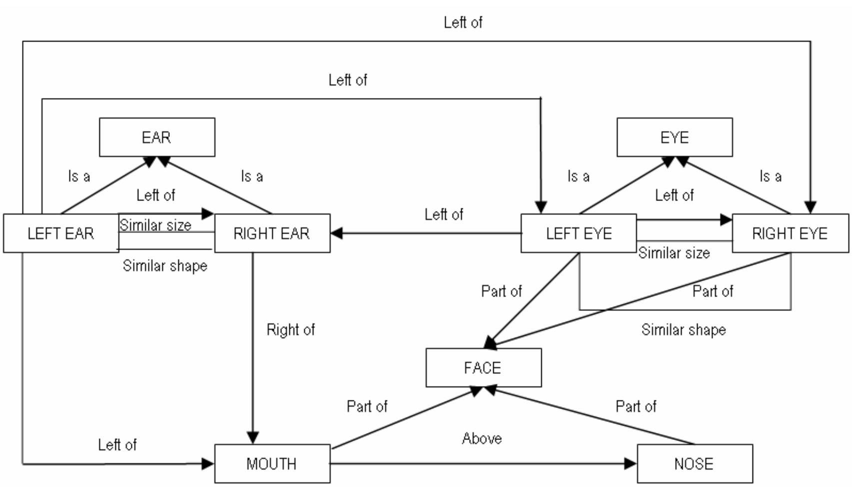

Fig. 4. Ontology of a "head"

Notice that some relationships have been omitted, such as “right of”, because we have considered “left of” (corresponding to the symmetric relationship of “right of”).

Our system will be capable of comparing the ontology and the spatial information obtained to guess that the image contains a head, and what it was labeled as A, B, C,… are LEFT EAR, RIGHT EAR, FACE, and so on, respectively. The matching is based on the ontology structural axioms. Each concept has a list of structural axioms (e.g., “A is a concept”, “A is related to B”,…) and each rule obtained is a potential axiom. If a subset of rules characteristing an object in the image accomplish with all the axioms of a concept, the system infers this object is an instance of such a concept.

LEFT(A,B)	LEFT(LEFT_EAR,RIGHT_EAR)	
LEFT(A,C)	LEFT(LEFT_EAR,FACE)	
LEFT(A,D)	LEFT(LEFT_EAR,MOUTH)	
LEFT(A,E)	LEFT(LEFT_EAR,NOSE)	
LEFT(A,F)	LEFT(LEFT_EAR,LEFT_EYE)	$\Rightarrow$ A is a LEFT_EAR
LEFT(A,G)	LEFT(LEFT_EAR,RIGHT_EYE)	
SIM_SIZE(A,B)	SIM_SIZE(LEFT_EAR, RIGHT_EAR)	
ABOVE(A,D)	ABOVE(LEFT_EAR, MOUTH)	
SIM_SHAPE(A,B)	SIM_SHAPE(LEFT_EAR, RIGHT_EAR)	
….	….	

Fig. 5. Matching of concepts

6 Discussion and Conclusions

In this paper, a semi-automatic method for acquiring knowledge from images has been presented. This approach is mainly based on the use of spatial qualitative analysis and ontologies to make the extraction of high-level information from images feasible. The framework allows to perform three main processes: (1) image segmentation and low-level features extraction; (2) qualitative spatial information extraction; and (3) comparison of the qualitative information extracted to ontologies with topological information. The image segmentation process is probably the most challenging one, because there is no segmentation process useful for images of all domains. Even for images of the same domain, they may need to be processed with different techniques to get important information. So the human assistance, who must select the filters the system would use to obtain the regions of an image, is necessary (at least once for each kind of images).

It is also remarkable that the methodology is capable of inferring many spatial relationships but the system needs to have ontologies which represent what the image (or part of it) contains. That implies it is necessary an important knowledge base with topological information.

Although the methodology has some hard requirements to get high-level information from images, it could be really good to develop computer vision systems capable of recognising some kind of images. Let us suppose a system to detect breast tumors is to be implemented. All the images will be quite similar to each other, so the computer vision system developer just needs to define the filters to be applied in the segmentation process. After that, a knowledge engineer must define an ontology for the domain under question with topological information, so that the system will be able to detect breast lumps and even say if it is malign or not (by using the information in the ontology).

We are currently developing a software system which will implement this methodology and will be used in a medical domain to detect some kind of tumors semi automatically. To be more precise, the system will detect automatically every part of the body from the image and infer if there is something wrong, detecting quickly a possible tumor. This high-level information will be stored in MPEG-7 format in order to make the information available easily for the hospital staff.

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Ad-Hoc and Personal Ontologies: A Prototyping Approach to Ontology Engineering

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Abstract. Large scale or common ontologies tend to be developed using structured and formal techniques that can be equated to the Waterfall system development life cycle. However, in domains that are not stable or well-understood a prototyping approach may be useful to allow exploration and communication of ideas. Alternatively, the ontology may be part of an intermediate step or representation that provides structure, organization, guidance and semantics for another task or representation. Given that the ontology is not the end goal and possibly not reusable, the overhead of developing or maintaining such ontologies needs to be minimal. This paper reviews some of the research using ad-hoc, one-off and, sometimes, throw away, personal ontologies and provides an example of a simple technique which uses Formal Concept Analysis to automatically generate an ontology as needed from a number of data sources including propositional rule bases, use cases, historical cases, text and web documents covering a range of applications and problem domains.

Keywords: Personal Ontology, Formal Concept Analysis, Ontology Engineering.

1 Introduction

Agile software development techniques such as Rapid Application Development (RAD) and extreme programming (XP) have become an accepted way of developing software systems where requirements are not well understood and where evolution and change are the norm for that application domain. Elements of these techniques include: short cycles and continuous integration to produce and refine one or more prototypes; a failure-driven approach involving test-first programming and design; refactoring to improve structure and the use of collective ownership which is achieved by ongoing collaboration between stakeholders and pair programming [26]. Agile software development offers a major alternative to the traditional Waterfall system development life cycle model and process. While some fear that agile methods may not scale up or may result in build-and-fix models, some organisations and/or development teams clearly prefer the flexibility and speed offered by agile methods even where the requirements are well understood up-front.

A. Hoffmann et al. (Eds.): PKAW 2006, LNAI 4303, pp. 13 – 24, 2006.

Similarly in knowledge engineering a case can be made for using techniques which develop ad-hoc and personal ontologies, which can be likened to an evolutionary or even throwaway prototype, as an alternative or exploratory precursor to the development of large-scale and/or common ontologies. This is almost the opposite to approaches which use personal ontologies to extract, restrict or guide an individual's usage or access to a larger ontology. For example, the work of Haase et al [18] allows the user to interact in *usage* or *evolution* mode with the ACM Topic Hierarchy, a domain ontology in Bibster. Usage mode restricts the user's view of the domain ontology to the topics the user has chosen to include in their personal ontology, while evolution mode allows the ontology to be extended for the individual. As [18] points out, this raises issues of management of the changing ontology and thus their work provides various change and alignment operations.

Approaching from the other direction, Chaffee and Gauch [7] ask the user to build a personal ontology in the form of a tree containing at least ten nodes and five pages per node (the goal of the ontology is to assist with web navigation) to represent their view of the world. The personal ontology is then mapped to a reference or upper level ontology. Similarly, the SemBlog personal publishing system uses a "loose and bottom-up ontology" based on a hierarchy of categories defined by the user on the basis that "everyone has those categories" which they "routinely [use to] classify … contents to the category" [28, p. 601].

Some approaches provide technical assistance for personal ontology development. Carmichael, Kay and Kummerfield [5] use the Verified Concept Mapping technique based on concept mapping commonly used in education and for knowledge elicitation. The system contains a number of semantic concepts. These concepts are shown to the user and may be used as building blocks to develop a personal ontology. Additionally the system allows the user to define their own concepts and add these to the model, but the system will not understand the semantics of user-defined concepts. Likewise, OntoPIM [21] uses a personal ontology to assist the user to manage their personal desktop information. The personal ontology is developed by providing a Semantic Save function which allows capture of domain independent as well as domain specific metadata when an object, such as a picture or a document, are saved. Following this step, concepts are automatically mapped into the personal ontology by the system.

Sometimes adhoc and temporary ontologies are used for translating from one representation to another. For example, Moran and Mocan [27] created an adhoc ontology equivalent to an XML schema to be used by a Web Service Description Language (WSDL) description to translate from XML and the Web Services Modeling Language (WSML).

In contrast to all of the aforementioned research, this paper looks at the use of personal and ad-hoc ontologies to enable understanding of the domain to be gained and enhanced, just as one would build a throwaway or evolutionary prototype to better or incrementally understand the system requirements, application domain or test a design solution. In knowledge engineering, repertory grids [36] and Protégé [14] have been used to aid the user to discover and develop their own knowledge in a domain. In some cases the systems built acted as a communication channel to share knowledge even though the end product may have never been deployed. Personal systems, and this includes ontologies, are often more acceptable to users as they tend to be more relevant and meaningful for the individual and allow the user to use their own terminology and structure according to the users context and preferences. However, unlike the use of Protégé or repertory grids, the ontology development approach described in the next section automatically generates ontologies from other sources. When changes to the sources occur, the ontologies are simply regenerated. Such a strategy is acceptable if maintenance and ongoing reuse of the ontology is not required, as in the case of a throwaway or exploratory prototype or model.

In various projects over the past decade, Formal Concept Analysis (FCA) [40] has been used to build domain specific, personal and/or shared, ad-hoc and usually throw away ontologies from a number of alternative sources including propositional rules, cases, use cases, software specifications, web documents and keywords. FCA achieves this through the notion of a concept as a basic unit of thought comprising a set of objects and the set of attributes they share, thus providing an intensional and extensional definition for each primitive concept. FCA then applies various algorithms based on lattice and set theory to generate new concepts and allow visualization of the consequences of partial order. Section 2 of this paper provides an example of the technique. Section 3 introduces some of the applications. Conclusions are given in section 4.

2 Automatic Generation of Ontologies

FCA generally relies on the definition of exemplars or stereotypical cases to find concepts. A crosstable where each object is a row and each attribute is a column can be created to provide a formal context for the cases. The notion of a formal context reflects the view that knowledge only holds within the context it is defined. An object which has a particular attribute is marked with an “X” in the corresponding cell, see the representation in Table 1. Using FCA we are able to perform a closure operation on each object to automatically find all formal concepts for a given formal context.

What constitutes an object or an attribute depends on the data to be explored. An object could be a sentence, with the attributes comprising of the (key)words and word phrases found in a use case description or a web-based document. In the following example, a rule base has been used as input. A benefit of starting with rules is that the attribute space has been reduced to the salient features in the cases. With this input type, the rules are the objects where the rule conditions are the attributes and the rule conclusion provides the classification or label for the object. As shown in Table 1, the rules relating to the Cendrowska’s contact lens dataset [6] have been used as input to the formal context. Treating each rule condition, which is really an attribute-value pair, as an attribute is similar to the technique known as *conceptual scaling* [17] which has been used to interpret a many-valued context into a (binary) formal context. The crosstable shown was automatically generated from the rules and thus did not require an additional translation step or human effort. Note that any propositional KB can be converted to a decision table [12] and therefore used in the ontology generation approach presented.

Table 1. Formal Context of Contact Lens Rules given in [6]

	1=1[1]	astigmatic = no	Tear_prod = normal	Age = Presbyopic	Prescription = myope	astigmatic = yes	age = young
Rule 0-Lens=None	X						
Rule 1 Lens=Soft	X	X	X				
Rule 2 Lens=Hard	X		X		X	X	
Rule 3 Lens=Hard	X		X			X	X
Rule 4 Lens=None	X	X	X	X	X		

The set of concepts are derived from the formal context in Table 1 by treating each row as an (object) concept and generating additional higher level concepts by finding the intersection of sets of attributes and the set of objects that share the set of attributes. For example, rules 1-4 (last four rows in Table 1) share the attribute: tear_prod=normal. This forms a new concept as shown in concept 2 in Fig. 1. Once all concepts have been found, predecessors and successors are determined using the subsumption relation ≥. This allows the complete lattice to be drawn. Disjunctions of conditions and negation must be removed to allow the rules to be converted into a binary crosstable. Fig. 1 shows the concept lattice for the Contact Lens Prescription domain. To find all attributes (rule conditions) and objects (rule numbers and conclusion codes in our technique) belonging to a concept, traverse all ascending and descending paths, respectively. For example, concept 7 in Fig. 1 includes the rule conditions (attributes) {prescription=myope, tear_production=normal, 1=1} and objects {4-%LENSN (i.e. rule 4, Lens=None) rule, 2-%LENSH (i.e rule 2, Lens=Hard)}.

From this example we can start to explore the relationships between the rules to improve our understanding of the domain. Table 1 has been provided for explanation of the approach, however, the user of this ontology development technique would not be required to define or work with the crosstable. From the user's point of view, they would firstly select the knowledge base or dataset of interest and then select which parts of the knowledge base or dataset that they wished to explore. This could be achieved via specifying one or more key words that are used to automatically select all cases or rules which contain the keywords. As the Cendrowska knowledge base is very small, all rules have been included. By looking at Fig. 1 we see the importance of the tear_production=normal concept and deduce that if we see a case where tear_production is not =normal then the default recommendation of "no lens" will be given. Alternatively, the absence of a condition covering the abnormal state may prompt the user to consider whether the default rule is adequate or whether an alternative or additional recommendation should also be given such as treatment=tear_duct_operation. Moving further down the lattice we can see that astigmatic is an important feature that will affect the prescription. If astigmatic=no then a soft lens is recommended, but only

[1] 1=1 ie the default condition that is always true. Rule 0 is the default rule, which will be true if no other rules fire. That is, prescription =no Lens unless …..

when the age=presbyopic and prescription=myope conditions are not true (concept 4 shows the exception rule stated in rule 4). If astigmatic=yes and the prescription=myope or age=young then a hard lens is recommended. While it is true that there is nothing shown in the concept lattice that can not be extracted from manually analysing the rules it should be apparent that the relationships between the rule conditions and conclusions are more structured and easily determined in the lattice. As in this example, the increased clarity can be useful in identifying knowledge that is potentially missing. The ontology has served as a means of understanding the domain and perhaps for validating/updating the Cendrowska knowledge base which was presumably used to provide expert opinion.

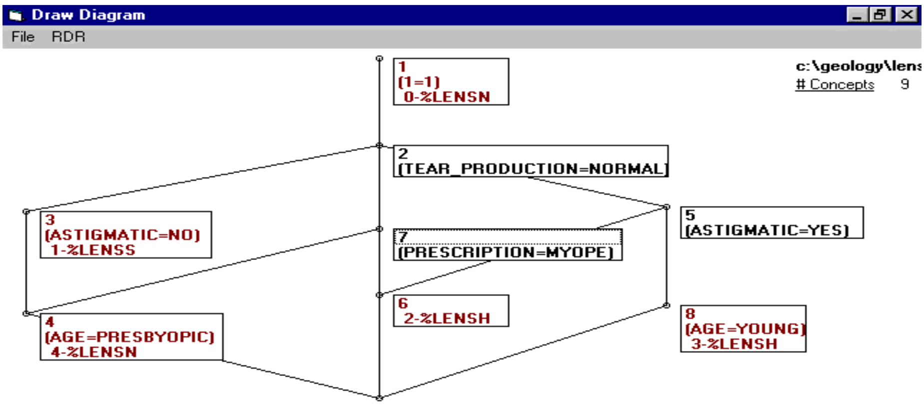

Fig. 1. The Diagram Screen in our tool which shows the Concept Lattice for the Formal Context in Table 1

The Cendrowska contact lens dataset and rules have been used by a number of researchers to demonstrate the value of various knowledge representations such as PRISM [6], INDUCT [15] and the Visual Language supported by Personal Construct Psychology [16]. We note that this data and knowledge is now out of date since the introduction of Rigid Gas Permeable (RGP) contact lenses have made hard contact lenses almost obsolete. Improvements have also been made to soft lenses in the past decade. Based on a recently expressed viewpoint of an expert optician[2] we demonstrate how new knowledge can be added to a crosstable for comparison with the old knowledge. The purpose of this comparison may be to determine if any conflicts have arisen and whether the original knowledge base needs updating. We do not include every attribute that could have been used. The rules created (i.e. the rows) and shown in Table 2 are our interpretation of the information given in the article and are not based on the use of a machine or human built set of rules developed from cases. We assume that had the optician's client data been available there would be multiple rules with exceptions to cover the four possible classifications. However, our technique is adequate for the purposes of demonstrating how knowledge from multiple sources of expertise can be displayed and reconciled using an FCA built ontology.

[2] http://www.epinions.com/well-review-5196-AFCVA2d-394701a9-prod2

Table 2. Formal Context of Contact Lens Rules identified from[1]

	Uncomfortable	Visual acuity=high	Price=low	Custom Made=yes	Age = Presbyopic	Healthy= Yes	astigmatic = yes	1=1[1]
V2-Rule 0-Lens=None								X
V2-Rule 1 Lens=Soft			X		X	X	X	X
V2-Rule 2 Lens=Hard	X	X			X		X	X
V2-Rule 3 Lens=RGP	X	X		X	X	X	X	X

Tables 1 and 2 can be viewed as two different viewpoints or sources of expertise. As shown in Fig. 1 we can generate an ontology in the form of a concept lattice using FCA. Thus we can view the merging of Tables 1 and 2 as the merging of two ontologies. To achieve this we can simply combine the two formal contexts and regenerate the lattice. Fig. 2 has been developed in a newer tool, known as ConExp[3]. The reading of concepts in ConExp is the same as in our system in Fig. 1 however, the nodes are colour coded where a non-white upper semicircle indicates an attribute attached to the concept, and a black lower semicircle indicates an object attached to the concept. The two viewpoints can be distinguished by the object label: the original viewpoint does not indicate which viewpoint it belongs to, the concepts belonging to the more recent viewpoint have objects labels starting with V2.

From Fig. 2 we see that there is now an inconsistency in that soft lens are appropriate if the patient is astigmatic (Viewpoint 2/Rule 1:V2-R1:SoftLens) but also that soft lens are appropriate if the person is not astigmatic (R1:SoftLens). Either the condition is no longer important for prescribing or choosing which lens is appropriate or the rules shown are incorrect. Perhaps R1 is no longer true, or perhaps V2-R1 needs to be further qualified to state that only Toric soft lenses are appropriate for astigmatic patients. As I am not an optician, I can not answer this question. There are further questions prompted by Fig. 2 that I would like to ask an optician, or to investigate myself through review of the literature, such as whether normal tear production is still a (pre)condition of prescribing any contact lens as appeared to be the situation from Cendrowska's dataset. Clearly the ontology opens up a communication channel for a novice such as myself to explore the domain further with or without a domain expert's assistance and also a means of assisting the domain expert to think about and articulate their knowledge about the domain.

The approach offered here is a human in the loop approach where the goal of the approach is to allow identification of similarities and differences between sources to be highlighted and reconciled via discussion. In a number of projects, we have extended the ontology merging process with a number of reconciliation strategies that assist in identifying if two concepts are in a state of contrast, correspondence, conflict or consensus and a means to identify the degree of consensus between two or more ontologies. See [3, 29, 30] for details. A more automated approach to bottom-up ontology merging can be achieved with the FCA-MERGE technique [36].

[3] http://www.sourceforge.net/projects/conexp

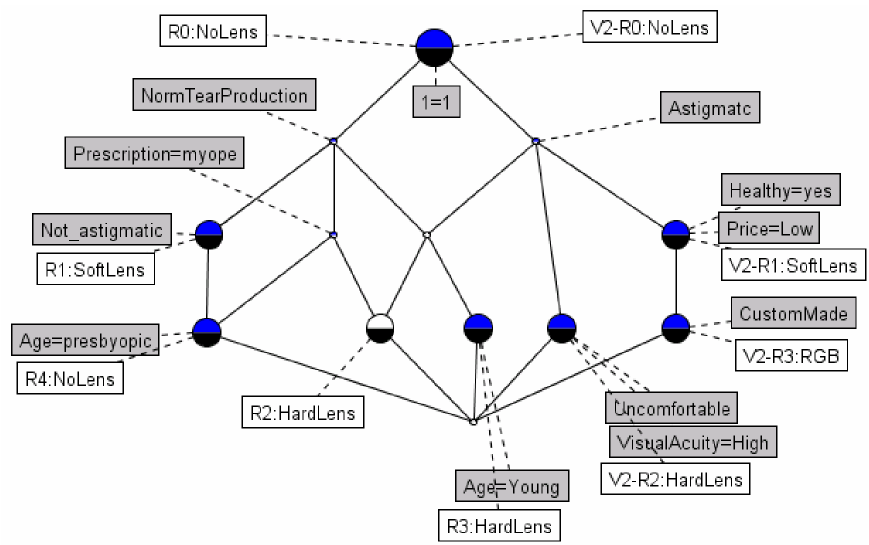

Fig. 2. The Diagram Screen in ConExp which shows the Concept Lattice for the Formal Contexts in Tables 1 and 2

3 Applications of Adhoc and Personal Ontologies

Common ontologies seek to provide a reusable library of concepts. Adequate time and effort needs to be taken to get the concepts right, define the terms, relationships, axioms and so on. The approach to development is typically top-down. FCA however allows us to work from bottom up, with minimal modeling of the domain beyond the creation of a crosstable containing objects and attributes. As demonstrated in the previous section, what is modeled as an object or an attribute can vary according to the input or questions to be explored. Table 3 provides a summary of a number of projects that have used FCA derived ontologies using input other than conventional cases for a range of different purposes. In each of the projects, the interplay of FCA and ontologies has provided a learning technique, allowed analysis and navigation of the derived ontology and the ontology has enhanced the FCA application [10]. The list of projects is far from exhaustive but gives a taste of the possibilities.

Elsewhere discussion can be found on the nature of the ontology developed using FCA (e.g. [10, 19]) together with a comparison of other techniques for ontology development (e.g. [32]). The purpose of this paper is to consider the role and value of using a domain and/or individual specific ontology as a communication channel, or alternatively, a mediating or temporary representation.

Whether FCA is used to compare rules in a knowledge base, use case descriptions or documents, the approach allows and encourages individuals to express themselves using their own terms and on their own without the interference and restrictions associated with group thinking. This has the benefit of increased engagement with the

Table 3. Generation of ontologies using FCA from non-standard cases

Project/Domain	Purpose of Ontology	Input	Reference
Treat Anorexia Nervosa Patients	Understand the individual patient	Personal construct and survey data	[37]
Web analysis and visualisation environment (WAVE)	Visualise Web pages	Web pages	[2]
Management of the Lotus Crop	1. The evolution and management of emerging knowledge 2. Combination of multiple KB	Rules from multiple MCRDR KB	[34]
Igneous Rock Classification	Reconcile multiple sources of knowledge	Laddered grids, structured interviews, protocol analysis and card sorts	[31]
Igneous Rock Classification	Build an initial model to provide initial domain understanding	Card sorts	[13]
The retrieval of web-based documents	Develop personal ontology to make retrieval more customized to the user	User defined categories	[24]
Requirements Engineering	1. Reconciliation of stakeholder viewpoints. 2. More complete use case description	Use case descriptions	[3, 32]
Software Engineering	Validation of models	Software Specifications	[39]
The retrieval of web-based documents	Structure key words, structure relevant documents	Key words, web documents	[8, 9, 25]
Pathology	Discovery of higher level knowledge and patterns	Knowledge bases	[35]
Travel Text Corpus	Merging Ontologies	Web Documents	[38]
Tacit Knowledge Measurement	Compare Responses to Scenarios in a Tacit Knowledge Inventory	Survey Data	[4]
Scientific Knowledge Management	Analyse the value of FCA in knowledge technologies and ontology building	Lists of PC Members, session topics, publications, entity relational data model	[19]

task and ownership of the knowledge. This becomes even more important when the goal is to build a shared model. By starting with separate sources each group member owns and defends a viewpoint to provide a truly representative and more complete final model. Just as a prototype developed with a 4GL may not give the developer as much freedom and control over the application developed at they might like, the end user can see results sooner and may even be able to use the 4GL to develop the system themselves. As in software engineering, knowledge and ontology engineering may benefit from simpler and user-definable languages, but perhaps with the tradeoff of expressivity. However, creating more expressive ontology languages does not necessarily result in humans being better able to express themselves as the learning curve and structure is usually greater and more complex.

Another plus is the use of the concept lattice for diagrammatic reasoning. For example, our evaluation studies showed that participants were able to identify similarities and differences between viewpoints more quickly and accurately than when presented with the same information in its original textual format [29, 31].

The FCA notion of a concept is compatible, though differences usually exist, with other concept processing approaches. Many of the projects combined FCA with other techniques such as language technology [3, 11, 30, 31], information retrieval [8, 9], Description Logics [29], Conceptual Graphs [41] and Knowledge Based Systems [33]. In the study by Spangenberg and Wolf [37] FCA was combined with the use of Personal Construct Psychology [22] and survey techniques. That study used the repertory grid approach to elicit the responses of anorexia nervosa patients to various people in their lives based on a number of bipolar scales. The goal of that work was to assist the physician to identify the issues faced by the individual patient and did not seek to determine a shared view across patients, which would have been irrelevant in this context, unless of course the patients were related to one another. This early work demonstrated the value of the FCA lattice to provide a personal ontology. To require these patients or the doctor to follow more conventional ontology building processes, typically requiring the assistance of a knowledge engineer, would be out of the question. The physician would probably be unwilling to undergo the special training needed and the presence of a knowledge engineer would interfere with the elicitation process and breach patient-doctor confidentiality.

4 Discussion and Conclusion

We note that there is some conflict between the goal of ontologies and their actual usage. Some have argued that Gruber's definition has led to a view that ontology is :

> " 'a model' where what is being modeled are the concepts or ideas people have in their minds. This reductive error has its roots in the recent tendency to use the word 'ontology' to mean little more than a controlled vocabulary with hierarchical organization"[4].

When one remembers that ontologies are concerned with the nature of being and the world, the focus on what is in people's heads or the words they use fits more with linguistics, psychology or epistemology rather than metaphysics.

We also note that the goal to create large-scale common ontologies sought to address the KA bottleneck by providing guidance and allowing sharing and reuse. However, it is unclear whether ontology engineering has simply moved the bottleneck higher and earlier in the KA process. Also the desire to share and reuse has led to the need for strategies for merging and reconciliation.

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[4] http://ontologyworks.com/what_is_ontology.php

Currently, ontologies are seen to play a pivotal role in the Semantic Web, together with semantic markup languages. However, the effort involved in the two-step authoring and annotation process in a formalism such as OIL and/or RDF "tends to reintroduce the impulse to set up the 'right' ontologies in advance. This seems contrary to letting 'anyone say anything' [2] or, perhaps, it simply raises the burden of generating Semantic Web content to an inhibitory level" [20]. To address this issue, Kalyanpur et al [20] offer the Semantic Markup Ontology and RDF Editor (SMORE) to support adhoc ontology use, modification, combination and extension. However, what SMORE attempts to achieve is a more seamless environment which merges and simplifies authoring and annotation. The approach allows adhoc use of ontologies, not to be confused with the use of adhoc ontologies as addressed in this paper. However, similar to SMORE, we seek to offer a practical approach.

Bennett and Theodoulidis [1] have investigated the notion of personal ontology and its relationship to organizational ontology and knowledge. They see that a personal ontology is the outcome of personal world experiences leading to personal knowledge that forms a personal ontology. When individuals begin to share their ontologies and agree on meanings, organizational ontologies begin to emerge. In contrast to the flow from experience to knowledge to ontology for the individual, at the organizational level, once an organizational ontology exists, organizational knowledge can emerge resulting in experiences at the organizational level which feed back into personal experiences. If such a cycle does exist, it may be necessary to ensure that approaches for engineering common, upper or reference ontologies support the ongoing development, sharing and integration of personal ontologies.

Despite its various shortcomings, the Waterfall system development life cycle is still the main development method used in many organizations. In practice the method is often modified to include incremental and iterative cycles within and between certain phases. Likewise, common ontologies, such as CYC or WordNet are in widespread use and are often used in conjunction with domain specific and sometimes personal ontologies. The use of FCA to rapidly develop domain and personal ontologies offers many parallels to agile software development in that the technique is incremental, rapid, collaborative and the development cycle is essentially test-first driven producing prototypes (adhoc ontologies) for exploring domain or individual-specific concepts. Using FCA to automatically generate an ontology from whatever source can be mapped to a crosstable with minimal effort, becomes attractive particularly where the ontology or domain itself is volatile and/or temporary.

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Relating Business Process Models to Goal-Oriented Requirements Models in KAOS

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Abstract. Business Process Management (BPM) has many anticipated benefits including accelerated process improvement, at the operational level, with the use of highly configurable and adaptive "process aware" information systems [1] [2]. The facility for improved *agility* fosters the need for continual *measurement* and *control* of business processes to assess and manage their effective evolution, in-line with organizational objectives. This paper proposes the GoalBPM methodology for relating business process models (modeled using BPMN) to high-level stakeholder goals (modeled using KAOS). We propose informal (manual) techniques (with likely future formalism) for establishing and verifying this relationship, even in dynamic environments where essential alterations to organizational goals and/or process constantly emerge.

1 Introduction

agility

control *trace*

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satisfaction

2 Business Process Modeling with BPMN

Business Process

flow objects *events* *activities*
decisions **connecting objects** *control flow links*
message flow links **swim lanes**
pools *lanes*

message flow links
activities *pools*
lanes
start event
Control flow links
decision gateway

end event

3 Goal-Oriented Requirements Engineering with KAOS

Goal Declaration in KAOS. *Achieve MeetingScheduled* *strategic* *refined* *operational*

Goal Definition in KAOS.

concerns *satisfy*

$\Rightarrow op$

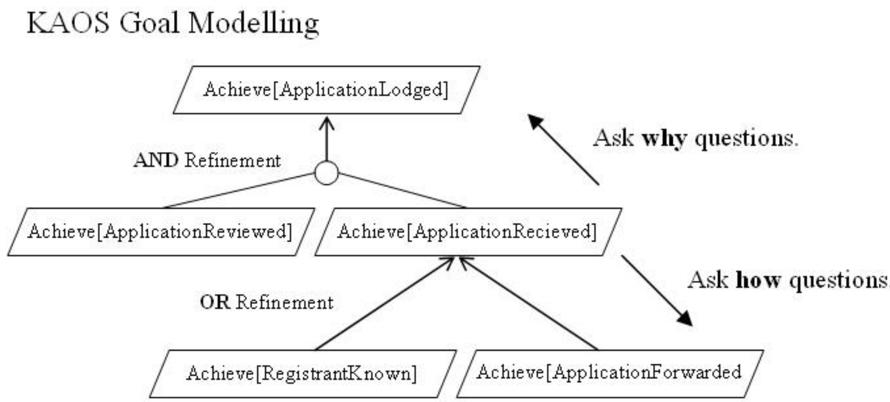

Fig. 1. Modeling goals in KAOS

op *some* $\diamond$ *all* $\square$

Goal
InformalDef
FormalDef $\forall$
$\Rightarrow \diamond$

attributes

Patterns for Declaring and Defining Goals.

Achieve Goals $C \Rightarrow \diamond T$

Cease Goals $C \Rightarrow \diamond - T$

Maintain Goals $C \Rightarrow \square T$

Avoid Goals $C \Rightarrow \square - T$

4 Linking Goal and Process Models

traceability links

satisfaction links

obstructs

customer that has submit a registration form

all new customer registrations

satisfaction link

- *Normative satisfaction links:* *must*
- *Descriptive satisfaction links:*

5 Using Model Annotations to Verify Goal Satisfaction

effect annotations

critical trajectories

descriptive

goal model update *process model update*

state-oriented

agent-oriented *workflow*

5.1 Effect Annotations

process activity

effect

effect annotation

cause

[illegible]

[illegible] *effect annotation* [illegible]

– *label* [illegible]
– *designation* [illegible]
– *informal definition* [illegible]
– *formal definition* [illegible] $\forall$ [illegible] $\exists$ [illegible]

[illegible]

5.2 Trajectory Decomposition

[illegible] *process trajectories* [illegible]

[illegible]

normal *exceptional*

5.3 Goal Satisfaction and Cumulative Effect Assessment

normal *exceptional*

strong *weak* *unsatisfied* *strong*

weak

unsatisfied

6 Example

[illegible]

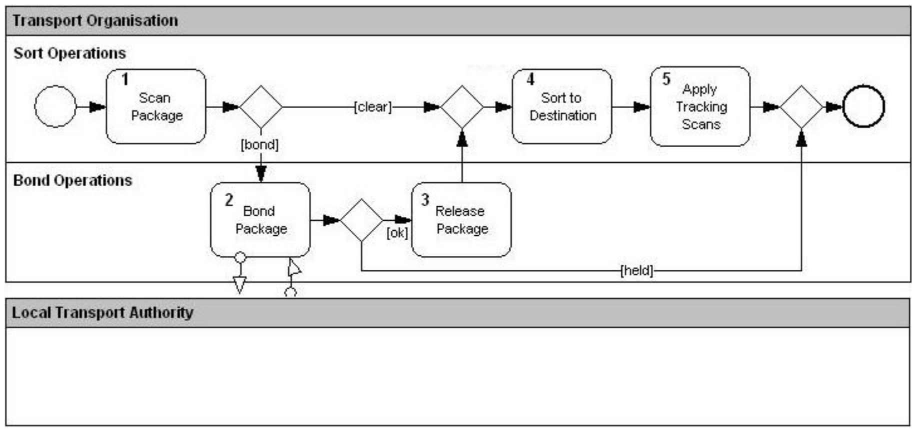

Fig. 2. The 'Package Sorting' Process of the Transport Organization

6.1 Current Business Context and Process

[illegible] *packages* [illegible] *sorting facility* [illegible] *Transport Organization* [illegible] *Customers* [illegible] *Transport Authorities* [illegible]

[illegible]

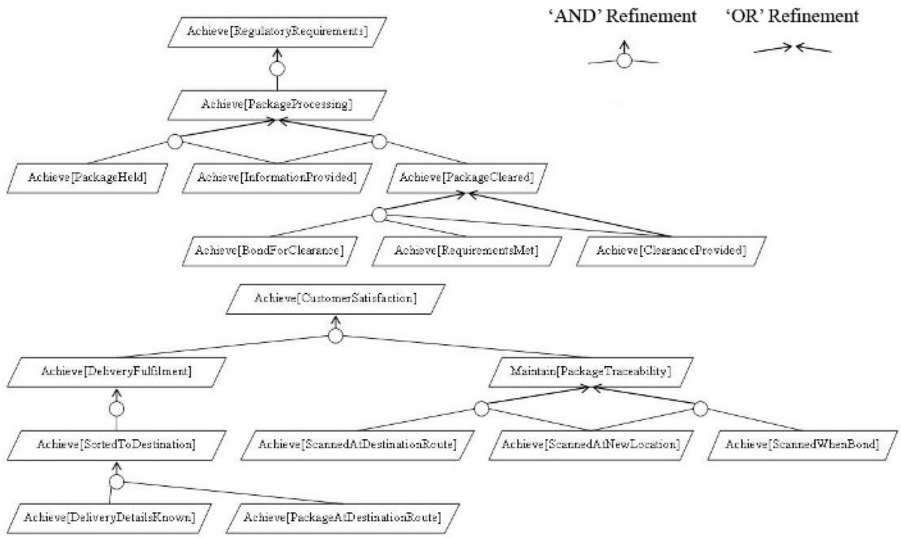

Fig. 3. Goals Traceable to the 'Package Sorting' Process

Goal Type	Goal Declaration	Concerned Objects	Antecedent	Consequent
Achieve	PackageProcessing	Package, SortFacility, TransportAuthority	Arrives(p, sf)	<>Processed(p, ta)
Achieve	InformationProvided	Package, SortFacility, TransportAuthority	Arrives(p, sf)	<>Provided(p.DeliveryDetails, ta)
Achieve	PackageCleared	Package, TransportAuthority	Provided(p.DeliveryDetails, ta)	<>Cleared(p, ta)
Achieve	PackageHeld	Package, TransportAuthority	Provided(p.DeliveryDetails, ta)	<>Held(p, ta)
Achieve	BondForClearance	Package, SortFacility, TransportAuthority	Provided(p.DeliveryDetails, ta)	<>Bond(p, sf) *W* Passed(p, ta.Requirements)
Achieve	RequirementsMet	Package, SortFacility TransportAuthority	Bond(p, sf)	<>Passed(p, ta.Requirements)
Achieve	ClearanceProvided	Package, TransportAuthority	Provided(p.DeliveryDetails, ta) ^ Passed(p, ta.Requirements	<>Cleared(p, ta)
Achieve	DeliveryFulfillment	Package, SortFacility, Customer	Arrives(p, sf)	<>Delivered(p, c)
Achieve	SortedToDestination	Package, SortFacility	Arrives(p, sf)	<>Sorted(p, p.Destination)
Achieve	DeliveryDetailsKnown	Package, SortFacility	Arrives(p, sf)	<>Known(p.DeliveryDetails, sf)
Achieve	PackageAtDestinationRoute	Package, TransportAuthority	Known(p.DeliveryDetails, sf)	<>Sorted(p, p.Destination)
Achieve	ScannedAtNewLocation	Package, SortFacility	Arrives(p, sf)	<>Scanned(p, sf)
Achieve	ScannedAtDestinationRoute	Package, SortFacility	Sorted(p, p.Destination)	<>Scanned(p, sf)
Achieve	ScannedWhenBond	Package, SortFacility, TransportAuthority	Bond(p, sf)	<>Scanned(p, sf)

Fig. 4. Definitions for Traceable 'Package Sorting' Goals

6.2 Applying GoalBPM

[illegible] *Arrives(p, sf)* [illegible] *PackageArrivesAtTheSortFacility* [illegible]

Analyzing Traceability. [illegible] *pre* [illegible] *post* [illegible] *Pre* [illegible]

#	Activity	Effect Annotation
	Pre Conditions	*Arrives(p, sf) AND Provided(p.DeliveryDetails, ta)*
	Possible Effects	*Passed(p, ta.Requirements) AND Cleared(p, ta)*
1	Scan Package	Known(p.DeliveryDetails, sf) AND Scanned(p, sf)
2	Bond Package	Bond(p, ta) AND Scanned(p, sf)
		Bond(p, ta) AND Scanned(p, sf) AND Held(p, ta)
3	Release Package	Passed(p, ta.Requirements) AND Cleared(p, ta)
4	Sort to Destination	Sorted(p, p.Destination)
5	Apply Tracking Scans	Scanned(p, sf)

T#	A#	Cumulative Effect Assessment
1	0	Arrives(p, sf) AND Provided(p.DeliveryDetails, ta) AND Passed(p, ta.Requirements) AND Cleared(p, ta)
	1	Known(p.DeliveryDetails, sf) AND Scanned(p, sf)
	4	Sorted(p, p.Destination)
	5	Scanned(p, sf)
2	0	Arrives(p, sf) AND Provided(p.DeliveryDetails, ta)
	1	Known(p.DeliveryDetails, sf) AND Scanned(p, sf)
	2	Bond(p, ta) AND Scanned(p, sf) AND Held(p, ta)
3	0	Arrives(p, sf) AND Provided(p.DeliveryDetails, ta)
	1	Known(p.DeliveryDetails, sf) AND Scanned(p, sf)
	2	Bond(p, ta) AND Scanned(p, sf)
	3	Passed(p, ta.Requirements) AND Cleared(p, ta)
	4	Sorted(p, p.Destination)
	5	Scanned(p, sf)

T#	A#	Goal Satisfaction
1	Pre	InformationProvided
		PackageCleared
		ClearanceProvided
	1	DeliveryDetailsKnown
		ScannedAtNewLocation
	4	PackageAtDestinationRoute
		SortedToDestination
	5	ScannedAtDestinationRoute
2	Pre	InformationProvided
	1	DeliveryDetailsKnown
		ScannedAtNewLocation
	2	PackageHeld
		ScannedWhenBond
3	Pre	InformationProvided
	1	DeliveryDetailsKnown
		ScannedAtNewLocation
	2	ScannedWhenBond
	3	PackageCleared
		RequirementsMet
		ClearanceProvided
	4	SortedToDestination
		PackageAtDestinationRoute
	5	ScannedAtDestinationRoute

Fig. 5. Tabulated Effect Annotation, Trajectory Decomposition, and Goal Satisfaction

[illegible] *Post* [illegible]

[illegible]

Effect Annotation. [illegible]

[illegible] *arrival of packages to the sort facility* [illegible] *provision of package information to transport authorities* [illegible] *clearance of packages for delivery* [illegible]

[illegible] *Scanning a package* [illegible] *delivery details being known* [illegible] *bonded for clearance* [illegible] *scan* [illegible] *held* [illegible] *passing of transport authority requirements* ... *clearance* ... *package being sorted to its destination* ... *scanning* ...

Trajectory Decomposition. ...

... *prior clearance of a package* ... *sorting of the package* ... *bonding prior to clearance* ... *held by the transport authority* ... *requiring the package to be bonded* ... *cleared by passing the authorities requirements* ... *sorted* ... *scanned at its destination*

Satisfaction Analysis. ...

... *weak* ...

6.3 Changes to the Goal Model

...

Goal Alterations. ... *desirability* ... *temporal ordering* ...

all packages be screened by the transport authority once they arrive at a sort facility

$$\forall \quad \Rightarrow \Diamond$$

Screened(p, ta) *PackageHeld* *PackageCleared*

Process Implications and Evolution. *achievement* *coordination*

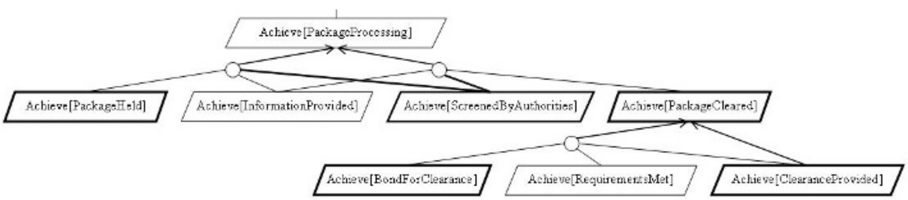

Fig. 6. Goal Model Additions for Screening Requirements

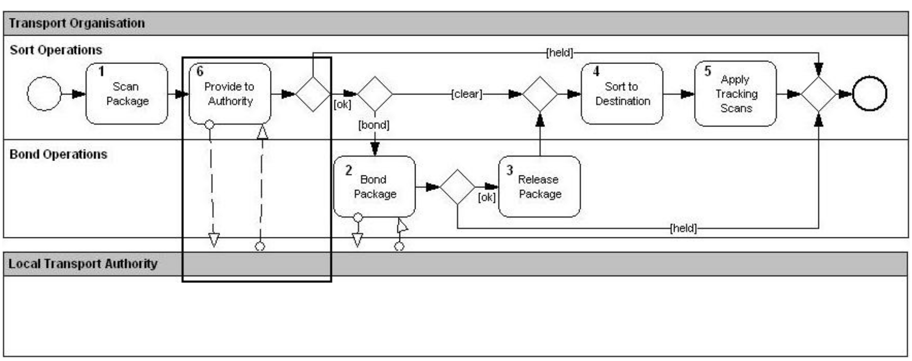

Fig. 7. Process Evolution to Achieve Goal Satisfaction

Screened(p, ta)

Screened(p, ta)

Held(p, ta)

7 Conclusion

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Heuristic and Rule-Based Knowledge Acquisition: Classification of Numeral Strings in Text

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Abstract. This paper describes the rule-based classification of numerals and strings that include numerals, composed of a number and semantic unit(s) that indicate a SPEED, NUMBER, or other measure, at three levels: morphological, syntactic, and semantic. The approach employs three interpretation processes: word trigram construction with tokeniser, rule-based processing of number strings, and n-gram based classification. We extracted numeral strings from 378 online newspaper articles, finding that, on average, they comprised about 2.2% of the words in the articles. To manually extract n-gram rules to disambiguate the number strings' meanings, our approach was trained on 886 numeral strings and tested on the remaining 3251 strings. We implemented two heuristic disambiguation methods based on each category's frequency statistics collected from the sample data, and precision ratios of both methods were 86.8% and 86.3% respectively. This paper focuses on the acquisition and performance of different types of rules applied to numeral strings classification.

1 Introduction

Most efforts directed towards understanding natural language in text focus on sequences of alphabetical character strings. However, the text may include different types of data such as numeric (e.g. "25 players") - or alpha-numeric (e.g. "25km/h") - with/without special symbols (e.g. "$2.5 million") [5]. In current natural language processing (NLP) systems, such strings are treated as either a numeral (e.g. "25 players") or as a named entity (NE e.g. "$2.5 million") at the lexical level. However, ambiguity of semantic/syntactic interpretation can arise for such strings at the lexical level only: for example, the number "21" in the phrase "he turns 21 today" can on the surface be interpreted as any of the following: (a) as a numeral of NP (noun phrase) – indicating NUMBER; (b) as a numeral of NP – indicating the DAY of a date expression; or (c) as a numeral of NP – indicating AGE at the lexical meaning level. This type of numeral string is called a *separate numeral string* (e.g. the quantity in "survey of *801* voters") in this paper. Some numeral strings would not be ambiguous because of their meaningful units, and they are referred to as *affixed numeral strings* (e.g. speed in "his serve of *240km/h*").

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In the case of separate numeral strings, some structural patterns (e.g. DATE) or syntactic functional relationships (e.g. QUANTITY as either a modifier or a head noun) could be useful in their interpretation. However, affixed numeral strings require the understanding of some meaningful units such as SPEED ("km/h" in "250km/h"), LENGTH ("m" in "a 10m yacht"), and DAY_TIME ("am", "pm" in "9:30pm").

Past research has rarely studied the understanding of varieties of numeral strings. Semantic categories have been used for named entity recognition (e.g. date, time, money, percent etc.) [7] and for a Chinese semantic classification system [13]. Semantic tags (e.g. date, money, percent, and time) and a character tokeniser to identify semantic units [1] were applied to interpret limited types of numeral strings. Numeral classifiers to interpret money and temperature in Japanese [11] have also been studied. The ICE-GB grammar [8] treated numerals as one of cardinal, ordinal, fraction, hyphenated, multiplier with two number features - singular and plural.

Polanyi and van den Berg [9] studied anaphoric resolution of quantifiers and cardinals and employed quantifier logic framework. Zhou and Su [14] employed an HMM-based chunk tagger to recognise and classify names, times, and numerical quantities with 11 surface sub-features and 4 semantic features like FourDigitNum (e.g. 1990) as a year form, and SuffixTime (e.g. a.m.) as a time suffix (see also [3] and [10] for time phrases in weather forecasts). FACILE [2] in MUC used a rule-based named entity recognition system incorporating a chart-parsing technique and semantic categories such as PERSON, ORGANISATION, DATE, and TIME.

We have implemented a numeral interpretation system that incorporates word trigram construction using a tokeniser, rule-based processing of number strings, and n-gram based disambiguation of classification (e.g. a word trigram - left and right strings of a numeral string). The rule-based number processing system analyses each number string morpho-syntactically in terms of its type. In the case of a separate numeral string, its assumed categories are produced at the lexical level. For example, "20" would be QUANT, DAY, or NUMBER at the lexical level. However, affixed numeral strings require rule-based processing based on morphological analysis because the string has its own meaningful semantic affixes (e.g. speed unit in "24km/h"). In this paper, the different types of rule needed to classify numeral strings are described in detail.

In the next section, the categories and rules used in this system are described. In section 3, we describe the understanding process for both separate and affixed numeral strings in more detail, and focus on classification rules. Section 4 describes preliminary experimental results obtained with this approach, and discussion and conclusions follow.

2 Syntactic-Semantic Categories and Rules

In this section, semantic and syntactic categories and rules (i.e. context-free rules used for affixed numeral strings) used to parse numeral strings in real text are described.

This system uses both syntactic and semantic categories to understand separate and affixed numeral strings, because a numeral string such as "20" (i.e. separate numeral string) can be understood by itself (as in "20 pages") or with reference to a structural relationship to adjacent strings (as in "on September 20 2003"). The separate numeral string “20” in “20 pages” can be interpreted as a QUANTITY to modify the noun “pages”. However, knowledge of the specific DATE representation (structural relationships between adjacent strings) in “on September 20 2003” is needed to understand “20” as DAY. This requirement is even more evident with “7/12/2003” which can mean July 12, 2003 (US) or 7 December, 2003 (e.g. in Australia and New Zealand). Thus semantic categories including DAY, MONTH, and YEAR are used for date representation.

We use 40 syntactic and semantic categories, including specific semantic categories for some numeral strings (e.g. semantic categories (e.g. MONEY, DATE) and syntactic categories – (e.g. NUMBER, FLOATNUMBER, FMNUMBER) – Table 1). For example, the category FMNUMBER (ForMatted Number) signals numbers that frequently include commas every 3 digits to the left of the unit digit for ease of reading, as in “*5,000* peacekeepers.”

Table 1. Sample categories and their examples

Category	Example in Real World Text
Age	“mature *20-year-old* contender”, “he turns *21* today”
Date	“*20.08.2003*”
Day	“August *11* 2005”
Daytime	“between *9:30am* and *2am*”, “at *3* o'clock”
Floatnumber	“support at *26.8* per cent”
FMnumber	“took command of *5,000* peacekeepers”
Length	"a *10m* yacht"
Money	“spend *US$1.4* billion”
Name	“Brent crude *LCOc1*”
Number	“*8000* of the Asian plants”
Ordinal	“a cake for her *18th* birthday”
Plural	“putting a *43-man* squad”
Phone-Number	“ph: (09) 917 1234”
Quant	“survey of *801* voters”
Range	“for *20-30* minutes”
Scores	“a narrow *3-6* away loss to Otago”
Speed	“His serve of *240km/h* this season”
Street-Number	“Address: *123* Moutain rd Mt. Eden”
Temperature	“temperatures still above *40C*”
Year	“by September *2026*”

There are two types of dictionaries in our system: one for normal English words with syntactic information such as lexical category, number, and verb’s inflectional form. The other dictionary (called the user-defined dictionary) includes symbol tokens (e.g. “(“, “)”) and units (e.g. “km”, “m”). For example, the lexical information for “km” is (:POS (Part of Speech) LU (Length Unit)) with its meaning KILOMETER.

The system uses 64 context-free rules to represent the structural form of affixed numeral strings. Each rule describes relationships between syntactic/semantic categories of the components (e.g. a character or a few characters and a number) produced by morphological analysis of the affixed string. Each rule is composed of a LHS (left hand side), RHS (right hand side), and constraints on the RHS (e.g. DATE → (DAY

DOT MONTH DOT YEAR), Constraints: ((LEAPDATEP DAY MONTH YEAR))). The interpretation rules are discussed in the next section in detail.

3 Numeral String Classification

The numeral string interpretation algorithm is composed of three processes: a morphological analysis module, a rule-based interpretation module, called ENUMS (English NUMber understanding System), which employs both a CFG (Context-Free Grammar) augmented by constraints and a parser, and a category disambiguation module to select the best category of an ambiguous numeral string by using word trigrams.

3.1 Morphological Analysis of Numeral Strings

Affixed numeral strings such as “240km/h serve” and “a 10m yacht” require knowledge of their expression formats (e.g. speed → number + distance-unit + slash + time-unit) for understanding. For example, the string “240km/h” is analysed morphologically into “240” + “km” + “/” + “h”. Our morphological analyser considers embedded punctuation and special symbols. In the case of the string “45-year-old”, the morphological analyser separates it into “45” + “-” + “year” + “-” + “old”. Thus we use the term, morphological analysis, rather than tokenisation because each analysed symbol is meaningful in numeral string interpretation. Table 2 shows some more results from the morphological analyser.

Table 2. Examples of morphological analysis of numeral strings

Category	Example	Morphological Analysis
MONEY	“($12.56)”	“(“ + “$” + “12” + “.” + “56” + “)”
DATE	“20.08.2003”	“20” + “.” + “08” + “.” + “2003”
FMNUMBER	“2,000”	“2” + “,” + “000”
SPEED	“240km/h”	“240” + “km” + “/” + “h”
RANGE/SCORES	“20-30”	“20” + “-” + “30”
DAYTIME	“9:30am”	“9” + “:” + “30” + “am”
FLOATNUMBER	“0.03”	“0” + “.” + “03”
CAPACITY	“8.2μmol/L”	“8.2” (“8” + “.” + “2”) + “μmol” + “/” + “L”
PLURAL	“1980s”	“1980” + “s”

After analysing the string, dictionary lookup and a rule-based numeral processing system based on a simple bottom-up chart parsing technique [6] are invoked. Instances that include some special forms of number (e.g. “03” in a time, day), are not stored in the lexicon. Thus if the substring is composed of all digits, then the substring is assigned to several possible numeric lexical categories. For example, if a numeral string “03” is encountered, then the string is assigned to SECOND, MINUTE, HOUR, DAY, MONTH, and BLDNUMBER (signifying digits after a decimal point, e.g. “0.03”). If the numeral string is “13” or higher, then the category cannot be MONTH. Similar rules can be applied to DAY and other categories. However, “13” can clearly be used as a quantifier.

Non-numeral strings are processed by dictionary lookup as mentioned above, and their lexical categories used are necessarily more semantic than in regular parsing. For example, the string “m” has three lexical categories: LU (Length Unit) as a METER (e.g. “a 10m yacht”), MILLION (e.g. “$1.5m”), and TU (Time Unit) as a MINUTE (e.g. “12m 10s” - 12 minutes and 10 seconds).

After morphological processing of substrings, an agenda-based simple bottom-up chart parsing process is applied with 64 context-free rules that are augmented by constraints. If a rule has a constraint, then the constraint is applied when an (inactive) phrasal constituent is created. For example, the rule to process a date of the form “28.03.2003” is DATE → (DAY DOT MONTH DOT YEAR) with the constraint (LEAPYEARP DAY MONTH YEAR), which checks whether the date is valid. An inactive phrasal constituent DATE1 with its RHS, (DAY1 DOT1 MONTH1 DOT2 YEAR1), would be produced and the constraint applied to verify the well-formedness of the inactive constituent.

The well-formedness of DATE (e.g. “08.12.2003”) is verified by evaluating the constraint (LEAPDATEP DAY MONTH YEAR). Some other rules for affixed/separate numeral string interpretation are:

RULE5
LHS: AGE
RHS: (NUMBER HYPHEN NOUN HYPHEN AGETAG) – e.g. “*38-year-old* man”
Constraints: ((INTEGER-NUMBER-P NUMBER) (SEMANTIC-AGE-P NOUN) (SINGULAR-NOUN-P NOUN))

RULE21
LHS: TEMPERATURE
RHS: (NUMBER CELC) – e.g. “*40C*”
Constraints: (INTEGER-NUMBER-P NUMBER)
Where CELC means CELsius-C

RULE22
LHS: RANGE
RHS: (NUMBER HYPHEN NUMBER) – e.g. “*20-30* minutes”
Constraints: (RANGE-P NUMBER NUMBER)

RULE30
LHS: FLOATNUMBER
RHS: (NUMBER DP BLDNUMBER) – e.g. “*20.54* percent”
Constraints: (FLOATNUMBER-P NUMBER DP BLDNUMBER)
where DP means Decimal Point and BLDNUMBER means BeLow-Decimal NUMBER.

RULE42
LHS: WEIGHT
RHS: (NUMBER WU) – e.g. “55kg”
Constraints: NIL.
where WU means Weight Unit.

3.2 Classification Based on Word Trigrams

For separate numeral strings, the interpreted categories can be ambiguous because there is no semantic unit attached. For example, “240km/h” would be uniquely interpreted as SPEED. However, the numeral string “20” could be either QUANT (e.g. “20 boys”) or DAY (e.g. “20 May 2005”) without using different context information. Thus word trigrams are used to disambiguate the syntactic/semantic categories of numeral strings.

Word trigrams are collected when a document is read and tokenised. While tokenising a string (tokenisation based on a single whitespace), the numeral string is identified with its word trigram (left and right string of the numeral string). For example, the numeral string "100" in "The company counts more than 100 million registered users worldwide." has its word trigram ("than" - left wordgram, "million" - right wordgram). If a numeral string occurs at either the start or end of a sentence, then either a left or right wordgram would be empty (i.e. NULL).

Table 3. Examples of feature types

Feature Type	Examples
Lexical Cateogry	Preposition-p: (preposition-p left wordgram ("to")) in "home to 22 superyachts"
Number information	Plural-noun-p: (plural-noun-p right wordgram ("voters")) in "801 voters"
Validity of value	Valid-day-p: (valid-day-p numeral string ("28") right wordgram ("February")) in "28 February 2004" – not "30 February 2004"
Conceptual type	Month-string-p: (month-string-p right wordgram ("February")) in "28 February 2004"
Case of a word	Capital-letter-p: (capital-letter-p left wordgram ("Lee,")) in "Lee, 41, has…"
Punctuation marks	Comma-p: (comma-p left wordgram ("Lee,")) in "Lee, 41, has…"

Disambiguation of categories is based on rules manually encoded by using sample data and each rule is based on morpho-syntactic features of the word trigrams. For example, a punctuation mark like comma is important for disambiguating the AGE category (e.g. "41" in "Lee, 41, has").

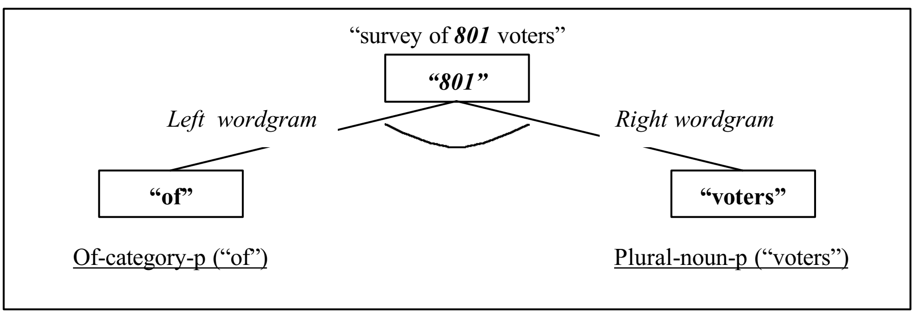

Fig. 1. Contextual constraints based on word trigrams

The features used for selection of the best meaning of an interpreted numeral string are based on syntactic and surface features. These features are joined together to reflect contextual information (e.g. using neighbour words information). The current system uses left and right adjacent words of the numeral string with the following features (Table 3): lexical category (e.g. NOUN, VERB), number information (e.g. PLURAL, SINGULAR), validity of values (e.g. valid DAY), semantic information (e.g. MONTH concept), Case of a letter (e.g. capitalisation), and punctuation marks (e.g. PERIOD, COMMA).

With the features extracted from a numeral string's word trigram, the contextual features of the word trigram are used for the selection of the 'best' category for that numeral string. The contextual information is extracted manually and its form is based on conjunction of the word trigrams features (Fig. 1).

For QUANT category disambiguation, 22 constraints are used. The word trigram (wordgram) for a numeral string "801" in the substring "survey of 801 voters" would be ("of" "801" "voters"). Thus one QUANT selection rule would be:

```
(and (of-category-p left-wordgram ("of"))
     (plural-noun-p right-wordgram ("voters"))).
```

If the numeral string "20" is in the string "March 20 2003", then the category would be DAY and one of four selection rules would be:

```
(and (month-string-p left-wordgram ("March"))
     (valid-day-p "March" "20") - not "March 35"
     (number-p right-wordgram ("2003"))).
```

If a numeral string (e.g. "41" in "Lee, 41, has") satisfies one of three AGE rules, then the numeral string is disambiguated as AGE. The rule is:

```
(and  (capital-letter-p left-wordgram( "Lee"))
      (comma-p left-wordgram ("," in "Lee,"))
      (comma-p numeral-string ("," in "41,")).
```

This rule means that if the word in the left wordgram begins with a capital letter, if the word in the left wordgram has a comma, and if the numeral string has a comma, then the rule applies.

For DAYTIME category (e.g. "on Tuesday (*0030* NZ time Wednesday)"), semantic meanings of word trigrams are used with the numeral string's surface pattern. The rule is:

```
(and   (weekday-string-p left-wordgram)
       (= 4 (length numeral-string))
       (daytime-string-p numeral-string)
       (country-name-p right-wordgram)).
```

For YEAR category (e.g. "end by September *2026*"), heuristic constraints are used as follows:

```
(and  (>= numeral-string 1000)
      (<= numeral-string 2200)).
```

The contextual information based on word trigrams is applied to disambiguate multiple categories resulting from the numeral string interpretation process. Two heuristic methods are implemented to compare their results:

- Heuristic Method 1 (Method-1) – Method 1 applies wordgram constraints and collects and then considers all satisfied constraints. For example, if the QUANT and NUMBER constraints for a numeral string are satisfied, then the two categories are used for the numeral's disambiguation. With collected categories, the annotation frequency of the categories collected from sample data (i.e. Sample data in Table 4) is used to select the best category. If the frequency of QUANT is greater than that of NUMBER in annotation statistics, then QUANT is selected for the category of the numeral string from the meanings processed by a numeral string interpretation system. If a constraint for AGE category is satisfied, then a new category, AGE, is produced because the numeral string interpretation system could not produce the category. If there is no category that satisfies the constraints, then preference rules with ordered categories based on frequency of annotation (e.g. QUANT > MONEY > DATE > etc.) are applied to select the best category.

- Heuristic Method 2 (Method-2) – Method 2 is similar to Method-1 except for the application of annotation statistics. To select the best category for an ambiguous numeral string, the rareness of annotation statistics is applied. If both YEAR and QUANT constraints are satisfied, and the annotation frequency of YEAR is less that that of QUANT, then YEAR is selected for the category of the numeral string. If there is no category that satisfies the constraints, then preference rules with ordered categories based on rareness of annotation statistics (e.g. DATE < MONEY < YEAR < etc.) are applied to select a category.

4 Experimental Results

We implemented our system in Allegro common lisp with IDE. We collected 9 sets of online newspaper articles and used 91 articles (sample data) to build disambiguation rules for the categories of numeral strings. The remaining 287 articles (test data) were used to test the system. Among the 48498 words in the 91 sets of sample data, 886 numeral strings (1.8% of total strings and 10 numeral strings out of 533 strings for each article on average) were found. In the case of the test data, 3251 out of 144030 words (2.2% of total strings and 11 numeral strings of 502 strings for each article on average) were identified as numeral strings (Table 4).

Table 4. Data size and proportion of numeral strings

Date Name	Total Articles	Total Strings	Total Numerals	Remark
Sample	91	48498	886 (1.8%)	2 sets
Test	287	144030	3251 (2.3%)	7 sets
Total	378	192528	4137 (2.1%)	-

The proportion of numeral strings belonging to each category in both sample and test data were QUANT (826 of 3251, 20.0%, e.g. "survey of *801* voters"), MONEY (727, 17.6%, e.g. "\$15m", "\$2.55"), DATE (380, 9.2%, e.g. "02.12.2003"), YEAR (378, 9.1%, e.g. "in 2003"), NUMBER (300, 7.3%, e.g. "300 of the Asian plants"), SCORES (224, 5.4%, e.g. "won 25 - 11"), FLOATNUMBER (8.0%, e.g. "12.5 per cent"), and others in order.

Table 5 shows the recall/precision/F-measure ratios (balanced F-measurement) based on the two disambiguation methods. Method-2 for the test data shows better recall ratio (77.6%) than Method-1. Method-1 for the test data shows better precision ratio (86.8%) than Method-2. However, the difference between Method-1 and Method-2 is 0.5% in recall ratio and 0.5% in precision ratio, indicating that the performance of each method is close to identical.

Table 5. Recall/Precision/F-measurement ratios of two heuristic methods by data set

DateName	Recall Ratio (%)		Precision Ratio (%)		F-measure (%)	
	Method-1	Method-2	Method-1	Method-2	Method-1	Method-2
Sample	86.0	86.6	95.3	93.4	90.2	89.8
Test	77.1	77.6	86.8	86.3	81.7	81.7
Average	81.5	82.1	91.1	89.8	85.9	85.8

Table 6 shows the recall/precision/F-measure ratios, of selected categories, based on the two disambiguation methods. The average performance difference between the methods is 0.7% in recall ratio, 0.6% in precision ratio, and 0.1% in F-measurement. The results for affixed numeral strings (e.g. FLOATNUMBER, FMNUMBER, MONEY, RANGE, SCORES) showed large differences in performance (10.3% to 100%) as did the results for separate numeral strings (e.g. AGE, DAY, NUMBER, QUANT, YEAR) (38.2% to 97.5%). The performance of the RANGE category is poor because of numeral strings such as “$US5m-$US7m” and “10am-8pm”. These numeral strings are presently not covered by our CFG (Context-Free Grammar).

Table 6. Recall/Precision/F-measurement ratios of two heuristic methods by categories

Category	Recall Ratio (%)		Precision Ratio (%)		F-measure (%)	
	Method-1	Method-2	Method-1	Method-2	Method-1	Method-2
Age	43.8	43.8	97.5	97.5	60.5	60.5
Day	68.7	69.3	86.8	81.9	76.7	75.1
Number	82.1	91.7	42.4	38.2	55.9	53.9
Quant	83.2	81.3	88.2	97.5	85.6	88.7
Year	86.9	70.0	92.6	87.9	89.6	77.9
Floatnumber	98.6	98.6	96.9	96.9	97.8	97.8
Fmnumber	100	100	98.8	98.8	99.4	99.4
Money	99.2	99.2	99.9	99.9	99.5	99.5
Range	10.3	55.2	66.7	35.6	17.9	43.2
Scores	84.8	74.1	89.2	97.1	87.0	84.1
*Average	74.9	75.6	90.0	89.4	81.8	81.9

(*average is the average of all categories)

Compared to other separate categories, the system interprets the QUANT category better than YEAR and NUMBER because the disambiguation module for QUANT category has more constraints based on wordgram information (i.e. 22 constraints for QUANT, 7 for YEAR, and 6 for NUMBER).

For disambiguation process using Method-1 and Method-2, 2213 (53.5%) of 4137 numeral strings were ambiguous after numeral string interpretation process. Among these, the numbers of satisfied constraints are no constraint (746 – 33.7%), one constraint (1271 – 57.4%), 2 constraints (185 – 8.4%), and three constraints (11 – 0.5%).

5 Discussion and Conclusions

It is not easy to compare our system to other NE (Named Entity) recognition systems directly because the target recognition of named entities is different. Other systems in MUC-7 [2] and CoNLL2003 [4] focused on the general recognition task of named entities including person, location, date, money, and organisation. The systems in MUC-7 and CoNLL2003 were trained and tuned by using the necessary training corpus with document preprocessing (e.g. tagging and machine learning). However, our system is focused on understanding the varieties of numeral strings more deeply and had no training phase. The manually annotated data from sample data (25%) was used for implementation of disambiguation rules. Performance of MUC-7 systems was greater than 90% in precision. Our system correctly interpreted 88.7% of numeral strings.

Further rules and lexical information are required to process more numerals in real world text (see [5]). For better disambiguation, more fine-grained disambiguation modules based on word trigrams would be required. Currently, syntactic categories of both left and right wordgrams of each numeral string are used. The major problem of the use of syntactic category is lexical ambiguity (e.g. "in" is lexically ambiguous as preposition, adverb, and noun). To reduce the ambiguities, more fine-grained surface patterns would be required. In addition, the extension of this system to other data such as biomedical corpora [12] is required to test the overall effectiveness of our approach.

Another research avenue would be the automatic acquisition of constraints for the disambiguation process and the determination of the significance of each feature for the disambiguation process. For example, for the QUANT category, the plural number information of a right wordgram could be more significant than various information in a left wordgram. In addition, the significance of offset (adjacency) of wordgrams to extract more contextual knowledge could be studied for better disambiguation precision for future development.

In conclusion, separate and affixed numeral strings are frequently used in real text. However, there seems to be no system that interprets numeral strings systematically; they are frequently treated as either numerals or nominal entities. In this paper, we have analysed the numeral strings at lexical, syntactic, and semantic levels with some contextual information. The system is composed of a tokeniser with word trigram constructor, numeral string processor which includes a morphological analyser and a simple bottom-up chart parser with context-free rules augmented by constraints, and a disambiguation module based on word trigrams. The numeral string interpretation system successfully interpreted 88.7% of test data. The system could be scaled up to cover more numeral strings by extending the lexicon and rules.

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RFID Tag Based Library Marketing for Improving Patron Services

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Abstract. In this paper, we deal with a method of utilizing RFID tags attached on books and extract tips that are useful for improving library services to their patrons. RFID is an AIDC (Automatic Identification and Data Capture) technology, with which we can automatically collect data how library materials are used and how often. By analyzing such data we are able to acquire knowledge that helps the librarians with better performing their jobs such as which books to collect, how to help their patrons, and so on. We will call such method "in-the-library marketing," because the data deal with how library materials are used by patrons in the library. It is more effective if we also add the data captured from out-of-the-library and integrate them for whole "library marketing." Furthermore, we also illustrate architecture for protecting the patron-related privacy data from leakage, which is another important issue for library marketing.

Keywords: RFID (Radio Frequency Identification), IC Tag, Digital Library, Library Automation and Digitization, Security Issue, Library Marketing.

1 Introduction

Thanks to the rapid progress of ICT (Information and Communication Technology), we are able to access to information much easier and more rapidly than before, so that we can use it for various problem solving in our life. As a social function to help us, or patrons, library should change itself in order to give improved patron services along with the change of social needs. The philosophy underlying this concept is the one proposed by Ranganathan in his Five Laws of Library Science [10]. In this paper we consider two important issues relating such changes: digitization and ubiquitization. These issues are important because they contribute to acquire better knowledge for improving patron services provided by libraries.

Relating to the first issue, it becomes popular that the announcements from a library are put also on its Web pages now. Patrons are able to know its opening hours without giving a call and asking. OPAC (Online Public Access Catalog) service is also provided via Web so that patrons are able to search for books they want to read without going to the library. Some libraries provide digital images of rare materials to public. Increasing number of e-Journals and e-Books are serviced so that patrons can

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browse the original contents at home. Such digital materials are provided on the Web based systems and thus it is easy to automatically collect data of which materials are used and which time they are used. By analyzing these data and acquire knowledge what services are more beneficial than others for patrons, librarians are able to get good tips for improved patron services.

For the second issue, the number of libraries that have installed the RFID (Radio Frequency Identification) tag system [3], which represents ubiquitous technology, is increasing rapidly in these couple of years. In Japan, for example, public libraries are more aggressive than other kinds of libraries. One of the reasons might be that many town libraries have been located in community centers and many towns have been wishing to construct library buildings of its own. It is a good chance for them to install the RFID tag system for efficiency of jobs and improvement of security and patron services.

Considering such changes, it is easy to expect that most of the library materials will be digitized and physical materials, e.g. ordinary books and magazines, will be used supplementary in the far future. Thus we are in the transitional stage from libraries of physical materials to libraries of digital materials. During this transitional period, they are hybrid libraries in which physical and digital materials are coexisting, and the ratio of digital materials is increasing gradually.

One of the most important things we have to do now is to establish a hybrid library system so that libraries can deal with both physical and digital materials in a uniform way and the transition goes seamlessly.

From this point of view, RFID technology is very appropriate for libraries to introduce. RFID is one of the technologies that are called AIDC (Automatic Identification and Data Capture). The AIDC technology gives two big advantages to libraries. First it provides a means of better and more efficient method of managing physical materials. Secondly it provides a means of automatically collect digital data how such physical materials are used. By utilizing such technologies we can easily collect data about which materials are used, when they are used, by whom they are used, and so on. The digitization in the first issue and the digital data collected with AIDC technology provides us with digital data, which are easy to be integrated and thus it is easy to construct a big and comprehensive database (DB) by collecting such whole data. In this way the data about physical materials and digital materials can be treated in a uniform way. Libraries having RFID tag system is also called "u-library (i.e. ubiquitous library)" [5, 8].

Once we have the integrated DB, we are able to extract information and acquire knowledge by applying some datamining (DM) techniques and analyze the data. In the current, i.e. traditional, libraries, the circulation data are virtually the only digital data that could be used for datamining. Thus adding up the new data collected from the digitized services and the one from RFID and acquiring useful knowledge for improving patron services are the new and challenging application field for knowledge acquisition(KA) researchers. Such knowledge is supposed to be used also for revising the ways of services and starting new library services that will be convenient for the patrons of the library. In this paper, we call such new method "in-the-library marketing" [6, 9].

Personalized patron service is very important in the next generation library services. We will call it "My Library" service. In the top page of My Library, patrons login to the service by type their library IDs and passwords. They can get their personal information: for example, which materials they are borrowing and when is the due date of them. They may get some recommended book list among the materials that are just cataloged and on the loaning service.

In order to provide such personalized services, the library needs the profile information of the patrons. The more appropriate information they have it is possible to provide more accurate and more sophisticated services to them. In this point of view, AIDC is again the very important key technology for libraries.

The AIDC technology mostly used in the libraries so far is "barcode." Comparing to the barcode technology, the RFID technology has advantages in a couple of aspects; it is faster to identify the IDs, it can read the data of tags that are located in the invisible places from the readers, e.g. tags attached inside of the books, and recognize multiple IDs, in one action. In this respect, RFID is more appropriate to capture data automatically about change of the status of materials and patrons.

This paper consists of five sections. In the next section, i.e. Section 2, we will briefly explain what the RFID tag system is like and how it is used in the libraries. In Section 3, we will discuss in what way the RFID tags are used for the in-the-library marketing, followed by the security issue in Section 4. Finally in Section 5, we conclude the discussions in this paper.

Throughout this paper, we mainly deal with how to automatically, i.e. easily, collect data that are appropriate for acquiring knowledge that are useful for improving patron services of libraries. This is the very first step of knowledge acquisition system for library marketing.

2 RFID Technology and Its Application to Libraries

In this section we will have a brief view what RFID system is all about and we put special focus on how it is currently used in library applications. First of all we describe what the RFID tag technology is like in Figure 1. The RFID system consists of two components; tags and reader/writers (R/Ws). Tags can communicate with the reader/writers which are located in near distance of the tags.

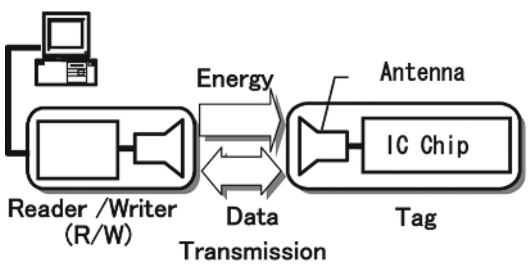

Fig. 1. RFID Tag System (Passive Type)

In Figure 1 the RFID tag at the right-hand side consists of an IC chip and an antenna. It has no batteries and thus cannot run standalone. At the left-hand side is an R/W, which provides energy to the tag. Then the tag gets energy from the R/W with electro-magnetic induction via the antenna. It waits until sufficient energy is charged. When it is ready, it communicates with R/W and exchange data such as its ID and status data by making use of the same antenna. At the backend of the R/W are applications such as databases.

The frequencies used in RFID systems range from about 100kHz up to GHz bands, which is in the ISM (Industrial, Scientific and Medical) bands [3]. The most popularly used frequency among them is 13.56MHz. It is mostly appropriate for applications with medium read distance, i.e. from about 1cm to 1m. Other frequencies such as UHF band and microwave band are also under evaluation. However, at the moment, 13.56MHz is considered to be the most appropriate one for the library application.

The tags described so far are called "passive tags" because they have no batteries and need external energy as is shown in Figure 1. There is another type of tags, which are called "active tags" because they are equipped with batteries and thus they can work without external energy supply. They will emit radio wave off the tag autonomously and the R/Ws receive the radio wave and get the data from the tag. The most important advantage of active tags is that the data transmission distance is much longer, for example about 10m to 20m, then passive tags and thus the security gate becomes more reliable. On the other hand, active tags have disadvantages such as they are thicker, heavier, much more expensive and shorter life span, probably up to a couple of years, than passive ones. However these problems might be overcome in the future and such tags may be widely used together with passive ones in libraries.

Figure 2 is an example that shows how RFID tag is attached on a book (in Chikushi Branch Library of Kyushu University Library [4], Japan). The tag is formed as a label on which the library name is marked together with the university logo. The material ID is also marked in barcode on the label. The barcode is supposed to be used when this material is carried to another library in the ILL (Inter-Library Loan), i.e. for interoperability, and when the tag has going bad and becomes broken, i.e. for insurance.

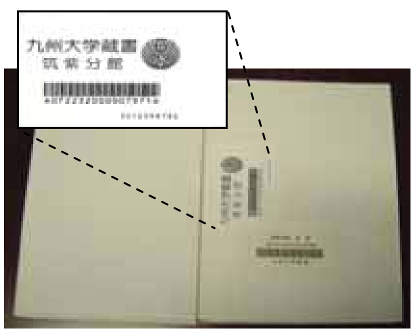

Fig. 2. RFID Tag Attached on a Book

Fig. 3. Self Checkout Machine

The tag is attached on the first leaf of the book next to the cover in this case. It is safer to be damaged than attaching on the outside of the cover. However it is more laborious to read its ID from its barcode label. You open the cover first and read the ID. On the other hand, when we read the ID by the RFID tag we just put the book near the reader without opening the cover.

As is seen in Figure 2, the tag is attached to very close place to the spine of the book. This is because it is more sensitive than attaching it at other place when we make an inventory. We use portable readers and scan the books as they are stored at the bookshelves. The reader is less powerful than the normal desktop type reader and security gate. Thus it is more preferable to arrange the tag close to the reader as possible, i.e. close to the spine.

Comparing to the barcode system which is mostly used now, RFID tag system has an advantage that it is much easier to position materials. As a result self checkout machine is easier to use so that it is good for children and elderly patrons. Figure 3 is an example. A patron is going to put a couple of books on the designated area. Then the machine will display the book IDs, the process ends when the patron pushes the OK button on the touch screen. The list of borrowed books will be printed at the right-hand side printer.

This is another type of advantage of RFID to barcode. It is not only more efficient but also more sophisticated and has much easier user-interface. This is a very important point. So far the dominating reason for the libraries whey they introduce the RFID tag system is that it is more efficient; i.e. it is faster to proceed circulation, it is supposed to have less running cost, and thus the number of librarians needed will be smaller, etc.

Here the most important motivation of introducing RFID tag system is efficiency. We will call it the step 1 of library automation. What will come next for the step 2? It should be effectiveness. By utilizing the RFID tag system we can create new methods not only for efficient but also for giving better, more sophisticated, more advanced services so that customer satisfaction increases. This is what we would like to pursue in library automation.

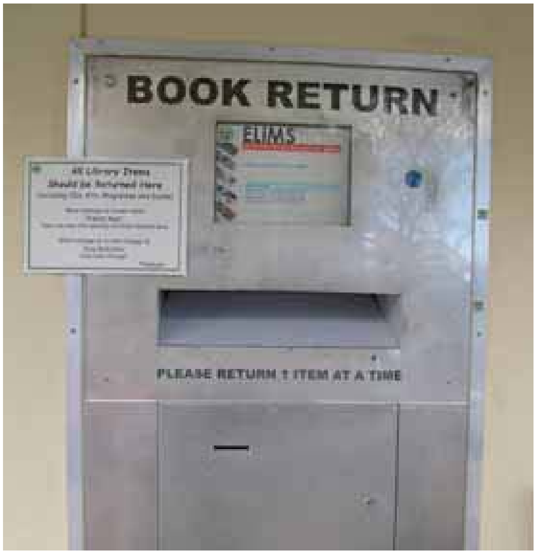

Fig. 4. Self Book Return Machine

Figure 4 shows another example. It is a self book return machine (in Baulkham Hills Library [2], Australia). The patrons are supposed to return their borrowing books by using this machine. Inside of the opening is a lid that is locked normally. You cannot put books inside of the machine. You are supposed to hold the book for a while as you return a book in the opening. Then the R/W installed near the lid reads the ID of the book and check if it an appropriate book for returning or not. The lock is released when the machine recognizes its appropriateness and you can drop the book into the box of the return machine. This is another good example for using RFID technology. It will be very difficult to make such a machine that discriminate the appropriate books from inappropriate ones if you use barcode for recognizing the book ID.

In a Web page of Baulkham Hills Shire Council, they say “This technology gives staff more opportunity to move from behind the desk and focus on value-added, proactive customer service,” which is the most important objective of the step 2 of library automation.

3 In-the-Library Marketing with RFID

As we have pointed out in the previous sections, RFID tag system can be effectively used for automatically capturing data by many R/Ws, by which we are able to acquire knowledge that should be useful for improving library’s patron services and management. Because the RFID tags and R/Ws collaboratively work and the knowledge is acquired from this collaboration, we can model this system based on multi-agent framework [8, 11].

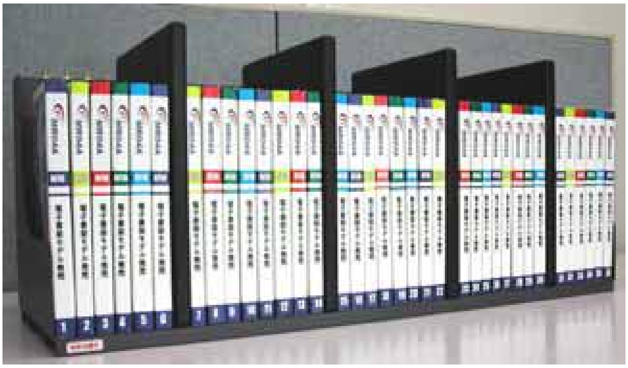

Fig. 5. Intelligent Book Shelf

3.1 Data Collection

An intelligent shelf is a bookshelf which has R/Ws in it so that it can read which books are stored in which shelf. Note that a similar shelf used in retail store is often called smart shelf. Figure 5 is an intelligent bookshelf, in which four antennas are placed like book separators in the bookshelf. The controller activates the antennas one by one and recognizes the book IDs in the active shelf. It also changes the active bookshelves themselves one by one so that one controller can deal with tens of antennas.

Currently the bookshelf R/Ws cannot detect in which part the book is located on a shelf. However if we make this R/W system more sophisticated so that we are able to locate more accurately and eventually to locate exactly where and in what order the books are arranged on a shelf.

By using such bookshelves the library system can detect whenever a book is taken out of the shelf and whenever it is returned on a shelf. For example the library system can make a list of books that were returned on wrong shelves. By using this list librarians are able to relocate such books to their right positions.

Also such data can be used to rank the books according to the frequencies of taking out and returning, which indicate how frequently the books are used in the library. This will give a good tip to librarians when they evaluate their book collection policy.

Currently the intelligent shelf is very expensive though. One example price is one million yen, or about ten thousand US dollars, for one line of bookshelves. It is far too expensive to replace all the bookshelves currently used in libraries. However it is worth considering if we first replace just one or a couple of bookshelves with intelligent shelves and increase the number gradually.

For such purpose one good candidate is the bookshelves for newly registered books and/or for those just returned by a patron. Such books attract patrons' interest and thus they will be used in high frequencies. By analyzing such data, librarians will be helped by the extracted information with choosing new books to be purchased.

Another candidate is, specifically in university libraries, for the books that are designated as subtexts by teachers. These books usually appear in the syllabuses. It is a great benefit for students to read such textbooks in the library.

(a) A Patron Reading a Book on the Table

(b) R/Ws under the Table

Fig. 6. Intelligent Browsing Table

If we use the intelligent shelves for such books, the library can collect the detailed data how these books are used; e.g. for each book when it was taken off the shelf and when it was returned, and maybe who did it.

By collecting and analyzing these data, the library might be able to decide how many volumes of a title to buy according to the data. If a book has little or no usage history, the library can let the teacher who recommended this book know this fact Then. he/she may encourage the students of the class so that they use this textbook more.

Book trucks might be a good choice to use in some situations. In some libraries the books taken out from the ordinary bookshelves are supposed to return on book trucks. If we set shelf readers to the book trucks, the system can get the data when the books are returned to the book trucks.

An intelligent browsing table is a table in a browsing room of the library, which has R/W(s) in it. Figure 6 is an example browsing table experimented in AIREF Library in Fukuoka City, Japan [1]. In this figure a patron is reading a book on the table. He has a couple of books around him (a) and two RFID readers (b) detect them and send the data to their server.

By analyzing the data from the intelligent browsing table(s), librarians are able to obtain information which books are read, how long, how often and others. Such information is useful for shelf arrangement and book collection. If the table readers can also collect patron IDs, they can get information who reads what books. By analyzing these data we can get which and which books are often read together by such and such patrons. This information is useful for book recommendation service to patrons by use of the collaborative filtering technology [6, 12], which has been well-known in agent researcher's communities.

3.2 Analysis

Automatically or manually collected data form a big database. It consists of, for example, catalog data for materials, circulation records, data by intelligent shelves, and others. We are able to extract statistical data not only from one type of data but also from some types of data by combining them.

From circulation records, for example, we are able to know how many books a patron borrowed so far, per year, per month, and so on. We are also able to know how many books were borrowed in each day of a week, and in which time zone in a day.

By combining it with patron's personal data, we are able to know, for example, the members of a department of a university borrows what sort of materials and how many, and differences of borrowed materials between two departments.

Furthermore, we will be able to acquire knowledge something like "patrons who come to the library in the morning borrows more materials than those who come in the afternoon" by applying a DM algorithm.

Such data and knowledge acquired by analyzing the databases will become good tips for libraries to improve their patron services.

Figure 7 illustrates the cyclic structure of database and services. In the left part are databases in a library. Catalog database is constructed partly manually and partly automatically. Circulation database will be constructed automatically by using an AIDC technology. Personal data of patrons will be obtained when the library issues patron cards.

In the right part of the figure are library services. The OPAC service uses the materials' catalog data. In order to provide the "My Library" service, the system will use some patron data, circulation data, and others. The catalog data and other information will be well used for the reference service. The big arrow from databases and services indicate such used-use relationship.

On the other hand, we can collect some log data of services. From the OPAC service, we are able to have the data of which keywords were used, which library materials were chosen for getting detail data, and so on. From the My Library service, who login this service, when they use, how much time they use, which specific information they access, and so on.

These data themselves form another database, which is indicated the "Service Log" in Figure 7. We can use this database also for improving various services.

Take, for example, the OPAC service. Suppose a patron is trying to find appropriate keywords. When he or she types a keyword, it may be more convenient for the patron if the OPAC system shows some keywords relating to the given one. This is a

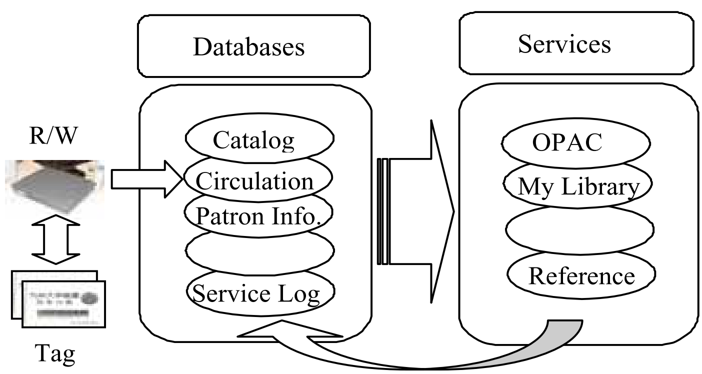

Fig. 7. Cyclic Structure of Database and Services

keyword recommendation [6] function. The keyword log data from the OPAC system itself provide its basis data. The system calculates the distance between two keywords in advance from this data. Then the recommended keywords are chosen among the keywords that are close to the keyword given by the patron.

If the My Library service provides a function of attaching comments to materials,this data can be used for OPAC service as well. Suppose we give a keyword and get a list of related library materials. The system can put a function of displaying what comments are attached on each material. The comments will help the patron with deciding if he or she reads it or not, reads in the library or borrows it when he/she decides to read

3.3 Improvement

As was mentioned in previous sections, RFID technology is very suitable to in-the-library marketing. By collecting and analyzing the data we can acquire useful knowledge that helps with providing better services to patrons, managing the library more efficiently and more effectively.

One important issue here is how to feedback the acquired knowledge to the patrons. An idea for improving the patron interface is the "virtual bookshelf [9, 13]." Figure 8 is an example screen. This is supposed to be a result of an OPAC system, in which the list of books is displayed with images of book spines. This way of display is much easier to intuitively recognize what books are in the list than that of display in text form. This is because we recognize and memorize books not only with title and/or authors, but also with the design of the book; color, font, arrangement, and so on.

One method of attaching extra information to each of the book is to put a link to the image of the spine of the book. If we click on a book spine, the information relating to the book will be displayed in a popup window. The information includes catalog data such as title, author, year of issue, etc. together with extra information such as comments by patrons and/or librarians.

Fig. 8. Virtual Bookshelf

Virtual bookshelf is also well used for personalized library services. Patrons may keep some number of his or her own virtual bookshelves in the library Web site. They can arrange the virtual books on whichever bookshelves they want. They are also able to rearrange the books whenever they want as if the bookshelves are their own and they are always at their study room. They can also put comments to the books from their personal views. The library system will collect such data and feedback the statistic results and other data including the evaluation data and comments to the patrons. One possible service is to recommend one or some books to the patrons that might be useful for the patrons to put in the patron's bookshelf.

4 Security Issue

Security issue is also important for RFID tag system [15]. In this section we discuss two types of security issues; how to protect library materials from theft and how to protect patron-related private data from leakage.

Take the first one. RFID tag system is used as a replacement of magnetic tag system, which is mostly used in university libraries in Japan. One reason of introducing the RFID tag system is to replace the magnetic tag for security and barcode book identification code with one RFID tag. This reduction of book processing cost somehow contributes the reduction of the cost of installing the RFID tag systems and the cost of tags. This aspect belongs to the step 1 of library automation with RFID tag system.

For the aspect of the step2, RFID tag system has an advantage of having much detail data about materials and patrons. By utilizing this advantage the system analyzes the data and extracts information such as what types of materials are stolen than other types, what types of attributes correlate to possibility of being theft, and so on.

Take the second issue; i.e. protection from leakage of private data. Figure 9 illustrates one possible solution to this issue. The basic idea of this system is to put a separated private data management server (PDMS) and control the flow of data to and from the server.

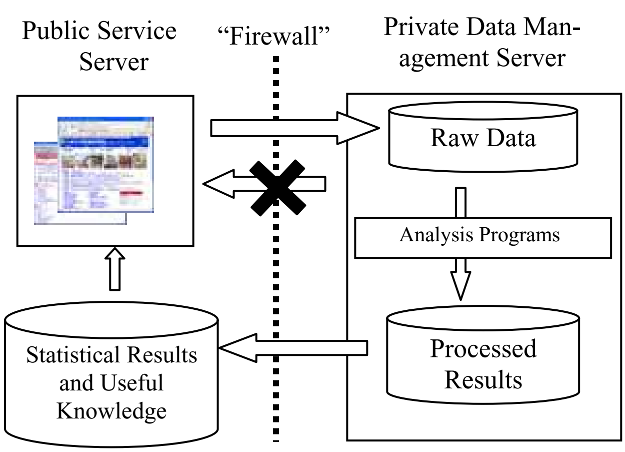

Fig. 9. Private Data Management System

The data of the library database that are needed in analyzing are stored in the IDMS. Only the manager operator of this machine can access to this original data. The analysis programs are invoked either automatically invoked programs or by an ordinary operator of this system. An ordinary operator is able to use only designated programs. The processed results, that are obtained by such analysis programs are accessible by the ordinary operators and thus they are allowed to be copied to outside of the machine. However, ordinary operators are not allowed to access to the original data in order to protect these data from leakage.

This mechanism is conceptually similar to firewall system for network traffic data. The major purpose of out mechanism is to protect data from leakage by operational errors.

5 Concluding Remarks

The background situation of this research lies that materials that are dealt with libraries are changing from physical ones such as books made of paper to digital ones. A big difference between these two materials is that digital materials are easy to deliver via network.

So the patrons do not need to visit a library to get materials. However, considering that we have a huge collection of books already, the library materials will be a mixed up of these two. So we expect the libraries last as hybrid libraries for a long time.

In this paper, we propose a model for hybrid libraries to transit seamlessly from the library where most materials are made of paper, i.e. books and journals, to the electric library, where most materials are provided as digital data. The key idea of this model is the good use of RFID tag system.

RFID is a representative technology of automatic identification and data capture (AIDC) technologies. With this technology, we have advantages of faster and multiple ID recognition, easy to use operational interface, etc., comparing to the barcode system, which is the currently dominating AIDC technology.

In the first step of introducing RFID for library automation, the major aim is to get efficiency and cost cutting. For example in a library of University of Connecticut, US [14], the number of counters can be reduced to half after installing RFID tag system. Even though the initial cost needed for RFID equipments is very high, the running cost is cheaper than that of barcode. However we would like to put strong stress on the importance of the second step for RFID in this paper. In the second step, we get extra data by utilizing RFID tag system and use the data for acquiring knowledge that is useful for improving library services (i.e. one of the library marketing [7] method).

The key equipment for the second step is RFID readers attached to the bookshelves, book trucks, browsing tables, and so on. By collecting and analyzing such data, we can extract statistical information and useful tips.

In order to feedback the knowledge to the user, we recommend the use of virtual shelf system. It is more intuitive and easy to recognize the books in a list. We have also illustrated that this system is a good platform to provide extra information to the patrons.

Lastly, we propose an system organization of private data management system. By using this model the raw data will be protected from leakage to public.

Currently the major reason for introducing RFID tag system is for efficiency. We are expecting and hoping that the major reason might change to for effectiveness in the near future.

Acknowledgments

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Extracting Discriminative Patterns from Graph Structured Data Using Constrained Search

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Abstract. A graph mining method, Chunkingless Graph-Based Induction (Cl-GBI), finds typical patterns appearing in graph-structured data by the operation called chunkingless pairwise expansion, or pseudo-chunking which generates pseudo-nodes from selected pairs of nodes in the data. Cl-GBI enables to extract overlapping subgraphs, but it requires more time and space complexities than the older version GBI that employs real chunking. Thus, it happens that Cl-GBI cannot extract patterns that need be large enough to describe characteristics of data within a limited time and given computational resources. In such a case, extracted patterns maynot be so interesting for domain experts. To mine more discriminative patterns which cannot be extracted by the current Cl-GBI, we introduce a search algorithm in which patterns to be searched are guided by domain knowledge or interests of domain experts. We further experimentally show that the proposed method can efficiently extract more discriminative patterns using a real world dataset.

1 Introduction

[illegible] *pseudo-node*

A. Hoffmann et al. (Eds.): PKAW 2006, LNAI 4303, pp. 64–74, 2006.

pseudo-chunking

2 Chunkingless Graph-Based Induction(Cl-GBI)

[1]

b

[1] Note that this does not mean that the link information of the original graphs is lost. It is always possible to restore how each node is connected in the extracted subgraphs.

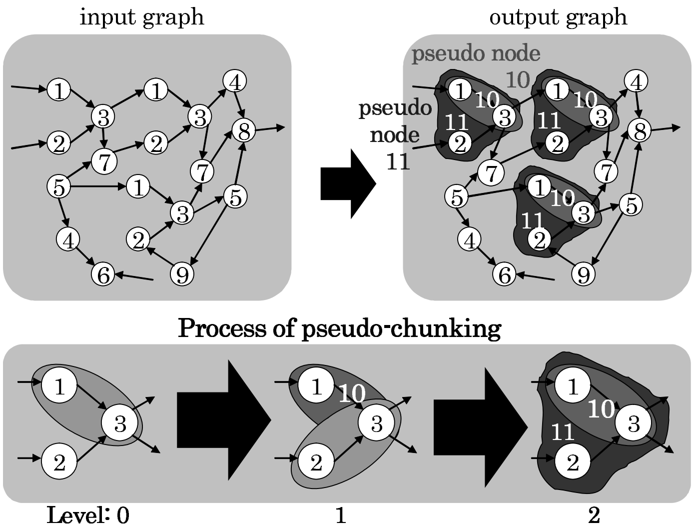

Fig. 1. An Example of Pseudo-chunking in Cl-GBI

[illegible] *pseudo-node* [illegible]

pseudo-chunking [illegible] → [illegible]

→ [illegible]

[illegible] b [illegible] N [illegible] θ [illegible] b [illegible] θ [illegible]

3 Constrained Search for Cl-GBI

3.1 Patterns Used as Constraints

[illegible]

Input. A graph database D, a beam width b, the maximal number of levels of pseudo-chunking N, a frequency threshold θ

Output. A set of typical patterns S

Step 1. Extract all the pairs consisting of two connected nodes in the graphs, register their positions using node id (identifier) sets. From the 2nd level on, extract all the pairs consisting of two connected nodes with at least one node being a new pseudo-node.

Step 2. Count frequencies of extracted pairs and eliminate pairs whose frequencies count below θ.

Step 3. Select the b most frequent pairs from among the remaining pairs at Step 2 (from the 2nd level on, from among the unselected pairs in the previous levels and the newly extracted pairs). Each of the b selected pairs is registered as a new node. If either or both nodes of the selected pair are not original but pseudo-nodes, they are restored to the original patterns before registration.

Step 4. Assign a new label to each pair selected at Step 3 but do not rewrite the graphs. Go back to Step 1.

Fig. 2. Algorithm of Cl-GBI

constraint patterns

INpattern

EXpattern

Constraint 1.

Constraint 2.

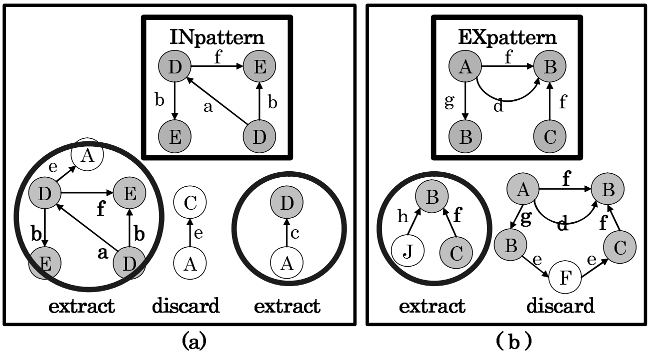

Fig. 3. Examples of INpatterns and EXpatterns

neighborhood pattern

P

P

3.2 Design of Constrained Search

x y

T_{num}

$$T_{num}\ x, y \qquad \sum_{L_k \in L(y)} f\ x, L_k\ ,$$

$L\ y$ y $f\ x, L_k$

$L_k \in L\ y$ x x y $T_{num}\ x, y$

$T_{num}\ y, y$ $T_{num}\ x, y$ $T_{num}\ y, y$

y x

P_i T_j

$T_{num}\ P_i, T_j\ < T_{num}\ T_j, T_j$ P_i T_j

$T_{num}\ P_i, T_j\ \geq T_{num}\ T_j, T_j$ P_i

T_j P_i T_j T_j

P_i

T_j P_i P_i

P_{info} x y

$$P_{info}\ x, y \qquad \bigwedge_{L_k \in L(y)} p\ x, y, L_k\ ,$$

$$p\ x, y, L_k \qquad \begin{cases} true & f\ x, L_k\ \geq f\ y, L_k\ , \\ false & . \end{cases}$$

$P_{info}\ P_i, T_j$ $true$

Step 1

D T

L_v L

L $PD\ P_i, T_j$

P_i T_j

P_i T_j

T_j P_i

T_j

T_j P_i P_i T_j

ExtPair(D, T, L, L_v, M)
Input: a database D, a set of constraint patterns T, the current level L_v,
a set of extracted pairs L (initially empty),
the constraint mode M (either "INpattern" or "EXpattern");
Output: a set of extracted pairs L with newly extracted pairs;
begin
  if $L_v = 1$ **then**
    if $M =$ "INpattern" **then**
      Enumerate pairs in D, which consist of nodes or links
      appearing in T, and store them in E;
    else
      Enumerate all the pairs in D and store them in E;
  else
    Enumerate pairs, which consist of one or both
    pseudo-nodes in L, and store them in E;
  for each $P_i \in E$ **begin**
    if P_i is marked **then**
      $L := L \cup \{P_i\}$; **next**;
    register := 1;
    for each $T_j \in T$ **begin**
      if $T\_num(P_i, T_j) \geq T\_num(T_j, T_j)$ **then**
        if $P_{info}(P_i, T_j) =$ **true then**
          if $M =$ "INpattern" **then**
            if $PD(P_i, T_j) =$ **true then** mark P_i;
          else
            if $PD(P_i, T_j) =$ **true then**
              discard P_i; *register* := 0; **break**;
    end
    if *register* = 1 **then** $L := L \cup \{P_i\}$;
  end
  return L;
end

Fig. 4. Algorithm of the constrained pattern extraction

4 Experimental Evaluation

4.1 Experimental Settings

[illegible] *constrained Cl-GBI* [illegible] *Response* [illegible] *Non-Response* [illegible] *R* [illegible] *N* [illegible] *R* [illegible] *N* [illegible]

Table 1. Size of graphs of the hepatitis dataset

class	R	N
number of graphs	38	56
average number of nodes in a graph	104	112
maximal number of nodes in a graph	145	145
minimum number of nodes in a graph	24	20
total number of nodes	3,944	6,296
kinds of node labels	12	
average number of links in a graph	108	117
maximal number of links in a graph	154	154
minimum number of links in a graph	23	19
total number of links	4,090	6,577
kinds of link labels	30	

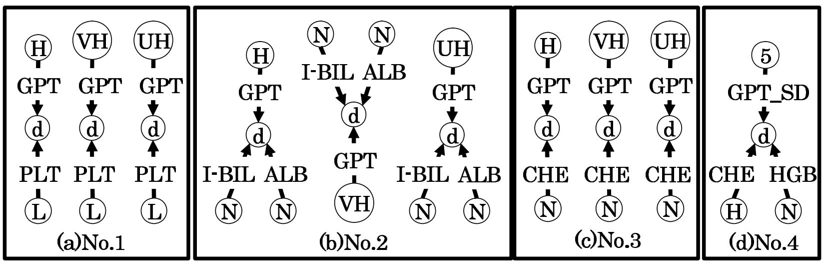

Fig. 5. INpatterns used in the experiments

R

MDpattern

b N

θ %

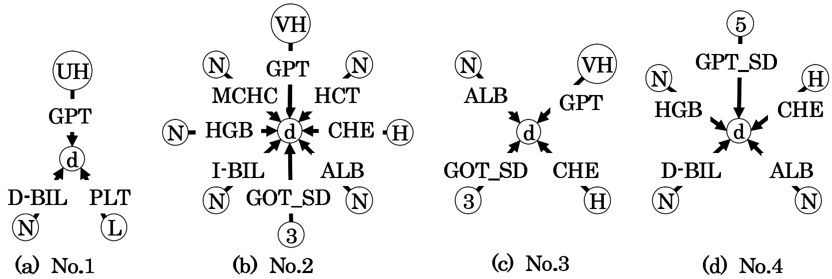

Fig. 6. MDpatterns Extracted by the constrained Cl-GBI

4.2 Experimental Results

Table 2. Experimental results

	time[sec]	max information gain
original	44,973 (—)	0.1139 (L:4, t:1292)
No.1	9,355 (66,211)	0.1076 (L:3, t:18)
No.2	6,893 (31,527)	0.1698 (L:5, t:376)
No.3	20,495 (159,434)	0.1110 (L:3, t:55)
No.4	4,970 (14,923)	0.1297 (L:4, t:39)

[illegible]

5 Conclusion

[illegible]

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Evaluating Learning Algorithms with Meta-learning Schemes for a Rule Evaluation Support Method Based on Objective Indices

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Abstract. In this paper, we present evaluations of learning algorithms for a novel rule evaluation support method in data mining post-processing, which is one of the key processes in a data mining process. It is difficult for human experts to evaluate many thousands of rules from a large dataset with noises completely. To reduce the costs of rule evaluation task, we have developed the rule evaluation support method with rule evaluation models, which are learned from a dataset consisted of objective indices and evaluations of a human expert for each rule. To enhance adaptability of rule evaluation models, we introduced a constructive meta-learning system to choose proper learning algorithms for constructing them. Then, we have done a case study on the meningitis data mining result, the hepatitis data mining results and rule sets from the eight UCI datasets.

1 Introduction

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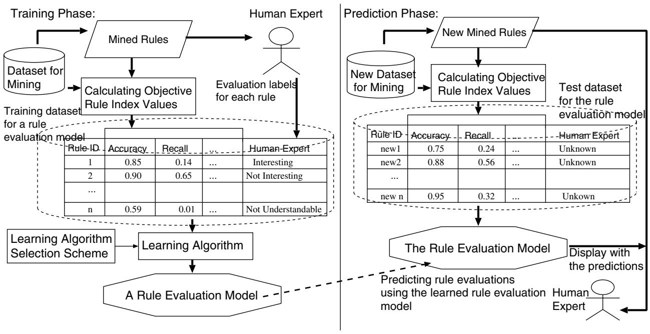

Fig. 1. Overview of the construction method of rule evaluation models

[illegible]

[illegible]

2 Rule Evaluation Support with Rule Evaluation Model Based on Objective Indices

[illegible]

[illegible]

3 Performance Comparisons of Learning Algorithms for Rule Model Construction

D … $Correct(D)$ … $Acc(D) = Correct(D)/|D| \times$ … $|D|$ … i … $Correct(D_i)$ … $Recall(D_i) = Correct(D_i)/|D_i| \times$ … $|D_i|$ … i … i … i … $Precision(D_i) = Correct(D_i)/Predicted(D_i) \times$

Table 1. The objective rule evaluation indices for classification rules used in this research. **P:** Probability of the antecedent and/or consequent of a rule. **S:** Statistical variable based on P. **I:** Information of the antecedent and/or consequent of a rule. **N:** Number of instances included in the antecedent and/or consequent of a rule. **D:** Distance of a rule from the others based on rule attributes.

Theory	Index Name (**Abbreviation**) [Reference Number of Literature]
P	Coverage(**Coverage**), Prevalence(**Prevalence**) Precision(**Precision**), Recall(**Recall**) Support(**Support**), Specificity(**Specificity**) Accuracy(**Accuracy**), Lift(**Lift**) Leverage(**Leverage**), Added Value(**Added Value**)[30] Klösgen's Interestingness(**KI**)[19], Relative Risk(**RR**)[3] Brin's Interest(**BI**)[6], Brin's Conviction(**BC**)[6] Certainty Factor(**CF**)[30], Jaccard Coefficient(**Jaccard**)[30] F-Measure(**F-M**)[28], Odds Ratio(**OR**)[30] Yule's Q(**YuleQ**)[30], Yule's Y(**YuleY**)[30] Kappa(**Kappa**)[30], Collective Strength(**CST**)[30] Gray andOrlowska's Interestingness weighting Dependency(**GOI**)[12] Gini Gain(**Gini**)[30], Credibility(**Credibility**)[13]
S	χ^2 Measure for One Quadrant(χ^2-**M1**)[11] χ^2 Measure for Four Quadrant(χ^2-**M4**)[11]
I	J-Measure(**J-M**)[29], K-Measure(**K-M**)[23] Mutual Information(**MI**)[30] Yao and Liu's Interestingness 1 based on one-way support(**YLI1**)[33] Yao and Liu's Interestingness 2 based on two-way support(**YLI2**)[33] Yao and Zhong's Interestingness(**YZI**)[33]
N	Cosine Similarity(**CSI**)[30], Laplace Correction(**LC**)[30] ϕ Coefficient(ϕ)[30], Piatetsky-Shapiro's Interestingness(**PSI**)[24]
D	Gago and Bento's Interestingness(**GBI**)[10] Peculiarity(**Peculiarity**)[34]

[illegible] [1] [illegible] [2] [illegible] [3] [illegible]

3.1 A Case Study on the Meningitis Datamining Result

[illegible]

Constructing a Proper Learning Algorithm to Construct the Meningitis Rule Evaluation Model. [illegible]

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[1] The kernel function was set up polynomial kernel.

[2] We set up the elimination of collinear attributes and the model selection with greedy search based on Akaike Information Metric.

[3] This stacking has taken the other seven learning algorithms as base-level learner and J4.8 as meta-level learner.

Table 2. Description of the meningitis datasets and their datamining results

Dataset	#Attributes	#Class	#Mined rules	#'I' rules	#'NI' rules	#'NU' rules
Diag	29	6	53	15	38	0
C_Cource	40	12	22	3	18	1
Culture+diag	31	12	57	7	48	2
Diag2	29	2	35	8	27	0
Course	40	2	53	12	38	3
Cult_find	29	2	24	3	18	3
TOTAL	—	—	244	48	187	9

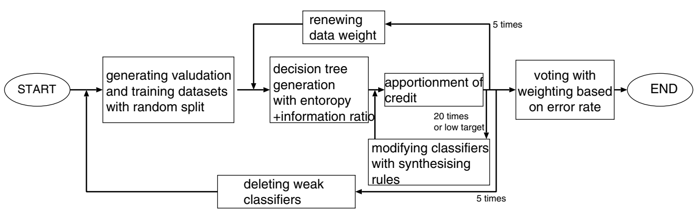


Fig. 2. The learning algorithm constructed by CAMLET for the dataset of the meningitis datamining result

Comparison on Classification Performances.

Table 3. Accuracies (%), Recalls (%) and Precisions (%) of the nine learning algorithms

Learning Algorithms	Evaluation on the training dataset						
	Acc.	Recall			Precision		
		I	NI	NU	I	NI	NU
CAMLET	89.4	70.8	97.9	11.1	85.0	90.2	100.0
Stacking	81.1	37.5	96.3	0.0	72.0	87.0	0.0
Boosted J4.8	99.2	97.9	99.5	100.0	97.9	99.5	100.0
Bagged J4.8	87.3	62.5	97.9	0.0	81.1	88.4	0.0
J4.8	85.7	41.7	97.9	66.7	80.0	86.3	85.7
BPNN	86.9	81.3	89.8	55.6	65.0	94.9	71.4
SVM	81.6	35.4	97.3	0.0	68.0	83.5	0.0
CLR	82.8	41.7	97.3	0.0	71.4	84.3	0.0
OneR	82.0	56.3	92.5	0.0	57.4	87.8	0.0

Learning Algorithms	Leave−One−Out(LOO)						
	Acc.	Recall			Precision		
		I	NI	NU	I	NI	NU
CAMLET	80.3	7.4	73.0	0.0	7.4	73.0	0.0
Stacking	81.1	37.5	96.3	0.0	72.0	87.0	0.0
Boosted J4.8	74.2	37.5	87.2	0.0	39.1	84.0	0.0
Bagged J4.8	77.9	31.3	93.6	0.0	50.0	81.8	0.0
J4.8	79.1	29.2	95.7	0.0	63.6	82.5	0.0
BPNN	77.5	39.6	90.9	0.0	50.0	85.9	0.0
SVM	81.6	35.4	97.3	0.0	68.0	83.5	0.0
CLR	80.3	35.4	95.7	0.0	60.7	82.9	0.0
OneR	75.8	27.1	92.0	0.0	37.1	82.3	0.0

[illegible]

Estimating Minimum Training Subsets for Each Learning Algorithms. [illegible]

%training sample	10	20	30	40	50	60	70	80	90	100
CAMLET	76.7	78.4	80.8	81.6	81.7	82.6	82.8	84.8	84.6	89.3
Stacking	69.6	77.8	75.3	77.9	72.2	82.2	75.4	83.4	86.5	81.1
Boosted J4.8	74.8	77.8	79.6	82.8	83.6	85.5	86.8	88.0	89.7	99.2
Bagged J4.8	77.5	79.5	80.5	81.4	81.8	82.1	83.2	83.2	84.1	87.3
J4.8	73.4	74.7	79.8	78.6	72.8	83.2	83.7	84.5	85.7	85.7
BPNN	74.8	78.1	80.6	81.1	82.7	83.7	85.3	86.1	87.2	86.9
SMO	78.1	78.6	79.8	79.8	79.8	80.0	79.9	80.2	80.4	81.6
CLR	76.6	78.5	80.3	80.2	80.3	80.7	80.9	81.4	81.0	82.8
OneR	75.2	73.4	77.5	78.0	77.7	77.5	79.0	77.8	78.9	82.4

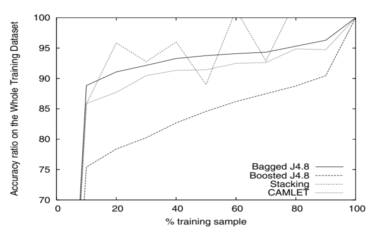


Fig. 3. Accuracies (%) with training sub-samples to the whole training dataset on the left table. And the chart of achieve rates(%) to the accuracies with the whole training dataset on the meta-learning algorithms.

[illegible]

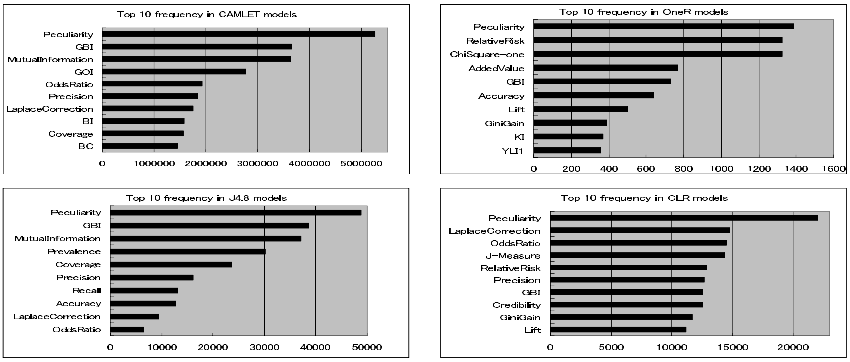


Fig. 4. Top 10 of frequencies of indices used in models of each learning algorithm with 10000 bootstrap samples of the meningitis datamining result dataset and executions

Rule Evaluation Models on the Meningitis Datamining Result Dataset.

3.2 A Case Study on the Chronic Hepatitis Datamining Results

Table 4. Description of datasets of the chronic hepatitis datamining results (left table). And Overview of constructed learning algorithms by CAMLET to the datasets of the chronic hepatitis datamining results (right table).

	#Rules	Class Distribution				%Def class
		EI	I	NI	NU	
GPT						
Phase1(GPT1)	30	3	8	16	3	53.33
Phase2(GPT2)	21	2	6	12	1	57.14
IFN						
First Time(IFN1)	26	4	7	11	7	42.31
Second Time(IFN2)	32	15	5	11	1	46.88

	original classifier set	overall control structure	final eval. method
GPT1	C4.5 tree	Bagging	Best selection
GPT2	C4.5 tree	CS+Boost+Iteration	Weighted Voting
IFN1	C4.5 tree	CS+Boost+Iteration	Weighted Voting
IFN2	C4.5 tree	CS+Boost+Iteration	Weighted Voting

CS means including reinfoecement of classifier set from Classifiser Systems
Boost means including methods and control structure from Boosting

Constructing Proper Learning Algorithms for Chronic Hepatitis Datamining Results.

Comparison on Classification Performances.

Estimating Minimum Training Subset to Construct a Valid Rule Evaluation Model.

Rule Evaluation Models on the Chronic Hepatitis Datamining Result Dataset.

Table 5. Accuracies(%), Recalls(%) and Precisions(%) of the nine learning algorithms on training dataset(the left table) and Leave-One-Out(the center table). Minimum training instances to construct valid rule evaluation models with each learning algorithm (the right table).

	On Training									Leave-One-Out									
		Precision				Recall					Precision				Recall				Min.
	Acc	EI	I	NI	NU	EI	I	NI	NU	Acc	EI	I	NI	NU	EI	I	NI	NU	Estim
GPT1																			
J4.8	96.7	100.0	88.9	100.0	100.0	66.7	100.0	100.0	100.0	50.0	0.0	60.0	60.0	0.0	0.0	75.0	56.3	0.0	14
BPNN	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	30.0	0.0	12.5	50.0	0.0	0.0	12.5	50.0	0.0	14
SVM	56.7	0.0	100.0	68.2	14.3	0.0	12.5	93.8	33.3	46.7	0.0	0.0	65.0	11.1	0.0	0.0	81.3	33.3	20
CLR	63.3	0.0	66.7	62.5	0.0	0.0	50.0	93.8	0.0	40.0	0.0	14.3	50.0	0.0	0.0	12.5	68.8	0.0	16
OneR	60.0	0.0	66.7	59.3	0.0	0.0	25.0	100.0	0.0	43.3	0.0	25.0	55.6	0.0	0.0	37.5	62.5	0.0	14
BagJ4.8	93.3	75.0	87.5	100.0	100.0	100.0	87.5	93.8	100.0	33.3	0.0	12.5	50.0	0.0	0.0	12.5	56.3	0.0	14
BooJ4.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	43.3	0.0	42.9	62.5	0.0	0.0	37.5	62.5	0.0	12
Stacking	70.0	0.0	62.5	72.7	0.0	0.0	62.5	100.0	0.0	36.7	0.0	33.3	61.5	0.0	0.0	37.5	50.0	0.0	24
CAMLET	73.3	0.0	50.0	87.5	100.0	0.0	75.0	87.5	66.7	43.3	0.0	6.7	33.3	3.3	0.0	6.7	33.3	3.3	16
GPT2																			
J4.8	90.5	66.7	85.7	100.0	0.0	100.0	100.0	91.7	0.0	76.2	0.0	66.7	90.9	0.0	0.0	100.0	83.3	0.0	6
BPNN	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	66.7	0.0	83.3	81.8	0.0	0.0	83.3	75.0	0.0	5
SVM	95.2	100.0	100.0	92.3	100.0	50.0	100.0	100.0	100.0	81.0	0.0	100.0	91.7	25.0	0.0	83.3	91.7	100.0	5
CLR	85.7	50.0	100.0	85.7	0.0	50.0	83.3	100.0	0.0	76.2	0.0	83.3	84.6	0.0	0.0	83.3	91.7	0.0	16
OneR	85.7	0.0	75.0	92.3	0.0	0.0	100.0	100.0	0.0	81.0	0.0	66.7	91.7	0.0	0.0	100.0	91.7	0.0	11
BagJ4.8	90.5	100.0	75.0	100.0	0.0	100.0	100.0	91.7	0.0	76.2	0.0	66.7	90.9	0.0	0.0	100.0	83.3	0.0	6
BooJ4.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	76.2	0.0	66.7	100.0	0.0	0.0	100.0	83.3	0.0	6
Stacking	61.9	66.7	0.0	100.0	0.0	100.0	0.0	91.7	0.0	71.4	0.0	83.3	76.9	0.0	0.0	83.3	83.3	0.0	11
CAMLET	81.0	0.0	75.0	84.6	0.0	0.0	100.0	91.7	0.0	76.2	0.0	28.6	47.6	0.0	0.0	28.6	47.6	0.0	8
INF1																			
J4.8	88.5	80.0	100.0	83.3	100.0	100.0	71.4	90.9	100.0	19.2	37.5	0.0	20.0	0.0	75.0	0.0	18.2	0.0	8
BPNN	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	26.9	40.0	22.2	25.0	25.0	50.0	28.6	18.2	25.0	6
SVM	46.2	26.7	0.0	70.0	100.0	100.0	0.0	63.6	25.0	34.6	21.4	0.0	54.5	0.0	75.0	0.0	54.5	0.0	10
CLR	53.8	100.0	0.0	47.6	66.7	50.0	0.0	90.9	50.0	19.2	33.3	0.0	28.6	0.0	25.0	0.0	36.4	0.0	16
OneR	50.0	0.0	50.0	50.0	0.0	0.0	85.7	63.6	0.0	19.2	0.0	11.1	23.5	0.0	0.0	14.3	36.4	0.0	18
BagJ4.8	96.2	80.0	100.0	100.0	100.0	100.0	100.0	90.9	100.0	26.9	33.3	37.5	22.2	0.0	50.0	42.9	18.2	0.0	10
BooJ4.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	23.1	42.9	0.0	27.3	0.0	75.0	0.0	27.3	0.0	8
Stacking	11.5	0.0	12.5	14.3	0.0	0.0	14.3	18.2	0.0	23.1	0.0	33.3	28.6	0.0	0.0	57.1	18.2	0.0	16
CAMLET	76.9	100.0	60.0	80.0	100.0	100.0	85.7	72.7	50.0	30.8	11.5	0.0	19.2	0.0	11.5	0.0	19.2	0.0	14
INF2																			
J4.8	90.6	88.2	100.0	90.9	0.0	100.0	80.0	90.9	0.0	75.0	76.5	66.7	75.0	0.0	86.7	40.0	81.8	0.0	6
BPNN	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	37.5	50.0	28.6	22.2	0.0	53.3	40.0	18.2	0.0	8
SVM	56.3	72.7	0.0	45.0	100.0	53.3	0.0	81.8	100.0	31.3	36.4	0.0	28.6	0.0	26.7	0.0	54.5	0.0	8
CLR	65.6	63.2	100.0	60.0	0.0	80.0	60.0	54.5	0.0	34.4	41.2	20.0	30.0	0.0	46.7	20.0	27.3	0.0	16
OneR	68.8	62.5	0.0	87.5	0.0	100.0	0.0	63.6	0.0	68.8	60.0	0.0	100.0	0.0	100.0	0.0	63.6	0.0	16
BagJ4.8	90.6	88.2	100.0	90.9	0.0	100.0	80.0	90.9	0.0	71.9	70.0	100.0	72.7	0.0	93.3	20.0	72.2	0.0	8
BooJ4.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	71.9	76.5	100.0	70.0	0.0	86.7	60.0	63.6	0.0	6
Stacking	40.6	46.2	0.0	33.3	0.0	80.0	0.0	9.1	0.0	53.1	58.8	0.0	58.3	0.0	66.7	0.0	63.6	0.0	12
CAMLET	90.6	83.3	100.0	100.0	100.0	100.0	100.0	72.7	100.0	43.8	18.8	0.0	18.8	0.0	18.8	0.0	18.8	0.0	8

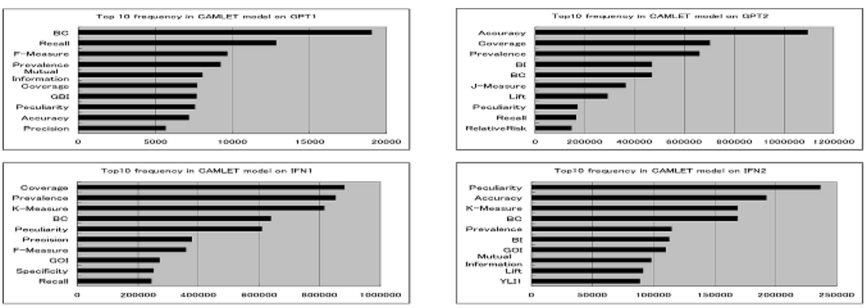
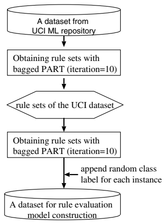


Fig. 5. Top 10 of frequencies of indices used in models of learning algorithms composed by CAMLET with 10000 bootstrap samples of the chronic hepatitis datamining results' datasets

Table 6. Flow diagram to obtain datasets and the datasets of the rule sets learned from the UCI benchmark datasets



	#Mined Rules	#Class labels L1	L2	L3	%Def. class
Distribution I		(0.30)	(0.35)	(0.35)	
anneal	95	33	39	23	41.1
audiology	149	44	58	47	38.9
autos	141	30	48	63	44.7
balance-scale	281	76	102	103	36.7
breast-cancer	122	41	34	47	38.5
breast-w	79	29	26	24	36.7
colic	61	19	18	24	39.3
credit-a	230	78	73	79	34.3
Distribution II		(0.30)	(0.65)	(0.05)	
anneal	95	26	63	6	66.3
audiology	149	49	91	9	61.1
autos	141	41	95	5	67.4
balance-scale	281	90	178	13	63.3
breast-cancer	122	42	78	2	63.9
breast-w	79	22	55	2	69.6
colic	61	22	36	3	59.0
credit-a	230	69	150	11	65.2

3.3 An Experiment on Artificial Evaluation Labels

[illegible]

[illegible]

[illegible] P [illegible] p_i [illegible] i [illegible] i [illegible] D_j [illegible] p_iD_j [illegible] P [illegible]

Constructing Proper Learning Algorithms for Rule Sets from UCI Datasets. [illegible]

Accuracy Comparison on Classification Performances. [illegible]

Table 7. Overview of constructed learning algorithms by CAMLET to the datasets of the rule sets learned from the UCI benchmark datasets

	Distribution I			Distribution II		
	original classifier set	overall control structure	final eval. method	original classifier set	overall control structure	final eval. method
anneal	C4.5 tree	Win+Boost+CS	Weighted Voting	C4.5 tree	Boost+CS	Weighted Voting
audiology	ID3 tree	Boost	Voting	Random Rule	Simple Iteration	Best Select.
autos	Random Rule	Win+Iteration	Weighted Voting	Random Rule	Boost	Weighted Voting
balance-scale	Random Rule	Boost	Voting	Random Rule	CS+GA	Voting
breast-cancer	Random Rule	GA+Iteration	Voting	Random Rule	Win+Iteration	Weighted Voting
breast-w	ID3 tree	Win	Weighted Voting	ID3 tree	CS+Iteration	Weighted Voting
colic	Random Rule	CS+Win	Voting	ID3 tree	Win+Iteration	Voting
credit-a	C4.5 tree	Win+Iteration	Voting	ID3 tree	CS+Boost+Iteration	Best Select.

CS means including reinfoecement of classifier set from Classifiser Systems
Boost means including methods and control structure from Boosting
Win means including methods and control structure from Window Strategy
GA means including reinforcement of classifier set with Genetic Algorithm

Table 8. Accuracies(%) on whole training datasets labeled with three different distributions(The left table). Number of minimum training sub-samples to outperform %Def. class(The right table).

	Distribution I								
	J4.8	BPNN	SVM	CLR	OneR	Bagged J4.8	Boosted J4.8	Stacking	CAMLET
anneal	74.7	71.6	47.4	56.8	55.8	87.4	100.0	27.4	77.9
audiology	47.0	51.7	40.3	45.6	52.3	87.2	47.0	21.5	63.1
autos	66.7	63.8	46.8	46.1	56.0	89.4	66.7	29.8	53.2
balance-scale	58.0	59.4	39.5	43.4	53.0	83.3	58.0	39.5	39.5
breast-cancer	55.7	61.5	40.2	50.8	59.0	88.5	70.5	23.8	41.0
breast-w	86.1	91.1	38.0	46.8	54.4	96.2	100.0	34.2	77.2
colic	91.8	82.0	42.6	60.7	55.7	88.5	100.0	29.5	67.2
credit-a	57.4	48.7	35.7	39.1	54.8	91.3	57.4	26.5	55.7
	Distribution II								
	J4.8	BPNN	SVM	CLR	OneR	Bagged J4.8	Boosted J4.8	Stacking	CAMLET
anneal	74.7	70.5	67.4	70.5	73.7	84.2	94.7	67.4	66.3
audiology	65.8	67.8	63.8	64.4	67.1	83.2	67.1	59.7	65.1
autos	85.1	73.8	68.1	70.2	73.8	87.9	100.0	66.7	67.4
balance-scale	70.5	69.8	64.8	65.8	69.8	80.1	85.8	62.6	63.0
breast-cancer	71.3	77.0	66.4	65.6	77.9	86.9	79.5	73.0	73.0
breast-w	74.7	86.1	73.4	68.4	74.7	87.3	100.0	63.3	70.9
colic	70.5	77.0	65.6	60.7	73.8	85.2	100.0	49.2	60.7
credit-a	70.9	70.0	65.2	65.2	71.3	85.7	87.8	61.7	65.2

	Distribution I								
	J4.8	BPNN	SVM	CLR	OneR	Bagged J4.8	Boosted J4.8	Stacking	CAMLET
anneal	20	14	17	29	29	16	14	36	20
audiology	21	18	65	64	41	21	14	56	27
autos	38	28	76	77	70	28	28	77	31
balance-scale	12	14	15	15	32	14	9	51	128
breast-cancer	16	17	22	41	22	14	14	41	36
breast-w	7	10	10	18	14	10	6	19	11
colic	8	8	9	22	14	8	8	24	8
credit-a	9	12	16	30	28	9	8	51	19
	Distribution II								
	J4.8	BPNN	SVM	CLR	OneR	Bagged J4.8	Boosted J4.8	Stacking	CAMLET
anneal	54	58	64	76	–	42	38	64	46
audiology	64	73	45	76	107	50	50	103	84
autos	66	102	84	121	98	45	39	76	76
balance-scale	118	103	133	162	156	86	92	132	–
breast-cancer	50	31	80	92	80	38	36	60	41
breast-w	44	36	31	48	71	34	34	52	53
colic	28	24	46	30	42	28	22	48	54
credit-a	118	159	–	–	173	76	76	120	109

Estimating Minimum Training Subset to Construct a Valid Rule Evaluation Model.

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4 Conclusion

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Training Classifiers for Unbalanced Distribution and Cost-Sensitive Domains with ROC Analysis

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Abstract. ROC (Receiver Operating Characteristic) has been used as a tool for the analysis and evaluation of two-class classifiers, even the training data embraces unbalanced class distribution and cost-sensitiveness. However, ROC has not been effectively extended to evaluate multi-class classifiers. In this paper, we proposed an effective way to deal with multi-class learning with ROC analysis. An EMAUC algorithm is implemented to transform a multi-class training set into several two-class training sets. Classification is carried out with these two-class training sets. Empirical results demonstrate that the classifiers trained with the proposed algorithm have competitive performance for unbalanced distribution and cost-sensitive domains.

Keywords: Classification, ROC, Cost-Sensitive Learning, Error Correcting Output Coding.

1 Introduction

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2 ROC Analysis

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3 EMAUC Algorithm

Table 1. A Multi-class Data Set

Sepal Length	Sepal Width	Petal Length	Petal Width	Class
4.6	3.2	1.4	0.2	S
5.3	3.7	1.5	0.2	S
7.0	3.2	4.7	1.4	V
6.4	3.2	4.5	1.5	V
6.3	3.3	6.0	2.5	I
5.8	2.7	5.1	1.9	I

Table 2. The ECOC for Multi-class Data Transformation

Class	Code Cluster
S	1 1 1
V	0 0 1
I	0 1 0

Table 3. A Transformed Data Set with ECOC (1)

Sepal Length	Sepal Width	Petal Length	Petal Width	Class
4.6	3.2	1.4	0.2	1
5.3	3.7	1.5	0.2	1
7.0	3.2	4.7	1.4	0
6.4	3.2	4.5	1.5	0
6.3	3.3	6.0	2.5	0
5.8	2.7	5.1	1.9	0

Table 4. A Transformed Data Set with ECOC (2)

Sepal Length	Sepal Width	Petal Length	Petal Width	Class
4.6	3.2	1.4	0.2	1
5.3	3.7	1.5	0.2	1
7.0	3.2	4.7	1.4	0
6.4	3.2	4.5	1.5	0
6.3	3.3	6.0	2.5	1
5.8	2.7	5.1	1.9	1

Table 5. A Transformed Data Set with ECOC (3)

Sepal Length	Sepal Width	Petal Length	Petal Width	Class
4.6	3.2	1.4	0.2	1
5.3	3.7	1.5	0.2	1
7.0	3.2	4.7	1.4	1
6.4	3.2	4.5	1.5	1
6.3	3.3	6.0	2.5	0
5.8	2.7	5.1	1.9	0

```
Input: Training Set S, Two-classifier C, Code Type T
Output: The value of EMAUC
    Begin
        Initialize(S);
        Code = GenerateCorrectCode(S,T);
         For each column of Code (i)
            SubTrainingSet(i) = FilterTrainingSet(S, Code(i));
            Classifier(i) = Construct Classifier(SubTrainingSet(i),C);
        EndFor;
        EMAUC = Avg(AUC(i));
    End.
```

Fig. 1. EMAUC Algorithm

Table 6. Datasets Used in EMAUC

UCI Dataset	Dataset Name	Sample Number	Attribute Number			Class Number
			Total	Discrete	Continuity	
anneal	ANN	898	38	32	6	6
artifical	ART	5109	7	0	7	10
audiology	AUD	226	69	69	0	24
auto-mpg	AUT	399	7	2	5	4
autos	AUS	205	25	10	15	7
balance-scale	BAL	626	4	0	4	3
bridges2	BRI	108	11	10	1	6
flag	FLA	194	27	17	10	6
glass	GLA	214	9	0	9	7
hayes-roth	HEY	132	4	4	0	3
heart-c	HEA	303	13	7	6	5
heart-h	HEH	294	13	7	6	5
hypothyroid	HYP	3772	29	22	7	4
lymph	LYM	148	18	15	3	4
machine	MAC	209	7	0	7	8
page-blocks	PAG	5473	10	0	10	5
primary-tumor	PRI	339	17	17	0	22
segment	SEG	2310	19	0	19	7
solar-flare	SOL	333	10	10	0	8
soybean	SOY	683	35	35	0	19
vehicle	VEH	848	18	0	18	4
waveform-5000	WF5	5004	40	0	40	3
vowel	VOW	990	13	3	10	11
wine	WIN	178	13	0	13	3
zoo	ZOO	104	17	16	1	7

4 Experimental Results

Table 7. EMAUC Derived from Different Two-class Classifiers

Dataset	ZeroR	C4.5	Logistic	Native Bayes	NBtree	NN
ANN	0.500	0.916	0.915	0.891	0.914	0.998
ART	0.500	0.688	0.915	0.676	0.862	0.820
AUD	0.500	0.998	0.926	0.941	0.981	0.989
AUT	0.500	0.882	0.985	0.826	0.969	0.979
AUS	0.500	0.995	0.918	0.882	0.995	0.994
BAL	0.500	0.722	0.995	0.741	0.650	0.809
BRI	0.500	0.953	0.660	0.923	0.965	0.986
FLA	0.500	0.989	0.959	0.912	0.984	0.989
GLA	0.500	0.839	0.973	0.807	0.900	0.912
HAY	0.500	0.986	0.928	0.986	0.986	0.990
HEA	0.500	0.811	0.969	0.800	0.877	0.889
HEH	0.500	0.770	0.840	0.757	0.827	0.840
HYP	0.500	0.972	0.765	0.958	0.972	0.892
LYM	0.500	1.000	0.811	0.981	0.998	0.949
MAC	0.500	0.934	0.995	0.934	0.949	0.991
PAG	0.500	0.973	0.957	0.954	0.991	0.976
PRI	0.500	0.831	0.990	0.814	0.877	0.976
SEG	0.500	0.966	0.906	0.889	0.999	0.998
SOL	0.500	0.883	0.999	0.823	0.871	0.886
SOY	0.500	0.999	0.605	0.954	0.996	0.999
VEH	0.500	0.903	0.998	0.749	0.907	0.974
WF5	0.500	0.813	0.981	0.825	0.998	0.998
VOW	0.500	0.953	0.995	0.926	0.974	0.993
WIN	0.500	1.000	0.996	0.999	0.995	1.000
ZOO	0.500	1.000	0.994	0.986	0.999	1.000
Average	0.500	0.911	0.919	0.877	0.937	0.953

5 Related Work

6 Conclusion

Acknowledgements

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Revealing Themes and Trends in the Knowledge Domain's Intellectual Structure

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Abstract. Thousands of academic papers related to scientific research appear every year, and the accumulated literatures over the years are voluminous. It may be very helpful to be able to visualize the entire body of scientific knowledge, and to be able to track the latest developments in the science and technology fields. However, to make knowledge visualizations clear and easy to interpret are very challenging tasks. This paper draws on a vast amount of knowledge management related citations to reveal the main themes and trends of this particular research field. It aims to help researchers to grasp the research focus and trends in knowledge management, which are hard to discern due to the sheer amount of relevant literatures. It also helps novice researchers gain useful and instant insights into the most important literatures in their chosen field of research.

1 Introduction

Thousands of academic papers related to scientific research appear every year, and the accumulated literatures over the years are voluminous. It is may be very useful be able to visualize the entire body of scientific knowledge and track the latest developments in particular science and technology fields. However, to make knowledge visualizations clear and easy to interpret are challenging tasks. Many studies have drawn their citation data by using a key phrase to query citation indexes. Retrieving citation data by a simple query of citation indexes is a rather crude and limiting technique.

A knowledge domain is represented collectively by research papers and their inter-relationships in this research area. A knowledge domain's intellectual structure can be discerned by studying the citation relationships and analyzing seminal literatures of that knowledge domain. Knowledge Management (KM) is a fast growing field with great potential. However, researchers have disagreeing opinions about what constitutes the content and context of the KM research area [1]. Our Intellectual Structure of the KM domain has been constructed with predominantly information systems and management oriented factors [2, 3]. Our study drew primarily on voluminous science and engineering literature that has given us some interesting

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results. The methodology we used to build the intellectual structure of the KM domain is reviewed in section 2 of this paper. Sections 3 and 4 present the KM structure and its research trends respectively.

2 Background Analysis in Knowledge Domain Intellectual Structure

The study of the intellectual structure of a discipline was pioneered by researchers in information science in the early eighties [4]. The Author Co-citation Analysis (ACA), a bibliometric technique, is used in presenting the intellectual structures of a knowledge domain. Recent studies in knowledge visualization adapt this ACA approach as its underlying methodology and outfit the intellectual structure with visual cues and effects [5-8]. The ACA intellectual structure method has been applied in much research [3, 9-11]. Our proposed approach is similar to ACA analysis to derive the intellectual structure of the domain of KM.

2.1 The ACA Knowledge Intellectual Structure Methodology

Authors who have made influential contributions to a given discipline constitute the unit of analysis in ACA. An author represents a reference to the concept for which the author is recognized by their works and citations received by their works. Co-citation analysis thus infers the relationship between key concepts, which is represented by the extent of joint citations of authors making seminal contributions in any given field. The approach relies on the intuitionally appealing thought that authors contributing to concepts viewed as being overlapping or closely related are more likely to be cited together by other researchers than by authors contributing to concepts viewed as distinct or different [3]. The method starts with identifying groups of authors who are frequency co-cited; they are grouped together based on their co-citations. The groups of authors are usually compiled from a list of the most cited authors using a representative key phrase, such as Knowledge Management, querying papers published between a designated period included in the Social Science Citation Index, Science Citation Index, or some other citation index. The co-citation relationships between authors are usually represented by a co-citation matrix, which serves as the input of factor analysis. The intellectual structure or subfields represented by factors derives from the factor analysis.

As an example of how ACA works, Chen [8] studied author co-citation patterns found in IEEE Computer Graphics and Applications (CG&A) magazine for a period of 18 years. The resulting CG&A citation data included 10,292 unique articles written by 5,312 authors. Those authors who had received less than five citations in CG&A were filtered out, and only 353 most cited authors were left for further analysis. Sixty factors were established from the factor analysis applied on the author co-citation matrix. Five most significant factors that explained 39% of the variance were discussed in detail by listing the contributing authors of each factor.

2.2 The Intellectual Structure Layout Methods

The co-citation matrix computes a correlation matrix of Pearson correlation coefficients. Researchers [8, 12] have applied Pathfinder network (PFNET) scaling to prune the network that the correlation matrix defines. PFNET scaling is used to extract the most important relationships from the correlation matrix [13]. The topology of a PFNET is determined by two parameters q and r and the corresponding network is denoted as PFNET(r, q). The parameter q constrains the scope of minimum cost paths to be calculated. The parameter r defines the Minkowski metric used for computing the distance of a path. The result of PFNET scaling is shown spatially as a sparsely connected graph whereas authors are represented by nodes in the graph. Other layouts, such as the multidimensional scaling map (MDS), which uses the correlation matrix to provide a spatial representation of authors have also been utilized [3].

2.3 Related Works Applying the Methodology in Knowledge Management

Ponzi [2] studied the intellectual structure and interdisciplinary breadth of KM. Intellectual structure is established by a principal component analysis applied to an author co-citation frequency matrix. The author co-citation frequencies used were derived from the 1994-1998 academic literature and captured by the single search phrase of "Knowledge Management." The study found four factors, which were labeled Knowledge Management, Organizational Learning, Knowledge-based Theories, and The Role of Tacit Knowledge in Organizations. The interdisciplinary breadth surrounding Knowledge Management was discovered mainly in the discipline of management. The study validated the hypothesis with empirical evidence that the discipline of Computer Science is not a key contributor in KM.

Subramani et al. [3] examined KM research from 1990-2002, and this examination highlighted the intellectual structure of management related researches in the field. The results revealed the existence of eight subfields of research on the topic, which include Knowledge as Firm Capability, Organizational Information Processing and IT Support for KM, Knowledge Communication, Transfer and Replication, Situated Learning and Communities of Practice, Practice of Knowledge Management, Innovation and Change, Philosophy of Knowledge, and Organizational Learning and Learning Organizations. These sub-fields reflect the influence of a wide array of foundational disciplines such as management, philosophy, and economics.

3 The Intellectual Structure of Knowledge Management

The studies reviewed above drew their citation data by using a key phrase querying citation indexes. The citation data retrieved by a simple query of citation indexes were rather limited. Our proposed approach is based on a scheme, which constructs a full citation graph from the data drawn from the online citation database CiteSeer [14]. The proposed procedure leverages the CiteSeer citation index by using key phrases to query the index and retrieve all matching documents from it. The documents retrieved by the query are then used as the initial seed set to retrieve papers that are citing or cited by literatures in the initial seed set [15]. The full citation graph is built by linking all articles retrieved, which includes more documents than the other schemes reviewed earlier. The resulted citation graph was built from the literatures and citation information retrieved by querying the term "Knowledge Management" from CiteSeer on March, 2006. The complete citation graph contains 599,692 document nodes and 1,701,081 citation arcs. In order to keep the highly cited papers and keep the literature to a manageable size, we pruned out papers were cited less than 150 times. The resultant citation graph contains 255 papers and 776 citation arcs.

3.1 Factor Analysis

The co-citation matrix is derived from the citation graph and fed to factor analysis. Seventeen factors were determined which explained 45.5% total variances. The unit of analysis used here is based on documents instead of authors. An author is considered as the proxy of the specialty S/He represents. However, a researcher's specialty may

Table 1. Factors and Loading

Factor	Descriptive Name	Variance Explained	Cumulative Variance
1	Query on Semi-structured Data	5.664	5.664
2	Inductive Learning and Inductive Logic programming	3.984	9.647
3	Efficient Search of Multi-dimensional objects	3.775	13.422
4	Logic Programming and Deductive Databases	3.586	17.008
5	Machine Learning and Classifiers	3.286	20.294
6	Distributed Problem Solvers and Rational Agents	3.018	23.313
7	Knowledge Interchange Format and Knowledge Sharing	2.672	25.985
8	Data Mining – Efficient Mining of Association Rules	2.423	28.407
9	Constraint Query Languages and Logic Programming	2.315	30.722
10	Unified Views of Information Sources	2.147	32.869
11	Modal and Temporal Logic	2.087	34.956
12	Parallel Distributed Model and Language	2.015	36.972
13	Functional Languages and Development Environment	1.899	38.870
14	Agent Development and Communication Languages	1.767	40.637
15	STRIPS Planning	1.685	42.322
16	World Wide Webs and Search Engines	1.648	43.971
17	Bayesian Networks Learning	1.549	45.520

change or evolve over time. We therefore took the document as the analysis unit in our study. The factors and their loading are listed in Table 1.

Factor one represents research on query of semi-structured data or heterogeneous Information Sources. In contrast with traditional relational and object-oriented database systems that force all data to adhere to an explicitly specified schema, much of the information available on-line, such as a WWW site, is semi-structured. Semi-structured data is relatively varied, irregular, or mutable to easily map to a fixed schema. Knowledge, in contrast with data and information, is inherently unstructured. The study of querying semi-structured data could be considered as the harbinger of the query of the semi-structured or unstructured knowledge base.

Factor two represents research on inductive learning and inductive logic programming. Inductive learning includes works focused on learning concepts from examples and learning algorithms. Inductive Logic Programming (ILP) is a machine learning approach that uses techniques of logic programming. ILP systems develop predicate descriptions from examples and background knowledge. The derived predicate descriptions, examples, and background knowledge are all described as logic programs. These areas of studies try to derive new knowledge from existing facts and background knowledge.

Factor three is characterized by researches on efficient search and data structure of multi-dimensional objects. This area of study includes the research of querying image content by specifying color, texture, and shape of image object, and the application of R+-Tree for dynamic indexing of multi-dimensional objects. Novel applications of this line of research in similarity search in massive DNA sequence databases are a new trend.

Factor four includes earlier knowledge-based related research such as that of deductive databases and logic programming. Non-monotonic reasoning and logic as well as semantical issues on non-monotonic logic and predicate logic were also covered.

Factor five represents machine learning related research, which encompasses inductive learning, statistical learning, classifiers, and learning algorithms and programs. The machine learning programs referred to here are based on a classification model that discovers and analyzes patterns found in records. C4.5 is an example of an inductive method that finds generalized rules by identifying patterns in data. This factor appears to be the transitional works that bridge or transcend from the area of machine learning to data mining.

Factor six represents distributed problem solvers and rational agents, where an agent is essentially a delegate who solves problems with human like intelligence. The study of the architecture of a resource-bounded rational agent and the formulation of the agent's intention seems to be the precursor of research in the area of intelligent agent. An intelligent agent is described as a self-contained, autonomous software module that could perform certain tasks on behalf of its users. It could also interact with other intelligent agents and/or humans in performing its task(s).

Factor seven represents Knowledge Interchange Format (KIF) and knowledge sharing. KIF is essentially a language designed for use in the interchange of knowledge among disparate computer systems. When a computer system needs to communicate with another computer system, it maps its internal data structures into KIF. Alternatively, when a computer system reads a knowledge base coded in KIF, it converts the data into its own internal form. The research of knowledge sharing tried to find ways of preserving existing knowledge bases and of sharing, reusing, and building on them. This line of research tries to develop the enabling technologies to facilitate reusing knowledge bases that have been built and used by AI systems.

Factor eight represents data mining research that discusses the effective and efficient algorithms of mining association rules from large databases. Data mining, in essence, is a knowledge discovering technique that tries to learn rules and patterns from a large amount of data. The roots of data mining can be traced back to machine learning as already mentioned.

Factor nine represents constraint query languages and constraint logic programming, which belong to the subfields of constraint programming that describe computations by specifying how these computations are constrained. Therefore, the constraint programming paradigms are inherently declarative, such as Prolog clauses.

Factor ten represents the study of providing unified views of information from diverse sources or data located within distributed and heterogeneous databases. Papers under this factor try to utilize the semantic model of a problem domain that could provide a unified view to integrate information from disparate information sources.

Factors eleven through seventeen explain less than eleven percent of the total variance. We therefore briefly review these factors altogether. Factor eleven is characterized by modal and temporal logic. Factor twelve represents a language independent model for parallel and distributed programming, such as the Linda system [16]. Factor thirteen represents functional languages and their development environments. Factor fourteen represents languages for the development and communication of information agents. Factor fifteen represents STRIPS planning, which is a simple and compact method of expressing planning problems. Instead of having complex logic statements in the knowledge base, STRIPS allows only simple positive facts and everything not explicitly listed as true in the knowledge base is considered false. Factor sixteen is characterized by World Wide Webs and search engines. Factor seventeen represents Bayesian networks, which combines knowledge with statistical data for learning.

3.2 Pathfinder Network

The Pearson correlation coefficients between items (papers) were calculated when factors analysis was applied. The correlation coefficients are used as the basis for PFNET scaling [17]. The value of Pearson correlation coefficient falls between the range -1 and 1. The coefficient approaches to one when two items correlate completely. Items that closely relate, i.e., are highly correlated, should be placed closely together spatially. The distance between nodes is normalized by taking $d = 1/(1 + r)$, whereas r is the correlation coefficient. The distance between items is inversely proportional to the correlationcoefficient, which maps less correlated items apart and highly correlated items spatially adjacent.

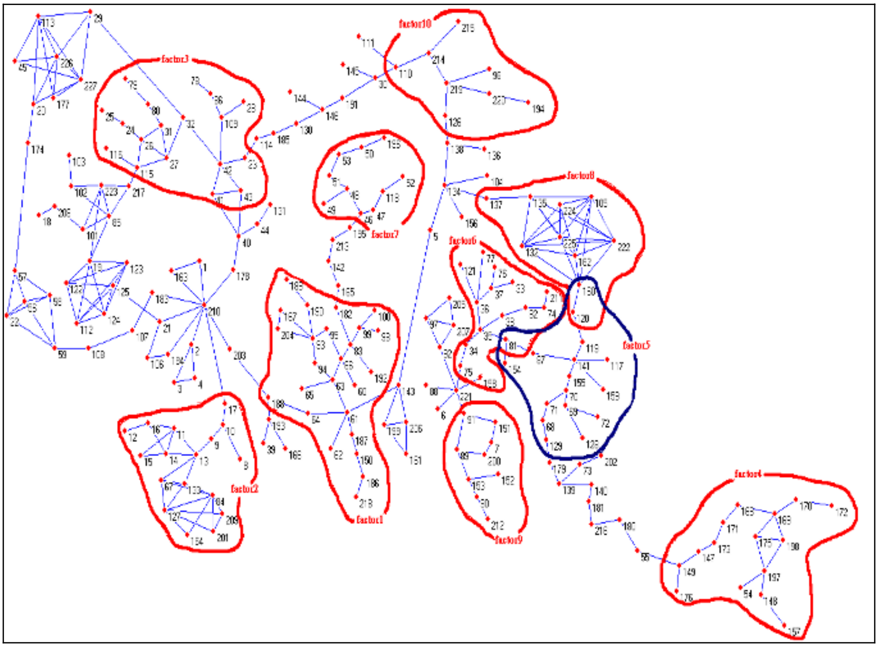

Fig. 1. PFNET Scaling with Papers under Same Factors Close to Each Other

4 Research Trends in KM

Similar to the reviewed methodologies, we sought to identify research trends in KM. Instead of searching all papers in the citation index database, we limited our search to literature published during the last four years. We do not repeat the description of the analytical procedure because it is the same as above in section 2.1. Ten factors were identified by the factor analysis procedure.

Semantic Web, Ontology, and Web Ontology related researches are recent popular research trends in the KM domain area. Distributed knowledge representation, reason systems, and description logic are also research interests due to World Wide Web proliferation. In addition, classifiers and patterns learning, especially in the area of Webs and hidden databases with Web front end, are active research areas too. Generally speaking, Extensible Markup Language (XML) and related topics are increasing. The issue of trust and reliable Web Services composition also represents one of the ten factors.

5 Conclusion

The intellectual structure of KM had been studied earlier by researchers in the Information Systems (IS) field. The finding of IS researchers is idiosyncratically inclined toward IS related research. This bias is probably due to their seminal author selection procedure, which is further compounded by the citation compilation process.

Our study draws on the CiteSeer citation index, which is primarily located in the fields of computer, information science, and engineering. The intellectual structure of knowledge management derived from a predominantly science and engineering oriented index is quite different from what has been provided by IS researchers. Our results reveal seventeen sub areas that form the conceptual groundwork of KM.

The current research trends of KM were briefly summarized. Research that intertwines World Wide Web and XML with classical AI topics seems to be the new direction. However, we have only seen limited new research that tries to leverage the rich AI tradition of the past to pursue Web related fields. Trust and security related issues are getting more attention due to the burgeoning Electronic Commerce and Electronic Business.

KM encompasses a fairly wide range of studies. It is also a field with great potential since knowledge has become the most important ingredient in modern businesses. The KM related research within science and engineering could provide the theoretical and infrastructural support that is needed by practitioners and researchers in other fields.

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Evaluation of the FastFIX Prototype 5Cs CARD System

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Abstract. The 5Cs architecture offers a hybrid Case And Rule-Driven (CARD) system that supports the Collaborative generation and refinement of a relational structure of Cases, ConditionNodes, Classifications, and Conclusions (hence 5Cs). It stretches the Multiple Classification Ripple Down Rules (MCRDR) algorithm and data structure to encompass collaborative classification, classification merging, and classification re-use. As well, it offers a very lightweight collaborative indexing tool that can act as an information broker to knowledge resources across an organisation's Intranet or across the broader Internet, and it supports the coexistence of multiple truths in the knowledge base. This paper reports the results of the software trial of the FastFIX prototype - an early implementation of the 5Cs model, in a 24x7 high-volume ICT support centre.

Keywords: Single Classification Ripple Down Rules, Multiple Classification Ripple Down Rules, SCRDR, MCRDR, Knowledge Engineering, Knowledge Acquisition, CARD, top-down rule-driven, bottom-up case-driven.

1 Introduction

The 5Cs model is comprised of the Collaborative generation and refinement of a relational structure of Cases, ConditionNodes, Classifications, and Conclusions (hence 5Cs). The 5Cs model is a Case And Rule Driven (CARD) system for Knowledge Acquisition (KA) that uses a Case Oriented Rule Acquisition Language (CORAL) to acquire rules in a similar way to Multiple Classification Ripple Down Rules (MCRDR) [7, 8] and its predecessor the Single Classification Ripple Down Rules (SCRDR) [4], but with significant extensions. For example, new data structures and algorithms are presented to allow experts to more effectively collaborate in building up both the knowledge and case bases.

The extensions have been motivated by our work in developing a trouble shooting system for a high volume ICT support centre. Knowledge in this domain changes rapidly and is driven by the need to maintain and link problem and solution cases. For this reason we chose to use the MCRDR combined case and rule based approach to incremental KA. However, in this domain we found that the knowledge needed to identify and solve the problem came from many, varied and globally distributed sources, and that the cases themselves were often in a state of flux and needed to be

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worked up as new information came to light. Sources of information could include: clients, peers, third party vendors or software/hardware engineers and was obtained through personal conversations and notes, Internet sites, manuals and specifications.

The 5Cs system allows knowledge workers to collaboratively refine and expand a topic using an expert systems approach by consistently asking users to confirm, add to, or refine the knowledge presented, typically within the context of a current case. 5Cs supports intuitive KA as it allows the capture and sharing of the questions that experts ask themselves when classifying incoming cases.

This work is similarly motivated to the early work to reconcile multiple sources of expertise that have been captured into multiple MCRDR KBS [9] using Formal Concept Analysis [13]. In that work, however, identification and resolution of conflict was not fully integrated into the KA cycle, but performed as desired when another expert view was to be compared and required making changes to the individual sources and regeneration of the combined model for further verification and validation.

More recently Beydoun et al. [3] have extended Nested RDR (NRDR) [2] to support cooperative KA. NRDR differs from MCRDR in that it allows multiple SCRDR trees to be combined into an hierarchical conceptual structure. The approach seeks to detect *internal inconsistencies*, which are inconsistencies between multiple experts, and are resolved by the domain expert as independent KBS are individually integrated into the system. To assist, various estimates are derived to determine the probability of internal inconsistency and then determine a "trend of external inconsistencies". The degree of external inconsistency is seen to reflect how well the model represents the world in terms of ontological consistency, completeness and accuracy. As with the work described in this paper, "the intuition is that a coherent collective expertise is a better reflection of 'reality'" [3, p. 48]. Our work differs from this research in that combining expertise is a normal part of each KA cycle to develop a shared and single model, which can contain managed inconsistencies, rather than a technique employed to deal with inconsistencies whenever a new KBS is to be integrated. This is necessary in the 24x7 follow-the-sun call centre environment as multiple individuals, often distributed by time and place, may be involved with specifying the same problem/solution and need a way of working with the knowledge entered by themselves and others over time.

A subset of the features proposed by the 5Cs model has been tested via a prototype system known as FastFIX. FastFIX was developed to support the troubleshooting process in a high-volume and complex 24x7 support center in the ICT domain [11, 12]. The 5Cs system architecture is presented in the next section. The results of the FastFIX software trial are then evaluated and presented.

2 The 5Cs System

In the 5Cs system, a condition mesh structure is provided, comprising of RuleNodes i.e. (ConditionNodes) as shown in Fig 1. In this structure, each parent RuleNode may have multiple child RuleNodes, and each child RuleNode may have multiple parents. As well, there is an N-to-N relationship between Cases and their live and/or registered ConditionNodes (i.e. RuleNodes); an N-to-N relationship between the

ConditionNodes and the Classifications that they represent; and an N-to-N relationship between the resultant Classifications and their Conclusions.

A Case can evaluate to TRUE for multiple Condition paths in the condition mesh, hence a Case can fetch multiple Classifications, where each Classification may be linked to multiple Conclusions. As well, Conclusions can be reused across multiple Classifications, and those Classifications may be reused across Condition paths, and across multiple Cases. Note that in Fig 1 only a subset of classifications and conclusions are shown for RuleNodes 6, 7, and 8 and for simplicity links to the classifications and conclusions at other RuleNodes have not been included in the figure. Note also that in the 5Cs system, the Attributes, Cases, Conditions, Classifications, and Conclusions may each be the subject of Collaborative creation, editing, or deletion. In addition, RuleNodes can be collaboratively relocated.

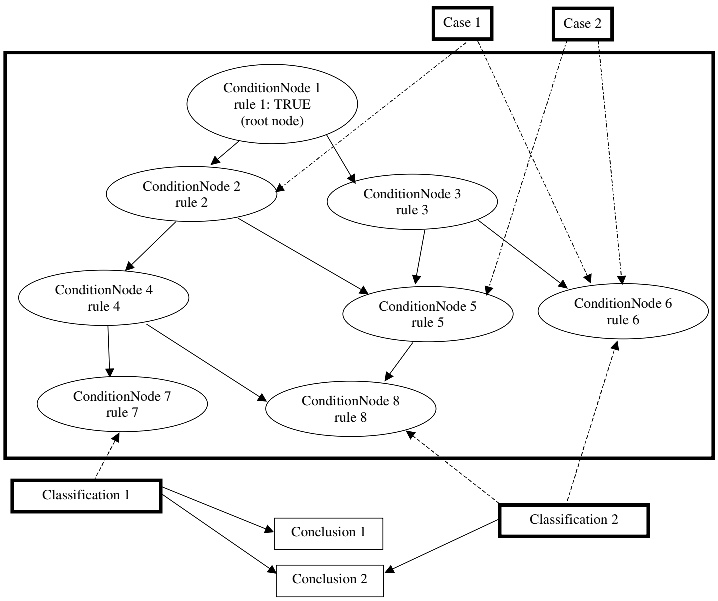

Fig. 1. 5Cs Condition Mesh

2.1 Tracking Case-RuleNode Associations

Unlike many MCRDR systems which only require cornerstone cases to be kept, in a domain like the call center where the cases are volatile we keep all cases and track all Case-RuleNode associations. This is somewhat similar to the use of an execution history, tracking of rule usage and the proposed review of rule usage against the case history in the HeurEAKA RDR system [1], which uses NRDR and genetic algorithms for channel routing in VLSI design. In the 5Cs model, a "Tracked" Case is one whose Live and Registered RuleNodes are being remembered by the system. A Live RuleNode for a given Case is one that is currently the last `TRUE` RuleNode on a given path through the knowledge base for that case. Its conclusions are part of the set of current conclusions derived from the knowledge base for the case. The system remembers its Live RuleNodes for "Tracked" cases. Live RuleNodes may be correct or incorrect. Correcting incorrect live RuleNodes is the primary role of a (human or computer) expert who trains the knowledge base.

A Registered RuleNode is one that has been confirmed by a User as being correct and `TRUE` for that Case. For each case, each RuleNode registration may be current or expired. The test for RuleNode-Case registration expiry is that if the last modification or creation date on the RuleNode-Case association is more recent than or the same as the last modified dates on the RuleNode and the Case, then the registration is current. Otherwise, the registration is expired. The expiry of registered case-RuleNode relationships is something that can be notified and displayed to users in the summary of cases or RuleNodes of interest to them. The user can also be notified whenever the list of live RuleNodes differs from the list of registered RuleNodes for a given case, or the list of live cases differs from the list of registered cases for a given RuleNode.

In the Pathology Expert Interpretative Reporting System (PEIRS), typographical or conceptual errors in RuleNode expressions were corrected with the use of "fall-through" rules [5, p. 119], but potentially resulting in corruption of the KBS [5, p.88]. Similarly, Kang identifies the situation where the domain knowledge represented by an existing rule tree needs to be changed in such a fashion that a cornerstone case for an existing RuleNode will *drop-down* to a new child RuleNode [7, p.50]. He suggests that if absolutely necessary, the rules suggested by the MCRDR difference list for the new RuleNode can be overridden [7, p. 65]. The approach was not fully explored [7, p. 67]. Note that cases don't only *drop-down.* They may drop-across from a sibling node; or they can *recoil* to an ancestor RuleNode for example when the editing or relocation of a dependent RuleNode is restrictive enough that the case under review is now excluded.

Unlike in pathology where each report handled a new case and changes to a patients data resulted in a new case with new conclusion, in the Call Centre domain it is likely that information about a customer problem will develop over days or even months in situations where a problem is intermittent or temporarily fixed but reemerges at a later date. A supposed solution to a problem may turn out to not have really fixed the problem at all. This means that the knowledge (ie the rules) and the problem/solution case/s may also need changing. The 5Cs structure and algorithms allow the knowledge base to evolve, including changes to cases, RuleNodes, intermediate conclusions, ontological entry or attributes. This is achieved through tracking of live vs registered case-RuleNode associations.

In fact, FastFIX tracks all changes to the system and identifies users when an inconsistency in the system occurs. The strategy assists with more rapid knowledge acquisition since it can highlight inconsistencies between expert opinions, just as MCRDR supported quicker KA by allowing more than one rule to be acquired for each case. It lets users capitalize on the knowledge acquisition opportunity presented by the case drop-down scenario, and this in turn may result in quicker coverage of the domain and greater learning opportunities for users. The separation of live and registered case-RuleNode associations is a key part of being able to resolve classification conflicts between multiple experts, and even between what a single expert thinks today, as compared with tomorrow [6].

2.2 The FastFIX Prototype

As mentioned earlier, a subset of the features proposed by the 5Cs model was tested in the ICT support center problem domain via a prototype system known as FastFIX. Significant novel ideas implemented in the FastFIX prototype and tested during the FastFIX software trial included:

- The ability for multiple users to build an MCRDR-based decision tree in a wiki[1]-style collaborative effort. This includes the identification of classes of incoming problem cases and manual indexing of solutions by multiple users using rule conditions equivalent to logical tags in a folksomony[2].
- Reference to multiple exemplar cornerstone cases for each RuleNode.
- The ability for users to edit previously created cases (including cornerstone cases) and RuleNodes in the system.
- Continuous background monitoring of changes to the knowledge base so that users with affected RuleNodes and Cases can notice and respond to the changes. This approach allows classification conflicts to be identified, clarified and resolved and hence it enhances knowledge acquisition.
- The ability for users to "work-up" a case using a novel Interactive and Recursive MCRDR decision structure.
- Separation between classifications and conclusions so that richer classification relationships can be maintained.
- The ability for users to relocate i.e. move RuleNodes in the system.

3 Results of the FastFIX Software Trial

Table 1 summarises user activity during the software trial. 12 users registered themselves, including the author (User ID 12). Most of the registered users were onlookers – managers, team leaders and other interested parties. In addition to the author, there were three main contributors with user IDs 1, 3 and 6. These contributors were able to use the system with minimal training and supervision (less than 60 minutes per contributor). Contributors commenced by providing troubleshooting knowledge for the most frequently occurring sub-domain of troubleshooting errors.

In total 172 cases and 107 RuleNodes were created. The total number of case edits was 139 and the total number of RuleNode edits was 141 demonstrating both the desire and capacity of users to contribute to knowledge evolution in this way. In total there were 104 case drop-throughs resulting from RuleNode creations. As well, there were 96 case drop-through events resulting from RuleNode edits where each of these events may have affected 1 or more cases. Fig. 2 provides a graphical representation of the data in Table 1.

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[1] Wikipedia (http://www.wikipedia.org/) defines a Wiki as the collaborative software and resultant web forum that allows users to add content to a website and in addition, to collaboratively edit it. Wikipedia demonstrates the power of the Wiki paradigm.

[2] The term "folksomony"[2] was first coined by Thomas Vander Wal[2] (2005) to describe forums in which people can tag anything that is Internet addressable using their own vocabulary so that it is easy for them to re-find the item.

Table 1. User Activity in the prototype FastFIX system

User ID	1	2	3	4	5	6	7	8	9	10	11	12	Totals
Total Case Creations	64	0	15	2	2	83	1	1	0	0	1	3	**172**
Total RuleNode Creations	42	0	13	0	0	30	1	0	0	0	0	21	**107**
Total Case Edits	45	0	22	0	0	33	0	0	2	0	7	30	**139**
Total RuleNode Edits	32	0	13	0	0	59	0	0	0	0	0	37	**141**
Total Case drop-throughs resulting from RuleNode Creations	59	0	1	0	0	43	0	0	0	0	0	1	**104**
Total Case drop-through Events resulting from RuleNodeEdits	24	0	6	0	0	48	0	0	0	0	0	18	**96**

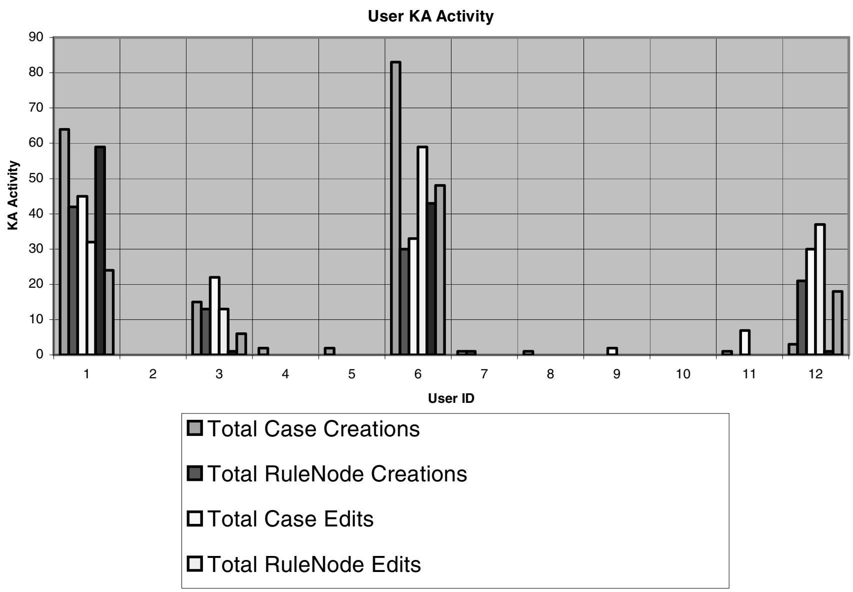

Fig. 2. User Activity in the prototype FastFIX system

3.1 Solution Effectiveness

After 7 hours of effort the test team had captured 105 cases and 55 RuleNodes. The red arrow in each of following figures has been used to indicate this point in time. At this point the team had provided enough RuleNodes to automatically solve approximately 90% of errors on errant equipment in the selected error sub-domain. These errors contribute to 30% of all errors seen by the system which account for 20% of the ~5,000 problem cases per day seen by the global ICT support centre. Hence after 7 hours of effort enough knowledge had been acquired to automatically provide solutions to more than 270 cases per day, without requiring the trouble-shooters to figure out the class of problem on hand, where to search for a solution, or what to search for, for example in the corporate solution tracking system.

Say that each case takes on average 15 minutes to solve, and that 1 minute of this time is spent in determining the problem and finding its solution. This represents a time saving of 1 mins * 270 cases per day, or 4.5 hours per day. Actually, the average solution search time is possibly a lot longer. One of the problems with manually searching for solutions is that if you haven't found the answer, you don't know if its just because your not searching for it correctly, or if its because a solution does not exist. The FastFIX system has the advantage that it unambiguously associates relevant solutions with their incoming problem classes. If the answer is unknown, FastFIX can provide that information.

After the first 105 cases and 55 RuleNodes, the test team broadened the knowledge domain being covered to include a new error sub-domain. This evaluation strategy parallels the strategy used in the 4 year PEIRS SCRDR software trial in which additional domains were incorporated incrementally after the pathologists had gained confidence in the performance of the system with the initially selected thyroid domain [5, p.90]. The trial of the prototype ceased after 107 RuleNodes and 172 cases had been accumulated. At that point, no new information was being gathered and attention was turned to additional features to enhance the system.

3.2 Case Drop-Throughs

Fig 3 shows the cumulative case and RuleNode creations and Case drop-throughs resulting from RuleNode Creations in greater detail. A unique KA Event ID has been assigned to each unique timestamp captured in this subset of data and it has been used to construct the x-axis. It can be observed in Fig 3 that the first 20 RuleNodes were provided to the system in a top-down (and hence rule-driven linear) manner. In contrast, RuleNodes 21 to 55 were provided mostly on the basis of cases seen in a case-driven bottom-up monotonically increasing and stochastic manner as described in [10]. After this point, users were selective in choosing which cases to train the system with, choosing cases that were expected to be novel. Hence RuleNodes 56 to 107 were provided to the system in a more top-down (and hence rule-driven linear) manner as for the first 20 RuleNodes.

It is difficult to say how the ability of users to edit RuleNodes affects the overall case and RuleNode creation trajectories. If most of the RuleNode edits were cosmetic e.g. as a result fixing spelling mistakes then it can be expected that these KA trajectories would be little affected by the RuleNode edits. However, if RuleNode editing represents a significant KA activity whereby genuinely new knowledge is being acquired, rather than existing knowledge being cosmetically corrected, then those RuleNode edit events should be added into the above case-driven KA trajectory. However, it was beyond the scope of this trial to examine this in any detail.

Fig 4 shows the Cumulative Case Creation and RuleNode Edit Curves. The number of RuleNode edits appears to grow in proportion to the number of cases seen by the system, which indicates that RuleNode editing tends to be a top-down knowledge acquisition activity.

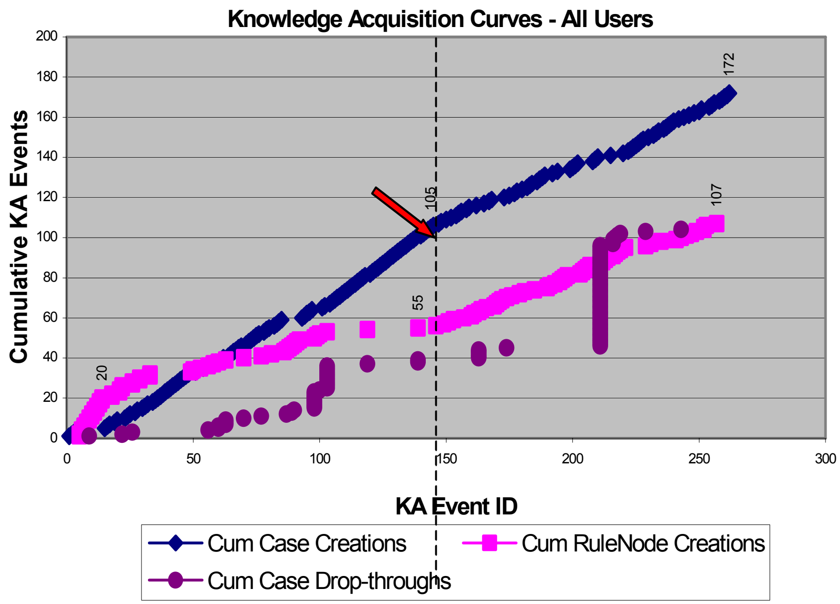

Fig. 3. Cumulative Case and RuleNode Creation Curves

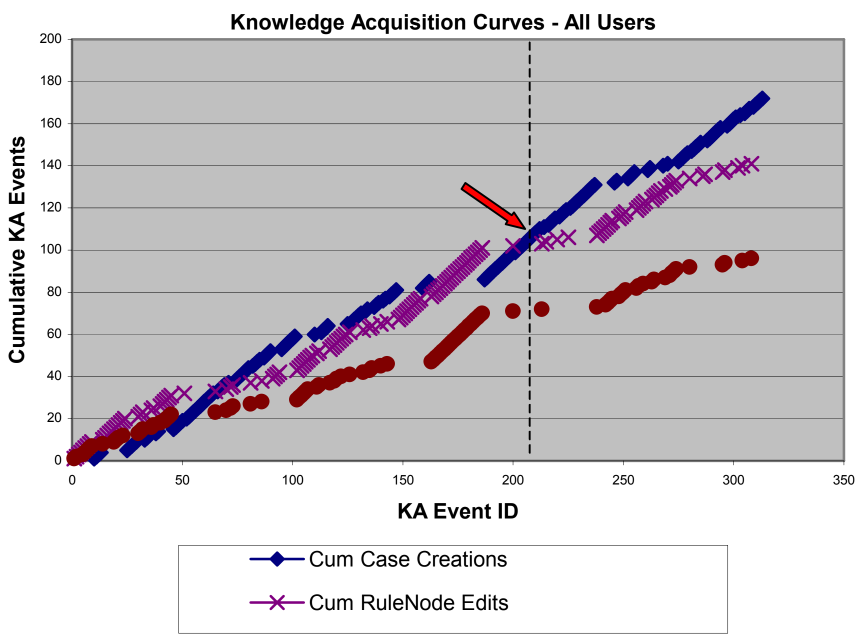

Fig. 4. Cumulative Case Creation and RuleNode Edit Curves

3.3 Individual KA Curves

Individual KA Curves are displayed in the next four figures for the 3 most active users (with User IDs 1, 6, and 12) in the system, including the author (User ID 12).

Vertical lines have been included in the graphs to show the co-occurrence of RuleNode Creations and their resultant case drop-downs, as well as RuleNode Edits and their resultant case drop-down events.

Case edit events have been left out of the curves to allow the rate of RuleNode accumulation to be compared with the rate of Case accumulation.

In Fig. 5, User 1's KA curves show a steady rate of accumulation of both cases and RuleNodes. It appears that RuleNodes are acquired bottom-up prior to the domain change, and top-down thereafter.

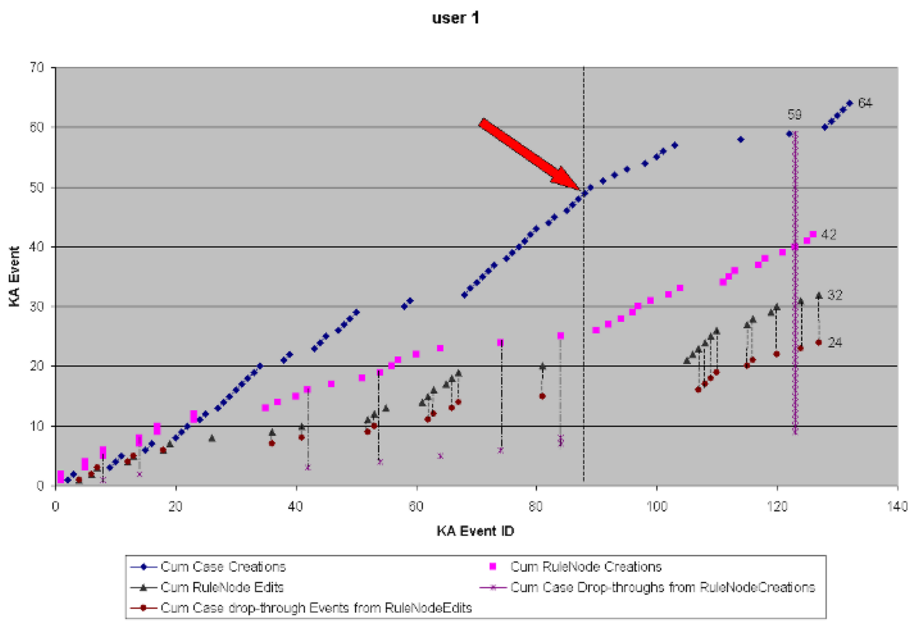

Fig. 5. User 1's KA Curves

In Fig 6, User 6's KA curves show a steady rate of accumulation of both cases and RuleNodes. As for User 1 it appears that RuleNodes are acquired bottom-up prior to the domain change, and top-down thereafter. We can also see that User 6 undertook a major RuleNode editing activity between KA event 80 and 100. This effort was focussed on widening the scope of the rule statements in a number of RuleNodes.

In Fig 7, User 12's (i.e. the author and researcher's) KA curves show a focus on RuleNode edits in the early phases. At this point the system was still under development so both the users and the system were changing in the way they interacted with each-other. User 12 created the first 20 RuleNodes in the system in a top-down fashion after consulting with User 6. In contrast, User 12 was involved in very few case creations.

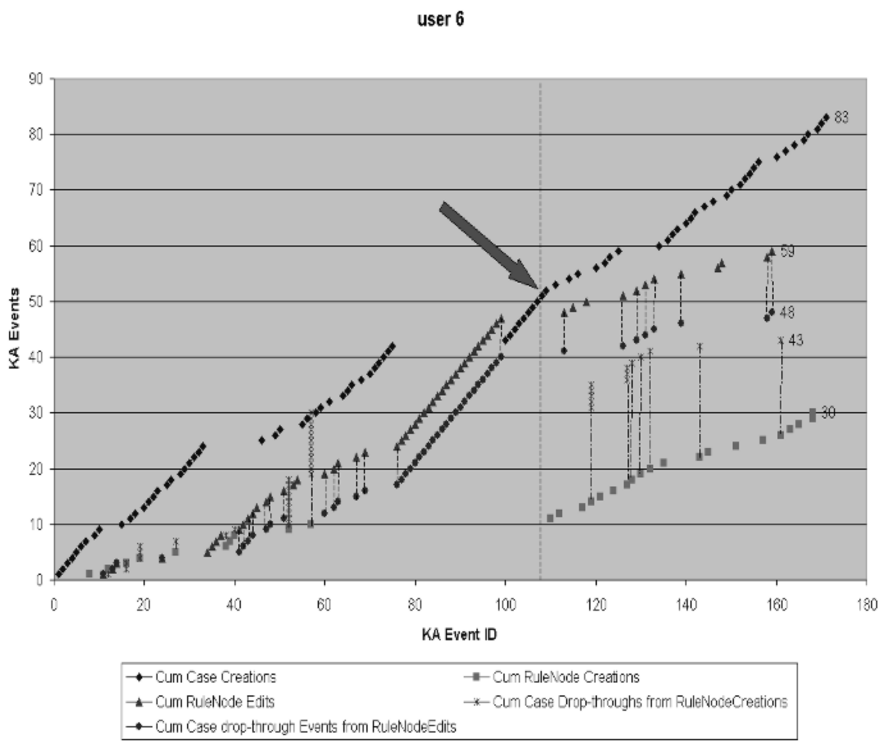

Fig. 6. User 6's KA Curves

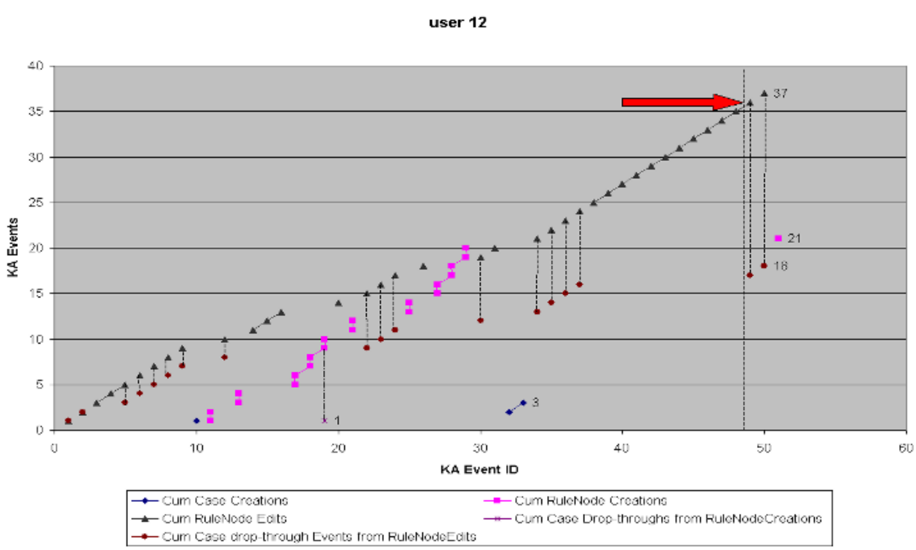

Fig. 7. User 12's KA curves (i.e. the author's)

Note that the initial knowledge base activity by user 12 parallels that reported in the early days of the PEIRS trial. In PEIRS the first 198 rules were added off-line while interfacing problems were sorted out [5, 7]. In FastFIX, the first 21 RuleNodes were added in this manner.

4 Conclusions

In summary, the results of the FastFIX software trial indicate that:

- Users were able to use the system with minimal training and supervision (less than 60 minutes on average per contributor).
- The system was able to support multiple users in collaboratively building the knowledge base, and was effective at communicating to colleagues when changes to the knowledge base occurred that might affect areas of the knowledge base that they had been working on.
- Case drop-downs occurred frequently (in this example, about as frequently as RuleNodes were created and edited), so it appeared to be an important enhancement to separately track the live vs registered RuleNodes for users.
- Given that case drop-downs occurred so frequently, it seemed to be an important enhancement to enable more representative cornerstone cases to be substituted for less representative ones when case drop-down occurred.
- Users were willing and able to work within both a case-based bottom-up and rule-based top-down mindset to edit RuleNodes, and to add knowledge to the decision tree.
- Users took advantage of the ability to label the classification represented by RuleNodes as distinct from the conclusions at that RuleNode. 22 of 106 manually constructed RuleNodes had their classifications labelled.
- Users found cause to refer to conclusions at other RuleNodes even though this feature was only made available at a late stage in the software trial.
- The ability to combine text and hyperlinks in the conclusions at RuleNodes meant that multiple conclusions could be referred to at a single RuleNode.
- Users found cause both to disable some RuleNodes, and to negate the effect of parent RuleNodes under certain rule conditions. Users disabled 10 RuleNodes by editing them and creating rule statements that were `FALSE`. In addition, users created 3 stopping RuleNodes to negate the validity of the parent RuleNode under certain rule conditions.
- Users were able to add new attributes to the system and the system provided a way for users to effectively “work-up” their problem cases via getAttribute() functional conclusions.
- Users were able to add new attributes to the system.
- The system was effective at rapidly acquiring sufficient knowledge to improve the effectiveness and efficiency of troubleshooting in the selected subdomains.

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Intelligent Decision Support for Medication Review

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Abstract. This paper examines an implementation of a Multiple Classification Ripple Down Rules system which can be used to provide quality Decision Support Services to pharmacists practicing medication reviews (MRs), particularly for high risk patients. The system was trained on 84 genuine cases by an expert in the field; over the course of 15 hours the system had learned 197 rules and was considered to encompass around 60% of the domain. Furthermore, the system was found able to improve the quality and consistency of the medication review reports produced, as it was shown that there was a high incidence of missed classifications under normal conditions, which were repaired by the system automatically.

1 Introduction

Sub-optimal drug usage is a serious concern both in Australia and overseas [1, 2], resulting in at least 80,000 hospital admissions annually - approximately 12% of all medical admissions and reflecting a cost of about $400 million annually, with the majority of these affecting elderly patients [3]. MRs are seen as an effective way to improve drug usage. However, the quality of MRs produced is inconsistent across reviewers. Further to this, many community-based pharmacists are still unwilling to undertake this new role, citing reasons including fear of error and a lack of confidence [4].

This paper proposes a different approach to improving the quality of the MRs, and possibly even improving the uptake of the role within the pharmaceutical community. It is suggested that the answer may lie in the development of medication management software which includes Intelligent Decision Support features. To date, the majority of incarnations of medication management software for producing MRs has lacked any form of genuine Decision Support features [5]. Unfortunately, Knowledge Based System (KBS) techniques which may be suitable to this problem have been designed to handle steadfast, well defined sets of knowledge, and have historically not been well suited to poorly structured or dynamic sets of knowledge such as the set found in the domain of MR. However, newer techniques such as Case Based Reasoning (CBR) and Ripple Down Rules (RDR) may offer new possibilities in handling knowledge of this kind, since they are easily, even naturally, maintainable and alterable [6, 7].

A. Hoffmann et al. (Eds.): PKAW 2006, LNAI 4303, pp. 120 – 131, 2006.

2 Medication Reviews

MR is a burgeoning area in Australia and other countries, with MRs seen to be an effective way of improving drug usage and reducing drug related hospital admissions, particularly in the elderly and other high risk patients [1, 3]. This has prompted the Australian government to initiate the Home Medicines Review scheme (HMR) and the Residential Medication Management Reviews (RMMRs) scheme. These schemes provide remuneration to pharmacists performing MRs via a nationally funded program [3]. However, it is known that despite Residential Medication Management Reviews (RMMRs) being introduced in 1997 they still do not have a conceptual model for delivery, which has resulted in a wide range of differing qualities of service being provided [4].

To perform a MR, Pharmacists assess potential Drug Related Problems (DRPs) and Adverse Drug Events[1] (ADEs) in a patient by examining various patient records, primarily their medical history, any available pathology results, and their drug regime (past and current) [8]. The expert looks for a variety of indicators between the case details provided checking for known problems, such as an: Untreated Indication – where a patient has a medical condition which requires treatment but doesn't have the treatment; Contributing Drugs – where a patient has a condition and is on a drug which can cause or exacerbate said condition; High Dosage – where a patient is potentially on a too high dosage because of a combination of drugs with similar ingredients; Inappropriate Drug – where a patient is on a drug that is designed to treat a condition they don't seem to have or is contraindicated in their condition; and many others besides. Once these indicators have been identified a statement is produced explaining each problem, or potential problem, and often what the appropriate course of action is.

3 Methodology

In order to produce a medication management system with intelligent decision support features it was necessary to produce two major software elements. The first was a standard implementation of a database "front-end" from which it is possible for a user to enter all the details of a given patient's case, or at least those parts which are relevant to the chosen domain. The second was an implementation of a Multiple Classification Ripple Down Rules engine which can sufficiently encapsulate the types of conditions and knowledge required for the domain and facilitate the design of an interface from which the engine can be operated, particularly during the Knowledge Acquisition phase.

3.1 Database

The design of the database to store the MR cases was relatively trivial, and will not be given much detail here. The preliminary design idea was taken from existing

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[1] Defined by the World Health Organisation as being "an injury resulting from medical intervention related to a drug." 2. Bates, D., et al., *Incidence of adverse drug events and potential adverse drug events. Implications for prevention. ADE Prevention Study Group.* JAMA, 1995(274): p. 29-34.

medication management software packages, and then extensively modified to allow for proper computerized analysis. The 126 cases considered in this study were then inserted into the database using a simple script which converted them from their current Mediflags [9] format.

3.2 Ripple Down Rules

Ripple Down Rules (RDR) is an approach to building KBSs that allows the user to incrementally build the knowledge base while the system is in use, with no outside assistance or training from a knowledge engineer [7]. It generally follows a forward-chaining rule-based approach to building a KBS. However, it differs from standard rule based systems since new rules are added in the context in which they are suggested.

Observations from attempts at expert system maintenance lead to the realisation that the expert often provides justification for why their conclusion is correct, rather than providing the reasoning process they undertook to reach this conclusion. That is, they say ‘why’ a conclusion is right, rather than ‘how’. An example of this would be the expert stating “I know case A has conclusion X because they exhibit features 1, 4 and 7”. Furthermore, experts are seen to be particularly good at providing comparison between two cases and distinguishing the features which are relevant to their different classifications [10]. With these observations in mind an attempt was made at producing a system which mimicked this approach to reasoning, with RDR being the end result.

3.3 Structure

The resultant RDR structure is that of a binary tree or a decision list [11], with exceptions for rules which are further decision lists. The decision list model is more intuitive since, in practice, the tree would have a fairly shallow depth of correction [12]. The inferencing process works by evaluating each rule in the first list in turn until a rule is satisfied, then evaluating each rule of the decision list returned by that satisfied rule similarly until no further rules are satisfied. The classification that was bound to the last rule that was satisfied is given.

RDR can be viewed as an enhancement to CBR [6, 13, 14], with RDR providing a utility, in the form of an algorithm, a structure and rules, with which to demonstrate which parts of the case are significant to a particular classification [15].

3.4 Multiple Classification Ripple Down Rules

The RDR method described above is limited by its inability to produce multiple conclusions for a case. To allow for this capability - as this domain must - MCRDR should be considered [16] to avoid the exponential growth of the knowledge base that would result were compound classifications to be used.

MCRDR is extremely similar to RDR, preserving the advantages and essential strategy of RDR, but augmented with the power to return multiple classifications. Contrasting with RDR, MCRDR evaluates all rules in the first level of the knowledge base then evaluates the next level for all rules that were satisfied and so on, maintaining a list of classifications that should fire, until there are no more children to evaluate or none of the rules can be satisfied by the current case [12]. An example of this can be seen in Fig. 1.

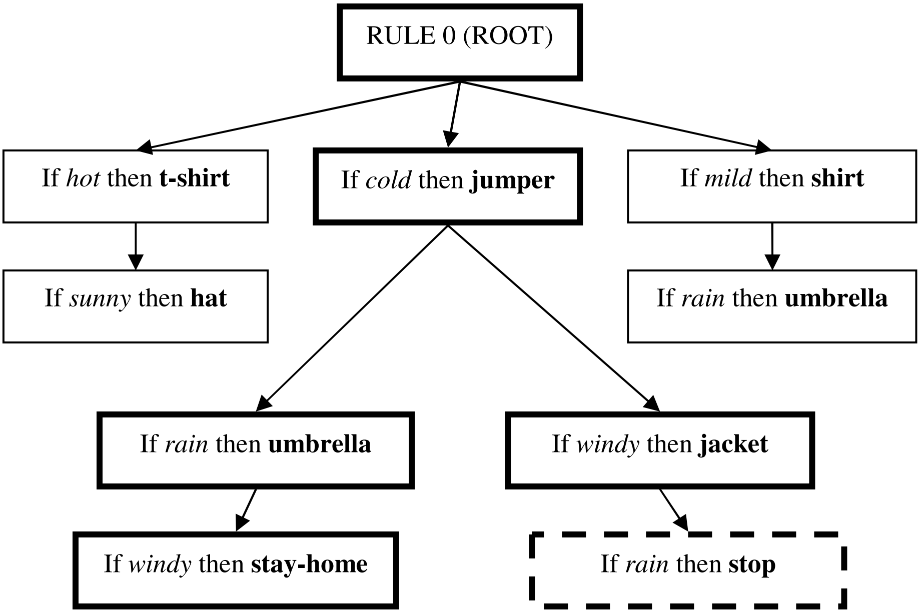

Fig. 1. The highlighted boxes represent rules that are satisfied for the case (cold, rain, windy), the dashed box is a potential stopping rule the expert may wish to add [17]

3.5 Knowledge Acquisition

Knowledge Acquisition is required when a case has been classified incorrectly or is missing a classification. It is divided into three separate steps: Acquiring New Classification (or Conclusion), Locating the New Rule, and Acquiring the New Rule. It should be noted that the order of applying steps one and two is unimportant to the validity of the method [12], and that for the purposes of this experiment it made sense to locate the rule before acquiring the new classification. Hence this is what was done.

Acquiring the New Classification is trivial; the system merely prompts the expert to state it [12]. To Acquire the New Rules the expert is asked to first select valid conditions from the current case that indicate a given classification. The rule they have created thus far is then compared against the cornerstone case base. If any cornerstone cases would fire on this new rule the expert is asked to select from a difference list (see Table 1) between the presented case and one of the cornerstone cases. A cornerstone case is a case for which the knowledge had previously been modified and which is valid under the current context [18]. The system then re-tests all cornerstone cases in the list against the appended set of conditions, removing cases from the list that are no longer satisfied. The system repeats this process until there are no remaining cornerstone cases in the list to satisfy the rule [12] or alternatively the expert has stated explicitly that the cornerstone cases that remain *should* fire on the new rule and this new classification was simply missed when the cornerstone case was originally considered.

Table 1. Example of a decision list from [7, 15, 17, 19]. The list can contain negated conditions.

Cornerstone case	*Current test case*	*Difference list*
Rain	Rain, Meeting	Meeting
Meeting	Meeting	Not applicable
Hot		Not(Hot)

To determine where the new rule must go it must first be determined what type of wrong classification is being made. The three possibilities are listed in Table 2.

Table 2. The three ways in which new rules correct knowledge base [12]

Wrong Classifications	To correct the Knowledge Base
Wrong classification to be stopped	Add a rule (stopping rule) at the end of the path to prevent the classification
Wrong classification replaced by new classification	Add a rule at the end of the path to give the new classification
A new independent classification	Add a rule at a higher level (to the root) to give the new classification

4 Results and Discussion

The system was handed over to the expert with absolutely no knowledge or conclusions pre-loaded. The expert was wholly responsible for populating the knowledge base. Over the course of approximately 15 hours they were able to add the rules required to correctly classify 84 genuine MR cases that had been pre-loaded into the system.

4.1 Growth of Knowledge Base

It is observed in Fig. 2 that the number of rules in the system progressed linearly as more cases were analysed, at a reasonably consistent rate of about 2.3 rules per case. This suggests that the system was still in a heavy learning phase when the experiment was finished, since it has previously been observed that RDR systems will show a flattening pattern in the rate of growth of the knowledge base at approximately 80% of domain coverage [12]. This has complications for many of the remaining tests, in that their results must be understood to reflect the knowledge base while it is still learning heavily. The general conclusion that can be applied here is that most results will be expected to improve with additional testing, and that further testing is indeed required. This is because without demonstrating that the rate of learning has begun to slow down it is impossible to adequately prove that the heavy learning phase, which requires a significantly higher level of expert maintenance, will cease.

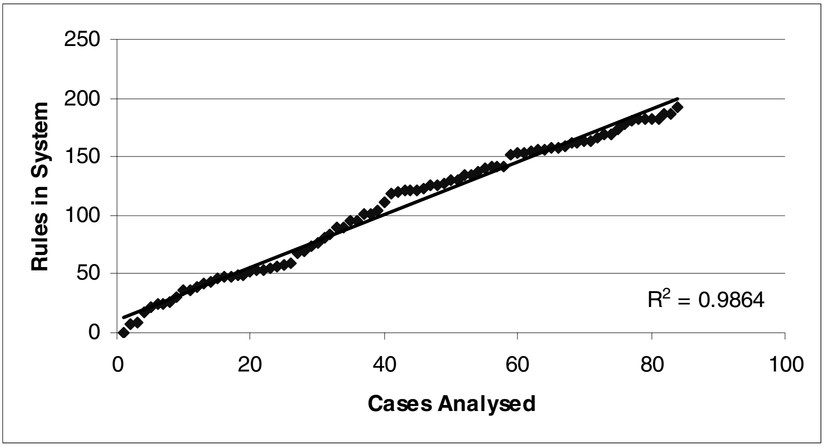

Fig. 2. The number of rules in the system grows linearly as more cases are analysed

4.2 Correct Conclusions Found

It was estimated by the expert at the time of cessation of the experiment that the system had encapsulated around 60% of the domain [20], this estimation is supported by the evidence shown in Figure 3. It can be seen that the average number of correct classifications the system provided rose quite steadily into the 60th percentile, although the percentage correct from case to case did vary quite a lot, as is to be expected when the system is still in the heavy learning phase.

The expert predicted potential classification rates in the order of 90% [20], so considering 84 cases had been analysed it could be estimated that in order to

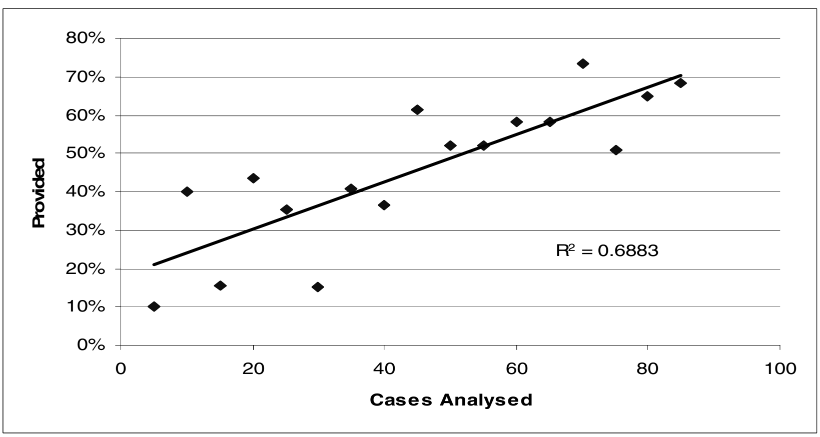

Fig. 3. The percentage of conclusions provided by the system for each case that were already correct

reach this rate at least another 40 cases should be analysed, and it would be unexpected if the number of additional cases needed to be analysed exceeded about 120, based on previous figures found for systems of this kind [12, 18]. These figures are justified by following the trend-line in Figure 3 which shows the clustered average of correct conclusions provided by the system for each group of 5 cases analysed, although it is conceded that this trend-line is only a rough approximation. If it is followed linearly as demonstrated thus far it reaches 90% at approximately 120 cases, if it is assumed that this trend-line may begin to plateau though, as expected, it is possible that the number of extra cases required may grow considerably, to reflect the slower rate of learning.

4.3 Classifications Found, Expert vs. System

The results shown in Figure 4 are very convincing, with the system sometimes finding half again as many classifications per case as the expert and quite consistently remaining at least one classification ahead. It should be re-iterated that the system found all these classifications using only a smaller set of the same knowledge the expert had. This suggests the expert consistently misses classifications they should find. In other words, they just don't notice them on the particular case. The system does not suffer from this, it will notice anything that it is trained to know about without exception.

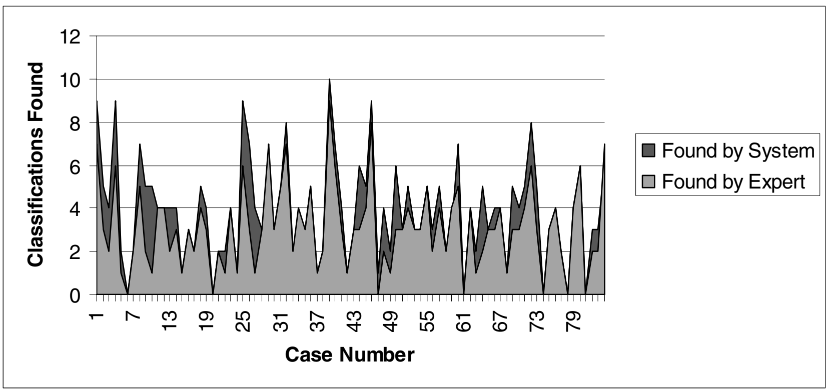

Fig. 4. The system found significantly more correct classifications than the expert

4.4 Percentage of Classifications Missed

It was found that the expert often appended classifications to previous cases after the systems prompting, particularly early in the systems training. Evidence of this is shown in Fig. 5. The percentage reduced dramatically even after only a small number of cases, suggesting the system was rapidly helping to reduce the experts rate of missed classifications, by suggesting the classifications for them, rather than making the expert notice themselves. The trend-line in Fig. 5 is only an approximation, since relatively few cases have been analysed thus far, and noise is still significant.

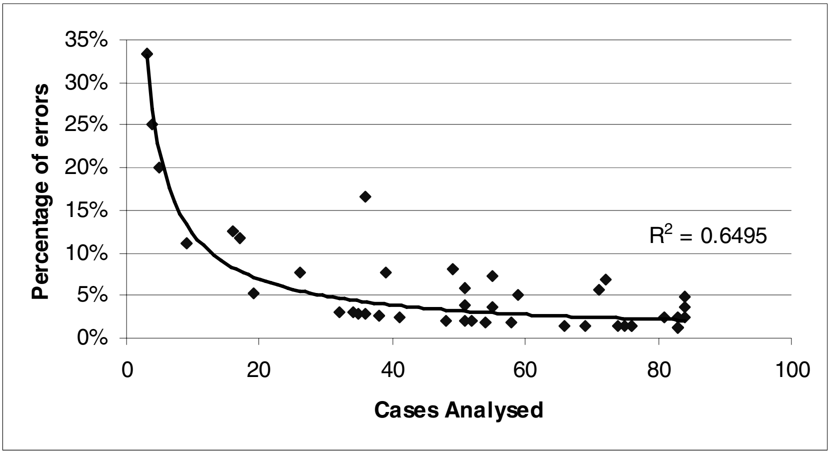

Fig. 5. The percentage of cases that gained new classifications

4.5 Total Errors per Case

It was found that the rate of error in each case was quite high, averaging 13.4% and with some going over 50%. Clearly the expert is making errors regularly, as was expected, and yet these numbers would be expected to be even higher were more complete training done. It is important to note that the results shown in Fig. 6 are representative of all the errors (missed classifications) that the system has fixed through the normal course of operation, and not the actual number of errors per case. This figure suggests that over 1 in 9 classifications are missed, although it is unclear what type of classifications these are. What level of threat are these classifications likely to pose? One would like to assume that the expert would not miss life threatening classifications, because they would have a particular focus on these, but additional experimentation is clearly required to determine what kinds of classifications the expert is missing and what the consequences of this is.

4.6 Maintainability and Usability

It was considered possible that the domain of MR might damage the maintainability and usability of the system due to both its inconsistent/dynamic nature, and the large number of variables within each case. It was considered possible that the dynamic nature of the domain might result in a need for an excessive number of exceptions to be added to the knowledge base, and that the large number of variables within each case may have resulted in an excessive number of conditions required for each rule. Each of these afflictions would increase the time taken to maintain/use the system and possibly make it untenable. As such, tests were carried out to determine whether these figures deviated remarkably from the normal range to be expected in a system of this nature.

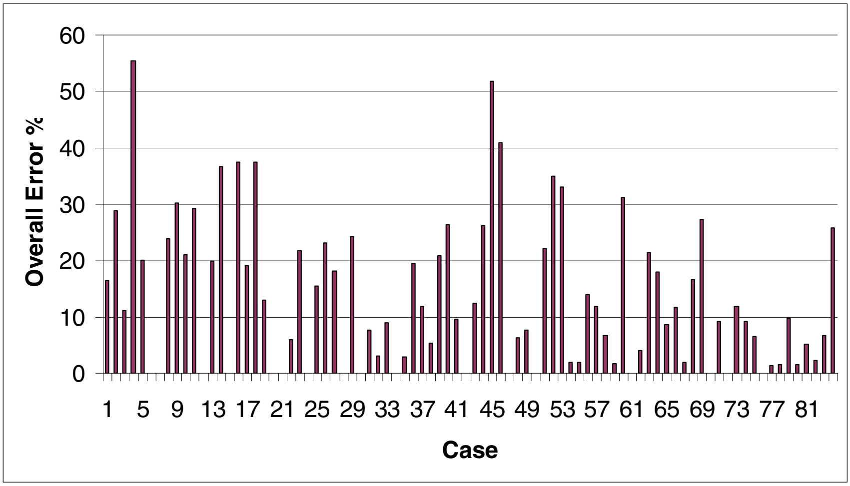

Fig. 6. The final percentage of classifications missed by expert per case

Time Spent: Adding Rules

Previous RDR systems have reported figures of around 3 minutes per rule [18], and it was found that this system continued that trend, with the average time taken to add a rule being 183 seconds (3 minutes).

Time Spent: Analysing Cases

It was found that the average time taken for the expert to complete a case analysis was about 10 minutes (621 seconds). This average extended over the entire 84 cases gives a total expert time taken as about 15 hours as reported earlier. Some cases were done in as few as 2 minutes when no or few new classifications were required, although the process did sometimes reach over 20 minutes.

Cornerstones Seen

The results here are promising from a usability point of view, with the expert rarely having to consider cornerstone cases in the creation of rules, with the majority of rules having no cornerstone cases to consider. In fact the expert saw an average of only 0.42 cornerstones per rule. What this means is that the expert should be able to add rules relatively quickly, with the time required to validate their rules being small.

4.7 Structure of the Knowledge Base

It can be determined from Table 3 that the structure of the knowledge base tree was extremely shallow and branchy, meaning the possibility of an excessive number of exceptions has not, at least at this point, come to light at all.

Table 3. Structure of the Knowledge Base Tree

Tree Property	Value
Average Depth	1.30
Depth 1	139
Depth 2	53
Depth 3	3

The nature of the rules in the knowledge base is also of interest, with further support for the maintainability of the system shown in the fact that the average number of conditions selected in a rule was only 1.7, with longer rules of 4 or 5 conditions being virtually non-existent and no rules with 6 or more being present.

To get a more complete view of the knowledge base it is necessary to analyse what outputs the rules map to. With the knowledge base that was built in the process of this experiment 85 individual conclusions were defined. When it is considered that every rule except stopping rules, of which there are 154, is linked to a conclusion it can be seen that there is 1 conclusion for every 1.8 rules, as can be demonstrated with the data used in Fig. 7. It is evident from this figure that, although most conclusions are only used by one rule, some conclusions are used very often. In other words they have many different sets of conditions which can lead to them.

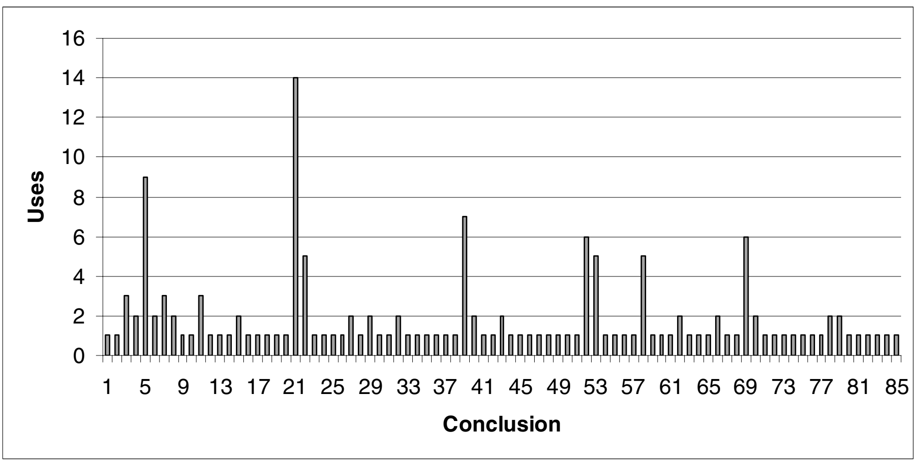

Fig. 7. How many times each conclusion was used

5 Conclusions

Initial experimentation suggests that the proposed method using MCRDR can successfully represent knowledge where the knowledge sources (human experts) are inconsistent. The system is shown to have reached about an 60% classification rate with less than 15 expert hours and only 84 cases classified – a good outcome in the circumstances. The knowledge base structure does not show any major deviations from what would be anticipated in a normal MCRDR system at this stage. The maintainability of the system does not appear to have been adversely affected thus far, with the expert being faced with only few cornerstone cases during the knowledge base validation, and the time taken to add rules being negligible.

From a MR perspective the system is seen to be capable of: providing classifications for a wide range of Drug Related Problems; learning a large portion of the domain of MRs quickly; producing classifications in a timely manner; and importantly, vastly reducing the amount of missed classifications that would otherwise be expected of the reviewer. It is expected that this system, or a future incarnation of this system, would be capable of achieving classification rates around 90% [20]. If this figure is to be realised it is possible that this system would be capable of achieving three major goals:

- Reducing the amount of missed classifications
  - Thus improving the consistency (quality) of service
- Improving the confidence of potential medication reviewers

It has already been noted that the number of errors this system detected and repaired was significant, and the number of errors was seen to reduce as the expert populated the knowledge base and this result alone would be enough to warrant further work. It has also been observed that the amount of time taken to perform a MR using this system should not be adversely affected. As for the final point it is anticipated that a system such as this might improve reviewer's confidence by providing a reliable second level of checking for their conclusions, since this system is designed and trained to act as an expert in the field did.

6 Further Work

It should be noted that the system built for this study was intended only for an initial proof of concept testing. Further testing is needed over a broader range of cases to verify the results shown in this paper, however initial testing does not suggest any insurmountable problems will arise. On top of this, the system could be more powerful and better encompass the domain by including the additional features mentioned below.

6.1 Time Series Data

An important feature that was missing from the prototype was the handling of time series data, such that the expert would be able to define rules such as "increasing" or "decreasing" for things like Weight, Blood Pressure, or a Pathology result. Further still, they might define things like "recent" or "old", which check whether a result is older or younger than defined thresholds, newest, oldest, average and others. As the system stands it will fire on a rule that states "Creatinine > 0.12" even if the result which says their Creatinine level was 0.13 was taken 15 years prior. This is undesirable, with the meaning of the results varying across periods of time such that the expert may wish to define rules based on different types of results.

6.2 Standardisation

It was observed that the knowledge acquisition workload is increased when inconsistent nomenclature is allowed, such as it so often is in many medical systems. To prevent this increased workload for the expert, it would be prudent to derive and enforce a strict scheme for the data input. A possible complication is that users may find it difficult to locate options which are not named as expected. To handle this it would be possible to implement another interpretive layer of hierarchy, essentially allowing the user to use their own preferred nomenclature, and then defining within the system that their chosen nomenclature is synonymous to whichever standardised equivalent is selected by the system designers.

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A Hybrid Browsing Mechanism Using Conceptual Scales

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Abstract. A Web-based document management and retrieval system has been developed aimed at small communities in specialized domains and based on free annotation of documents by users. In the proposed approach, the main search mechanism is based on browsing a concept lattice of Formal Concept Analysis (FCA) formulated with a set of keywords with which users annotated the documents. In this paper, we extend our search mechanism by combining the lattice-based browsing structure with conceptual scales of FCA for ontological domain attributes. Our experience with a prototype suggests that conceptual scaling helps users not only to get more specific search results, but also to search relevant documents by the interrelationship between the keywords of documents and ontological attributes.

Keywords: Conceptual scaling, Browsing mechanism, Formal concept analysis.

1 Introduction

Formal Concept Analysis (FCA) was developed by Rudolf Wille in 1982 [17]. FCA is a theory of data analysis which identifies conceptual structures among data based on the philosophical understanding of a 'concept' as a unit of thought comprising its extension and intension as a way of modeling a domain. The extension of a concept is formed by all objects to which the concept applies and the intension consists of all attributes existing in those objects. This results in a lattice structure, where each node is specified by a set of objects and the attributes they share. The mathematical formulae of FCA can be considered as a machine learning algorithm which can facilitate automatic document clustering. A key difference between FCA techniques and general clustering algorithms in Information Retrieval is that the mathematical formulae of FCA produce a concept lattice which provides all possible generalization and specialization relationships between object sets and attribute sets. This means that a concept lattice can represent conceptual hierarchies, which are inherent in the data of a particular domain.

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FCA has been successfully applied to a wide range of applications. A variety of methods for data analysis and knowledge discovery in databases have also been proposed based on FCA. A number of researchers have proposed an FCA lattice structure for document retrieval [2], [10], [14]. Several researchers have also studied the lattice-based information retrieval with graphically represented lattices for specific domains such as flight information, e-mail management and real estate advertisements [4], [5], [7]. Recently, FCA has been also applied to ontology engineering for structuring and building of ontologies [3], [15].

We also proposed a theoretical framework for a Web-based document management and retrieval system aimed at small communities in specialized domains based on FCA [13]. This approach allowed users themselves to freely annotate their documents. Any relevant documents can be managed by annotating with any terms the users or authors prefer. A number of annotation support tools were proposed not only to allow users to find appropriate annotations for their documents but also to be able to evolve a terminological domain ontology. This resulted in the automatic generation of a lattice-based browsing system which holds hierarchical inheritance relationships among the evolved terms (concepts) in the lattice structure. Document retrieval is based on navigating this lattice structure.

Experiments were conducted in the domain of annotating researchers' home pages according to their research interests in the School of Computer Science and Engineering, University of New South Wales (UNSW). The goal was a system to assist prospective students and potential collaborators in finding research (i.e., staff and student home pages) relevant to their interests. Results indicated that the annotation tools provided a good level of assistance so that documents were easily organized and a lattice-based browsing structure that evolves in an *ad hoc* fashion provided good efficiency in retrieval performance. It was also clear from the results that there is an advantage in lattice-based browsing over hierarchical browsing. The findings suggested that the concept lattice of FCA, supported by annotation techniques was a useful way of supporting the flexible open management of documents required by individuals, small communities and in specialized domains.

In our approach, the main search mechanism is based on browsing a concept lattice of FCA formulated with a set of keywords with which users annotated documents. This concept lattice is reformulated dynamically and incrementally by the addition of a new document with a set of keywords or by refining the existing keywords of the documents. The concept structure can fit into a predetermined terminological ontology used for browsing in information retrieval.

In this paper, we extend our search mechanism by combining the lattice-based browsing structure with conceptual scales of FCA for ontological information. The purpose of this is to allow a user to get more specific search results and to reduce the complexity of the visualization of the browsing structure. The more fundamental purpose of this is to support a hybrid browsing mechanism by combining a structure with keywords and a structure with ontological attributes. This is to allow a user to search relevant documents by the interrelationship between the keywords of documents and ontological domain attributes. The properties such as *author*, *title* and *publication year* can be ontological attributes in a domain relevant to papers. The ideal would be to support both approaches simultaneously because the organization of background knowledge, not only with the vocabularies in taxonomies but also with ontological structures in the form of properties, would be useful for navigating document. For example, a user may want to find papers which are related to “knowledge acquisition” at first. Then, the user wants to see recently published papers only among the search result (i.e., “publication year” ≥ 2005).

This paper is organized as follows. Section 2 gives a brief description of FCA. Section 3 presents a formal framework of conceptual scaling to combine the lattice-based browsing structure with conceptual scales of FCA for ontological attributes. Section 4 describes a system implemented on the Web to demonstrate the value of conceptual scaling. We then conclude with a discussion of possible future directions of the research presented in this paper.

2 Formal Concept Analysis

2.1 Basic Notions of Formal Concept Analysis

FCA starts with a formal context which is a binary relation between a set of objects and a set of attributes. It was defined for the document retrieval system that we proposed in the paper [13] as follows: A *formal context* is a triple $C = (D, K, I)$ where D is a set of documents (objects), K is a set of keywords (attributes) and I is a binary relation which indicates whether k is a keyword of a document d. If k is a keyword of d, it is written dIk or $(d, k) \in I$.

For the domain of research interests used for experiments in the previous work [13] and used in this paper, a document corresponds to a home page and a set of keywords is a set of research topics. That is, D is the set of home pages and K is the set of research topics for a context (D, K, I). However, the word *documents* and *keywords* are also used interchangeably to denote *home pages* (or simply *pages*) and *research topics* (or simply *topics*), respectively in this paper.

From the formal context, formal concepts and a concept lattice are formulated. A formal concept consists of a pair with its extent and intent. The extension of a concept is formed by all objects to which the concept applies and the intension consists of all attributes existing in those objects. These generate a conceptual hierarchy for the domain by finding all possible formal concepts which reflect a certain relationship between attributes and objects. The resulting subconcept-superconcept relationships between formal concepts are expressed in a concept lattice which can be seen as a semantic net providing “hierarchical conceptual clustering of the objects… and a representation of all implications between the attributes” [18, pp.493]. The implicit and explicit representation of the data allows a meaningful and comprehensible interpretation of the information. This lattice is used as the browsing structure. Fig. 1 shows an example of a lattice and a data structure for organizing documents in the lattice. More detailed formulae and explanations of FCA can be found in [9], [13].

2.2 Conceptual Scaling

Conceptual scaling has been introduced in order to deal with many-valued attributes [8], [9]. Usually more than one attribute exists in an application domain and each attribute may have a range of values so that there is a need to handle many values in a context.

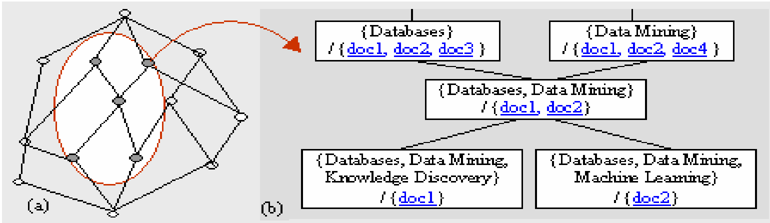

Fig. 1. An example of a browsing structure. (a) Lattice structure. (b) Indexing of the lattice.

In addition, often there is a need to analyze (or interpret) concepts in regard to interrelationships between attributes in a domain. This is the main motivation for conceptual scaling.

For instance, the domain of a "used car market" consists of a number of attributes such as *price*, *year built*, *maker*, *color*, *transmission* and others, and each attribute with a set of values. Such attributes can be considered all together in a context named with a many-valued context. Then, when one is interested in analyzing "used cars" regarding an interrelationship between certain attributes in the many-valued context, they can combine the attributes of interest into a concept lattice. This means that each attribute, or a combination of more than one attribute of the many-valued context, can be transformed into a one-valued context. The derived one-valued context is called a conceptual scale. Then, if one is interested in analyzing the interrelationship between attributes, s/he can choose and combine the conceptual scales which contain the required attributes. This process is called conceptual scaling. A case for the use of this can be seen with TOSCANA[11] and [4]. Conceptual scaling is also used with one-valued contexts in order to reduce the complexity of the visualization [5], [16]. In this case, scales are applied for grouped vertical slices of a large context.

3 Formal Framework of Conceptual Scaling

There are two ways in which we use conceptual scales. Firstly, ontological attributes can be used where readily available (e.g., person, academic position, research group and so on). These correspond to the more structured ontological properties used systems such as Ontoshare[6] and CREAM[12]. The key point of our approach is flexible evolving ontological information but there is no problem with using more fixed information if available. We have included such information for interest and completeness in conceptual scaling. Secondly, a user or a system manager can also group a set of keywords used for the annotation of documents. The groupings are then used for conceptual scaling.

The main difference between our approach and conceptual scaling in TOSCANA is that in our approach all the existing ontological attributes are scaled up together in the nested structure. On the other hand, in the TOSCANA system only one attribute (i.e., a scale) can be combined into the outer structure of an attribute at a time.

3.1 Conceptual Scaling for Ontological Attributes

A many-valued context for ontological attributes is defined as a formal context $C = (D, M, W, I)$ where D is a set of documents, M a set of attributes, W a set of attribute values. I is a ternary relation between D, M and W which indicates that an document d has the attribute value w for the attribute m. We formulate a concept lattice with a set of documents and their keywords. This lattice structure is the main browsing space, but is also an outer structure. Other attributes in a many-valued context are then scaled into a nested structure of the outer structure at retrieval time.

Table 1 is an example of a many-valued context in the domain of research interests. Researchers can be the objects of the context as they are the instances of the home pages. The attributes in the many-valued context can be represented in a partially ordered hierarchy as shown in Fig. 2. The attribute "*position*" in Table 1 is located as a subset of the attribute "*person*" in the hierarchy.

Table 1. An example of the many-valued context for the domain of research interests

	Research group	Sub-group of AI	Person	Position
Researcher1	Artificial intelligence	Knowledge Acquisition	Academic staff	Professor
Researcher2	Computer systems	-	Research staff	Research associate
Researcher3	Networks	-	Academic staff	Associate professor
Researcher4	Databases	-	Academic staff	Senior lecturer
Researcher5	Software engineering	-	Research student	Ph.D. student

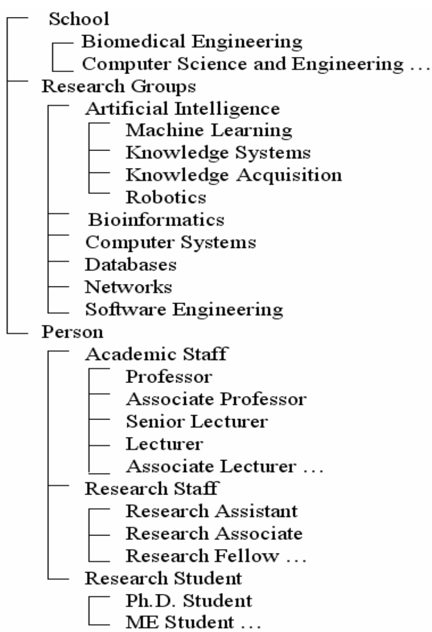

Fig. 2. Partially ordered multi-valued attributes for the domain of research interests

To explain this in a more formal way, the following definition is provided. For example, the has-value relation $\Re$ on the attributes "*person*" and "*position*" is: $\Re$ = {(academic staff, professor), (academic staff, associate professor), …, (research staff, research assistant), …, (research student, Ph.D. student), (research student, ME student)} from Fig. 2. This hierarchy of the many-valued context with the relation $\Re$ is scaled into a nested structure using pop-up and pull-down menus.

Definition 1. Let S_p be a super-attribute and S_c be a sub-attribute. There is a binary relation $\Re$ called the "has-value" relation on S_p and S_c such that $(p, c) \in \Re$ where $p \in S_p$ and $c \in S_c$ if and only if c is a sub-attribute value of p.

Fig. 3 shows examples of inner browsing structures corresponding to concepts of the outer lattice. A nested structure is constructed dynamically from the extent (home pages) of a corresponding concept of the outer lattice incorporating the ontological hierarchy. When a user assigns a set of topics for their page, the page is also automatically annotated with the values of the attributes in the many-valued context. A default home page for individual researchers is provided on the School Web site and as well as every researcher has a login account at the School. We make use of this login account when a user annotates their home page. This provides the default home page address of the user.

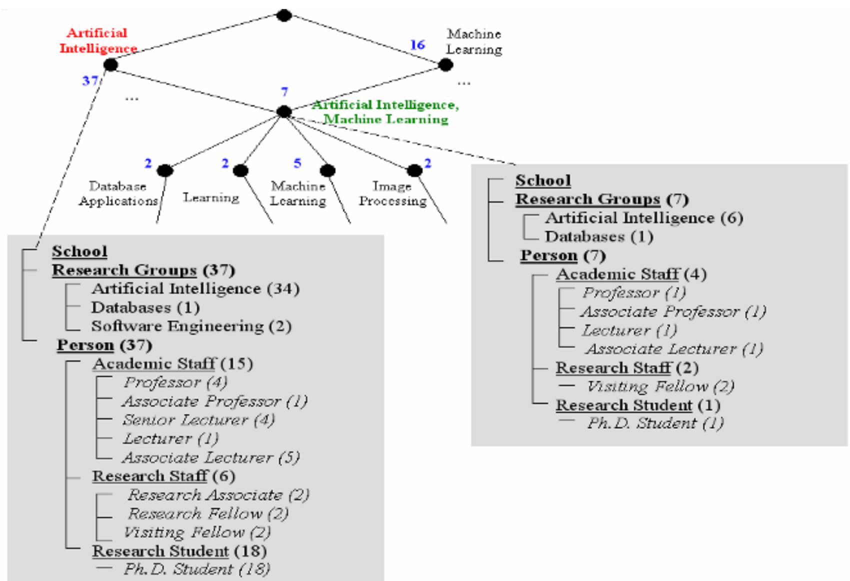

Fig. 3. Examples of nested structures corresponding to concepts. This shows the outer structure of the concepts "artificial intelligence" and "artificial intelligence, machine learning" constructed from a set of home pages and their topics. Numbers in the lattice and in brackets indicate the number of pages corresponding to the concept of the lattice and the attribute value, respectively. The nested structure is presented in a hierarchy deploying all embedded inner structures. The structure is implemented using pop-up and pull-down menus as shown in Fig. 4.

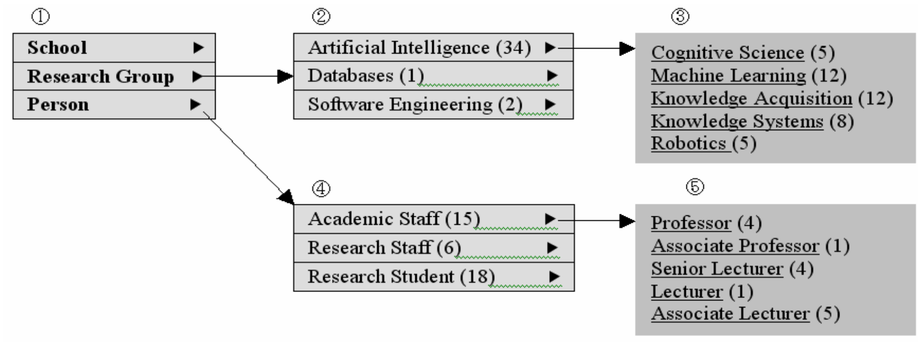

Fig. 4. An example of pop-up and pull-down menus for the nested structures of a concept

The page is an HTML file in a standard format including the basic information about the researcher such as their first name, last name, e-mail address, position and others. The system parses the HTML file and extracts the values for the pre-defined attributes. From the attributes and their extracted values, we formulate a nested structure for a concept of the lattice at retrieval time. Note that the attributes which do not exist in the default home page can be used for conceptual scaling. The user will need to provide the values of those attributes when they assign a set of keyword for their document. For this case, a simple interface to click selection of values or a series of text boxes to be filled is given to the user.

A user can navigate recursively among the nested attributes observing the interrelationship between the attributes and the outer structure. By selecting one of the nested items, the user can moderate the cardinality of the display. Again, the structure with the most obvious attributes can be partly equivalent to the ontological structure of the domain and consequently is considered as an ontological browser which is integrated into the lattice structure with the keywords set.

Fig. 4 shows an example of pop-up and pull-down menus for the nested structure of the concept "artificial intelligence" in Fig. 3. The menu of ① appears when a user clicks on the concept "artificial intelligence". Each item of menu ① is equivalent to a scale in the many-valued context. Suppose that the user selects the attribute *Person* in menu ①, the system then will display a sub-menu of the attribute as shown in menu ④.

3.2 Conceptual Scaling for Grouping Keywords

Conceptual scaling is also applied to group relevant values in the keyword sets used for the annotation of documents. The groupings are determined as required, and their scales are derived on the fly when a user's query is associated with the groupings. This means that the relevant group name(s) is included into the nested structure dynamically at run time. Table 2 shows examples of groupings for scales in the one-valued context for the attribute '*keyword*'. To deal with grouping for scales, the following definition is provided:

Definition 2. Let a formal context $C = (D, K, I)$ be given. A set $G \subseteq K$ is a set of grouping names (generic terms) of C if and only if for each keyword $k \in K$, either $k \in G$ or there exists some generic term $\kappa \in G$ such that k is a sub-term of κ. We define $S = K \setminus G$ and a relation $gen \subseteq G \times S$ such that $(g, s) \in gen$ if and only if s is a sub-term of g.

Table 2. Examples of grouping for scales in the one-valued context for the attribute '*keyword*'

Grouping (generic) names	The members of the grouping names
RDR	FRDR, MCRDR, NRDR, SCRDR
Sisyphus	Sisyphus-I, Sisyphus-II, Sisyphus-III, Sisyphus-IV, Sisyphus-V
Knowledge acquisition	Knowledge acquisition methodologies, Knowledge acquisition tools, Incremental knowledge acquisition, Automatic knowledge acquisition, Web based knowledge acquisition, …
Computer programming	Concurrent programming, Functional programming, Logic programming, Object oriented programming, …
Programming languages	Concurrent languages, Knowledge representaion languages, Logic languages, Object oriented languages, …
Databases	Deductive databases, Distributed databases, Mobile databases, Multimedia databases, Object oriented databases, Relational databases, Spatial databases, Semistructural databases
…	…

Then, when a user's query is $qry \in G$, a *sub-formal context* $C' = (D', K', I')$ of (D, K, I) is formulated where $K' = \{k \in K \mid k = qry$ or $(qry, k) \in gen\}$, $D' = \{d \in D \mid \exists k \in K'$ and $dIk\}$ and $I' = \{ (d, k) \in D' \times K' \mid (d, k) \in I\} \cup \{ (d, qry) \mid d \in D'$ and $qry \in K' \cap G\}$. For instance, suppose that there are groupings as shown in Table 2 and a user's query "*databases*". The query *databas*es $\in G$ so that a sub-context C' is constructed to include a scale of the grouping name *databases* and build a lattice of C'. The user can then navigate this lattice of C'.

Fig. 5 shows an example of a scale with the grouping name "*databases*". The grouping name is embedded into an item of the nested structure along with other scales from the many-valued context in the previous section. There are 12 documents with the concept "Databases" in the lattice, and the node (Databases, 12) embeds the scales as shown in menu ①. The scale "Databases" was derived from the groupings in the one-valued context, while other scales (items) were derived from the many-valued context (i.e., ontological attributes). A user can read that there is one document related to "deductive databases", and two documents with "multimedia databases" etc. By selecting an item of sub-menu ②, the user can moderate the retrieved documents which are only associated with the selected sub-term.

A knowledge engineer/user can set up or change the groupings using a supported tool (i.e., ontology editor) whenever it is required. When a grouping name with a set of sub-terms is added, the system gets the set of documents that are associated with at least one of the sub-terms of the grouping name. Then, the context C is refined to have a binary relation between the grouping term and the documents related to the sub-terms of the grouping term. Next, the lattice of C is reformulated when any change in C is made. If a grouping name is changed, it is replaced with the changed one in the context C and its lattice.

In the case of removal of a grouping in the hierarchy, no change is made in the context C. With this mechanism, the outer lattice can always embed a node which can assemble all documents associated with the sub-terms of a grouping. That is, the.

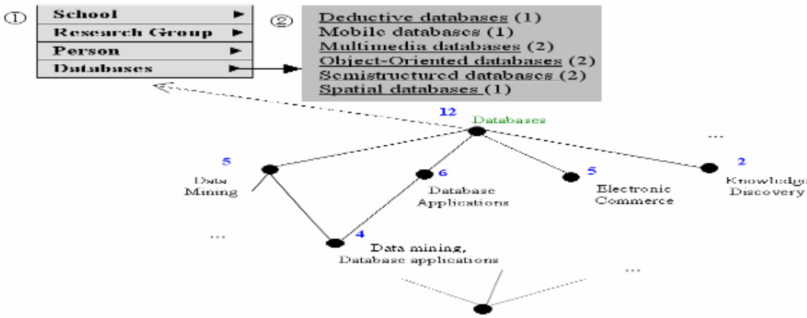

Fig. 5. A conceptual scale for the grouping name "*databases*"

groupings play the role of intermediate nodes in the lattice to scale the relevant values. Groupings can be formed with more than one level of hierarchy. This means that a sub-term of a grouping can be a grouping of other sub-terms.

4 Implementation

To examine the value of conceptual scaling, a prototype has been implemented with a test domain for research topics in the School of Computer Science and Engineering, UNSW. There are around 150 research staff and students in the School who generally have homepages indicating their research projects. The aim here was to allow staff and students to freely annotate their pages so that they would be found appropriately within the evolving lattice of research topics.

Fig. 6 shows an example of conceptual scaling for ontological attributes. It shows examples of inner browsing structures corresponding to the concept "*Artificial Intelligence*" of the outer lattice. We scale up ontological attributes into an inner nested structure. The nested structure is constructed dynamically and associated with the current concept of the outer structure. In other words, the nested attribute values are extracted from the result pages. A nested pop-up menu appears when the user clicks on the "nested" icon in the front of the current node. If the user clicks on one of the attributes items, the results will be changed according to the selection. The user can navigate recursively among the nested attributes.

For instance, we suppose that the user selects the attributes items *Position* → *Academic Staff* → *Professor*. The result then will be changed accordingly. The user can see that there are four researchers whose research topic is "*Artificial Intelligence*" and whose position is *Professor*. Numbers in brackets indicate the number of documents (i.e., homepages) corresponding to the attribute value.

As well, a knowledge engineer can arrange related terms by accessing a tool which allows him or her to set up hierarchical grouping related terms under a common name as described in Section 3.2. Then, when a user's query is related to the grouping(s), the grouping name is included into the inner structure on the fly. Fig. 7 shows an example of conceptual scaling for the grouping "*Databases*". Other items (i.e., *School, Research Groups, Position*) are derived from the ontological attributes. There are 12 documents with the concept "*Databases*" in the lattice.

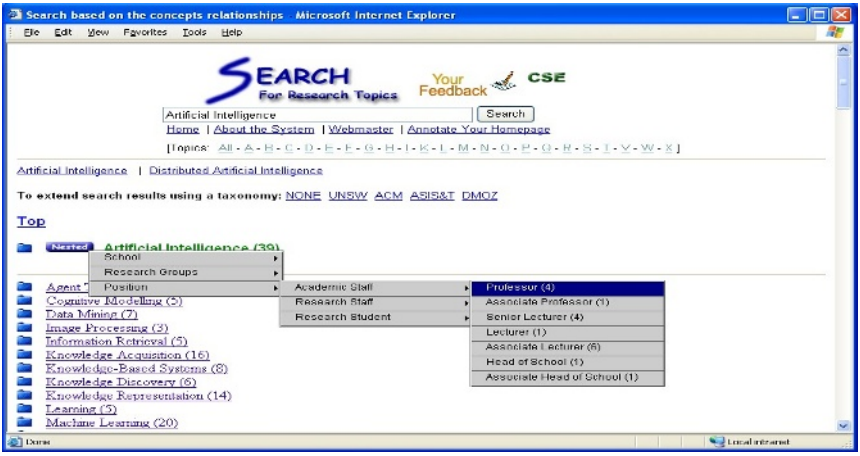

Fig. 6. An example of conceptual scaling for ontological attributes

Fig. 7. An example of conceptual scaling for the grouping "*Databases*"

The user can read that there is one document related to "*Mobile databases*", two documents with "*Multimedia databases*" and so on. By selecting one of the grouping members, the user can moderate the retrieved documents which are only associated with the selected sub-term.

5 Discussion and Conclusion

Having completed a prototype implementation of the presented approach, it seems clear that conceptual scaling facilitates users to get more specific results and to search relevant documents by the interrelationship between the keywords of documents and the domain attributes.

Another purpose of conceptual scaling in our approach was to support a hybrid browsing mechanism by connecting an outer structure with keyword sets of documents (terminological ontology) and an inner nested structure with ontological attributes (ontological structure). The ideal would be to support both approaches simultaneously because the organization of background knowledge, with the vocabularies in taxonomies as well as with ontological structures in the form of properties, would be useful for navigating information.

More fundamentally, conceptual scaling is to deal with multiple Boolean attributes which hold multiple inheritance relations within a one-valued context of FCA. The essence of conceptual scaling is to impose on this a single inheritance hierarchy or equivalently some of the Boolean attributes are reorganized as being mutually exclusive values of some unnamed attributes. Either way there is recognition that a group of Boolean attributes are mutually exclusive. In conceptual scaling, one selects one of the mutually exclusive attributes from a set and a sub-lattice containing these values is shown. A number of attribute selections can be made at the same time to give the sub-lattice. Existing attributes can be used as the parent of a group of mutually exclusive attributes or new names for the grouping can be created.

We had previously carried out user studies on the general usefulness of evolving ad hoc lattices [13]. A next step is to evaluate the usefulness of our approach to conceptual scaling and its scalability with large data sets. The user interface for conceptual scaling also needs to be improved. Users may want to find documents from ontological attributes first, then scale up their search result with keyword sets (i.e., the opposite of the current interface) or interchangeably.

Further work would be related to the extension of our approach regarding ontologies. We have adapted conceptual scaling of FCA to scale up the browsing structure derived from the keywords of documents with ontological information where readily available such as *person*, *academic position* and *research group*. However, ideally we would derive conceptual scales from an existing ontology, which is imported from standards or constructed for the system. The use of these scales could be automated if the document was appropriately marked up according to the ontology. This would give us a system that was flexible and open, but also had the type of ontological commitment represented by the KA^2 initiative[1] and CREAM[12]. It will be interesting to examine the trade-offs in allowing such requirements to emerge rather than anticipating them and also the relative costs in marking up documents rather than providing information to a server.

It will be also essential to use one of ontology representation languages such as RDF, OIL and OWL as standards instead of the proprietary text formats used currently both for the concept lattice and the ontological attributes.

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Knowledge Representation for Video Assisted by Domain-Specific Ontology

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Abstract. Video analysis typically has been pursued in two different directions. Either previous approaches have focused on low-level descriptors, such as dominant color, or they have focused on the video content, such as person or object. In this paper, we present a video analysis environment not only to bridge these two directions but also can extract and manage semantic metadata from multimedia content autonomously for addressing the interaction between browsing and search capabilities. Concretely speaking, we implemented a tool that links MPEG-7 visual descriptors to high-level, domain-specific concepts. Our approach is ontology-driven, in the sense that we provide ontology based domain-specific extensions of the standards for describing the knowledge of video content. In this work, we consider one shot (episode) in the billiard game of video as the specific domain and we will be through the practical works to explain the process of representation of video knowledge. In the experiment part, we prove our approach effectiveness by comparing with the video content retrieval based on only key-word.

1 Introduction

Although new multimedia standards, such as MPEG-4 and MPEG-7 [1], provide the needed functionalities in order to manipulate and transmit objects and metadata, their extraction, and that most importantly at a semantic level, is out of the scope of these standards and is left to the content developer. Extraction of low-level features and object recognition are important phases in developing multimedia database management systems.

There has been a research focus to develop techniques to annotate the content of images on the Web using Web ontology languages such as RDF and OWL. Past efforts have largely focused on mapping low-level image features to ontological

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concepts [2] and have involved the development of tools that are closely tied to domain specific ontologies for annotation purposes [3,4]. Additionally, the lack of precise models and formats for object and system representation and the high complexity of multimedia processing algorithms make the development of fully automatic semantic multimedia analysis and management systems a challenging task. This is due to the difficulty that often mentioned as the semantic gap. The use of knowledge domain is probably the only way by which higher level semantics can be incorporated into techniques that capture the semantic concepts. So, in this paper, a comprehensive method for video content analysis based on the specific knowledge domain was proposed using on the tools of Protégé which is the classical ontology editor and PhotoStuff that is the most promising annotation software that allows users to makeup of an image/video key-frame with respect to concepts in an ontology.

We organize the remainder of the paper as follows: Section 2 is about the overview for video analysis. Section 3 introduces the infrastructure of domain knowledge. As the major part, section 4 shows us how to present video content through one specific domain ontology. It contains two sub-sections: ontology building and mapping from the low-level features to high-level semantics for video knowledge representation. And, Analysis results for video content retrieval are showed in Section 5. After these comprehensive explanations, we will conclude in section 6.

2 Overview for Video Analysis

Video is a structured medium in which actions and events in time and space convey stories, so, a video program (raw video data) must be viewed as a document, not a non-structured sequence of frames.

From Figure 1, we can see the second layer: video conceptual feature which was represented by video shots that are the basic units used for accessing video and a sequence of frames recorded contiguously and re-presenting a continuous action in

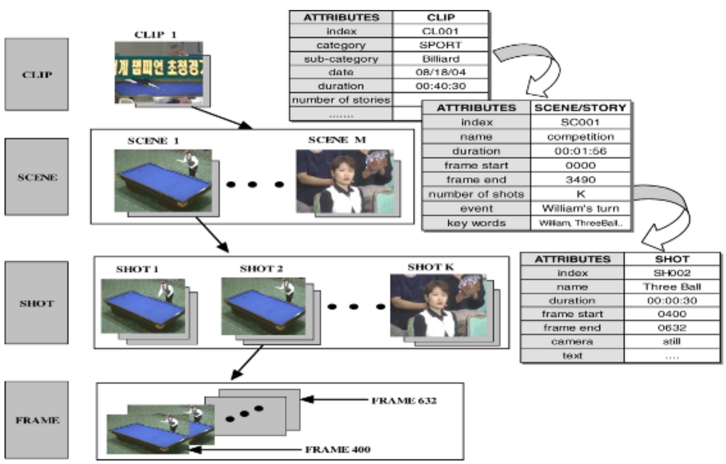


Fig. 1. Video Modeling and Representation

time or space. And we consider a shot that contains a series of actions that can be used to express one meaningful event in the video as one Knowledge Domain.

Since there are three frame types (I, P, and B) in a MPEG bit stream, we first propose a technique to detect the scene cuts occurring on I frames, and the shot boundaries obtained on the I frames are then refined by detecting the scene cuts occurring on P and B frames. For I frames, block-based DCT is used directly as

$$F(u,v) = \frac{c_u c_v}{4} \sum_{x=0}^{7} \sum_{y=0}^{7} I(x,y) \times \cos\frac{(2x+1)u\pi}{16} \cos\frac{(2y+1)v\pi}{16} \tag{1}$$

Where

$$C_u, C_v = \begin{cases} \frac{1}{\sqrt{2}} & \text{for } u,v=0 \\ 1 & \text{otherwise} \end{cases} \tag{2}$$

One finds that the dc image [consisting only of the dc coefficient (u=v=0) for each block] is a spatially reduced version of I frame. For a MPEG video bit stream, a sequence of dc images can be constructed by decoding only the dc coefficients of I frames, since dc images retain most of the essential global information of image components.

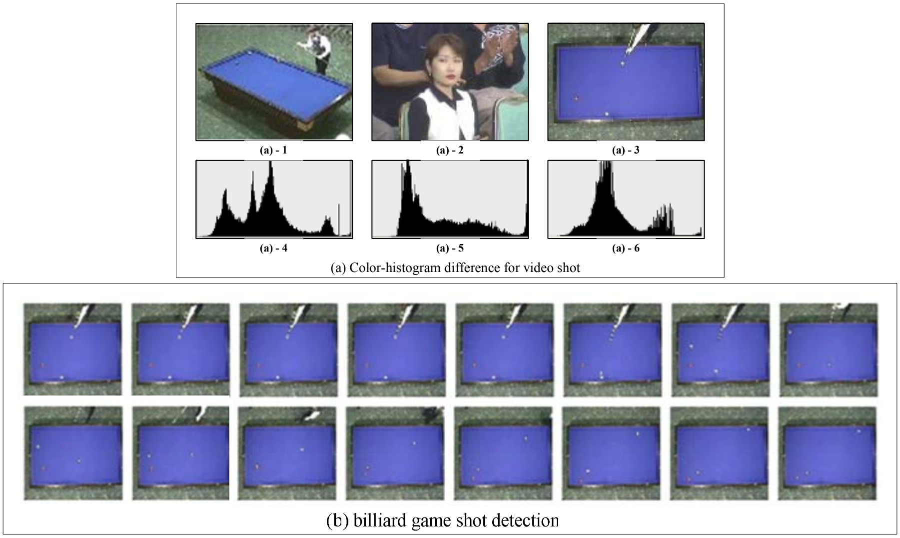
Yeo and Liu have proposed a novel technique for detecting shot cuts on the basis of dc images of a MPEG bit stream, [5] in which the shot cut detection threshold is determined by analyzing the difference between the highest and second highest histogram difference in the sliding window. In this article, an automatic dc-based technique is proposed which adapts the threshold for shot cut detection to the activities of various videos. The color histogram differences (HD) among successive I frames of a MPEG bit stream can be calculated on the basis of their dc images as

$$HD(j, j-1) = \sum_{k=0}^{M} [H_{j-1}(k) - H_j(k)]^2 \tag{3}$$

where $H_j(k)$ denotes the dc-based color histogram of the jth I frame, $H_{j-1}(k)$ indicates the dc-based color histogram of the (j – 1)th I frame, and k is one of the M potential color components. The temporal relationships among successive I frames in a MPEG bit stream are then classified into two opposite classes according to their color histogram differences and an optimal threshold $\overline{T_c}$,

$$\begin{aligned} &HD(j, j-1), > \overline{T_c}, \quad \textit{shot\_cut,} \\ &HD(j, j-1), \le \overline{T_c}, \quad \textit{non\_shot\_cut} \end{aligned} \tag{4}$$

The optimal threshold $\overline{T_c}$ can be determined automatically by using the fast searching technique given in Ref. [5]. The video frames ~including the I, P, and B frames. Between two successive scenes cuts are taken as one video shot. The following figures have shown us the shot we have detected using the algorithm mentioned above. The shot has contains a series of I frames.



(a) Color-histogram difference for video shot

(b) billiard game shot detection

Fig. 2. Knowledge domain obtainment

3 Domain Knowledge Infrastructure

Video Domain knowledge is usually presented by the visualization in still images and videos in terms of low-level features and media structure descriptors. Structure and semantics are carefully modeled to be largely consistent with existing multimedia description standards like MPEG-7. MPEG-7 is a means of attaching metadata to multimedia content [6], it offers a comprehensive set of audiovisual description tools including metadata elements and their structures and relationships defined by the standard in the form of Descriptors and Description Schemes. The DDL(Description Definition Language) also allows the extension for specific applications of particular DSs [7]. The description tools are instantiated as descriptions in textual format (XML) based on the DDL (based on XML Schema).

Figure 3 illustrates possible conceptual aspects and abstractions of a specific instance (image: “billiard_ShotI01.jpg”) of a video shot content. The Structure DSs and Semantic DSs can be related by a set of links allowing the shot content to be described on the basis of both content structure and semantic structures. The links relate different semantic concepts to the instances within the shot content described by the segments.

Furthermore, most of the MPEG-7 content description and content management DSs are linked together and in practice, also often included within each other in the MPEG-7 descriptions. In our case, our structure DS is the event –“Three Cushion”, and it related to three kinds of DSs: “Semantic time”, “Semantic Location”, “Object” and with their corresponding semantic concept definitions. Based on the MPEG-7’s Visual Part and Description Scheme, we have created the following billiard game ontology like the framework shows in Figure 4.

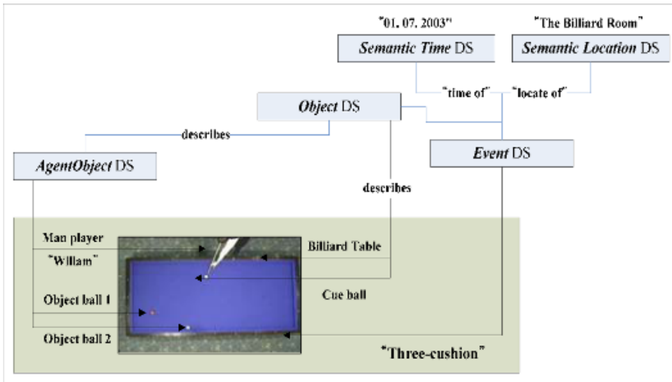


Fig. 3. Conceptual abstractions of a video shot content

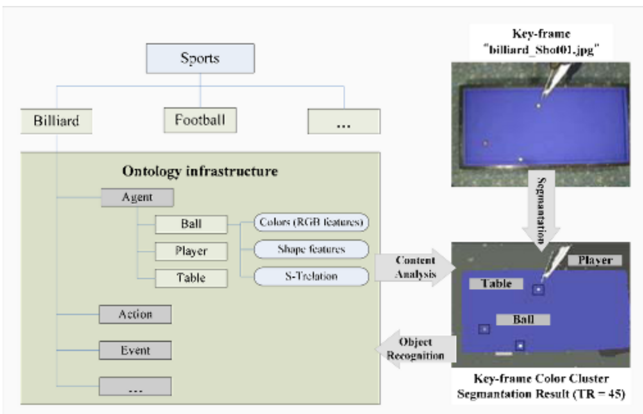


Fig. 4. Ontology based video content representation

In order to achieve our aforementioned aims for bridging the chasm existing between the high and low levels, we propose a comprehensive ontology infrastructure which is based on the MPEG-7 scheme that was analyzed above, and details will be described as follows. The summarized knowledge infrastructure can be divided into two major parts.

One is the domain ontology, in the multimedia annotation framework, is meant to model the content layer of multimedia content with respect to specific real-world domains, such as sports events like billiard game which was considered the example in this paper. We want to extract semantic information from one image but without a gap between the high-level concept and low-level features, the domain ontology should be explored. As the figure shows us, the middle part-"Billiard Ontology" in the knowledge domain of sports plays the important role of "mapping". Ontology is structured as the middle in Figure 4 shows. It contains some significant classes like Event, Action, Agent and so on and their corresponding instances, for example, in the class of Agent, it has the instances like ball, player, and table, etc, also following their property values we called "low level feature".

The other part is to represent how the visual characteristics are associated with a concept [8, 9]. One has to employ several different visual properties depending on the concept at hand. For instance, in the billiard domain as was described in the scenario in the aforementioned section, the billiard ball might be described using its shape (e.g. round), color (e.g. white or red), or in case of video sequences, motion.

4 Video Content Representation Through Domain-Specific Ontology

Based on knowledge infrastructure summarized in the Section 3, this part will be concentrated on introducing the billiard game domain ontology building in Protégé for video content representation.

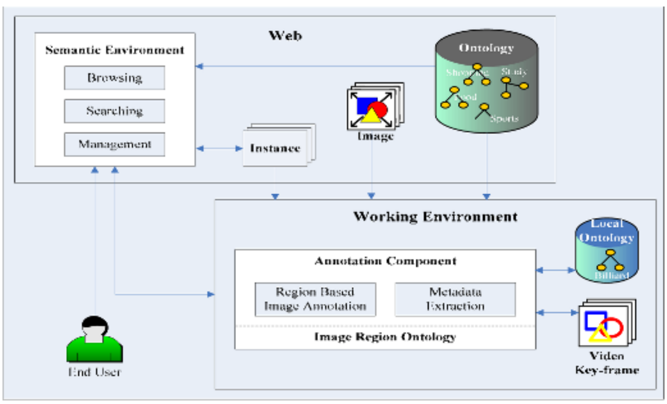


Fig. 5. Video content annotation architecture

First and foremost, video content annotation architecture (depicted in Figure 5) is built in which the Photo-Stuff [10] was considered as the annotating environment. The annotation architecture is primarily composed of two capabilities namely ontology-based video or image annotation and image metadata management on the Semantic Web. We specifically do the experiment towards one specific key-frame in billiard video which was obtained in section 2 through the segmentation algorithm to realize the mapping from low-level feature to semantic level. According to the Architecture shows in Figure 5, we can build our own local ontology for being necessary. By referencing to the MPEG-7 description scheme and instances semantic relations, a billiard game domain ontology was structured in Protégé like the Figure 6 depicted. It shows the Protégé editing environment [11].

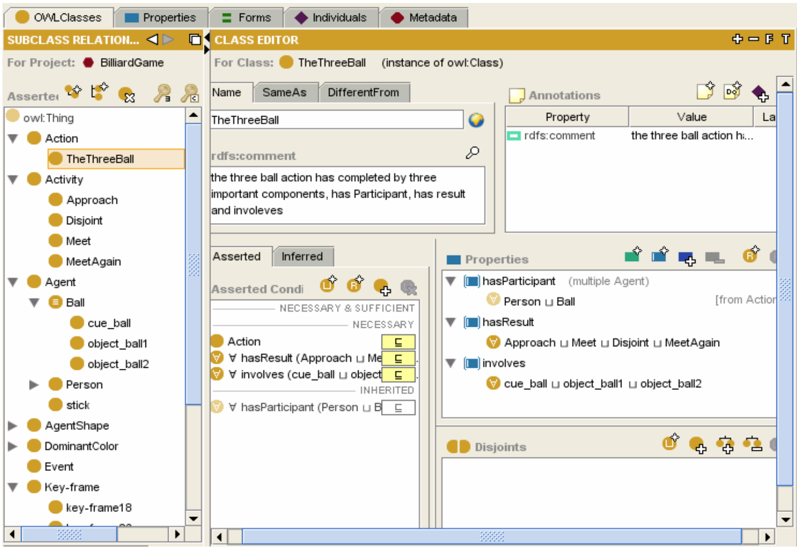


Fig. 6. A Protégé snapshot of specific billiard video ontology

The low-level features automatically extracted from the resulting moving objects are mapped to high-level concepts using ontology in a specific knowledge domain, combined with a relevance feedback mechanism is the main contribution in this part. In this study, ontologies [12] are employed to facilitate the annotation work using semantically meaningful concepts (semantic objects), Figure 6 displays the hierarchical concepts of the video shot ontology with a great extensibility to describe common video clips, which has the distinctive similarity of knowledge domain. The simple ontology gives a structural framework to annotate the key frames within one shot, using a vocabulary of intermediate-level descriptor values to describe semantic objects' actions in video metadata.

The Protégé environment composes these three parts: Asserted Ontology Hierarchy at which we have defined a billiard game domain ontology files in OWL[13]; Class Editor; Asserted Conditions and Properties Definitions areas. OWL classes are interpreted as sets that contain individuals, such as Action, Event, Agent, etc. They are described using formal (mathematical) descriptions that state precisely the requirements for membership of the class. For example, the class "BilliardGame-Agent" would contain all the individuals (ball, player, table, stick and audience, etc.) that are billiard game in our domain of interest. This ontology allows assertions to be made stating that an image contains a region that depicts certain concepts.

Through this domain ontology, we map from the low-level features to the high-level semantic concepts for the video knowledge representation. So in the previous works, a local billiard game ontology has been pre-specified in OWL, defining a small set of concepts for video key-frames, regions, depictions, etc. And in order to realize the billiard domain ontology's function, we explore the Photostuff software[10] as our assisted tool for video annotation. Photostuff is a platform independent (written in Java), image annotation tool which uses an ontology to provide the expressiveness required to assert the contents of an image, as well information about the image (date created, etc.). The annotation works are proceeded as follows:

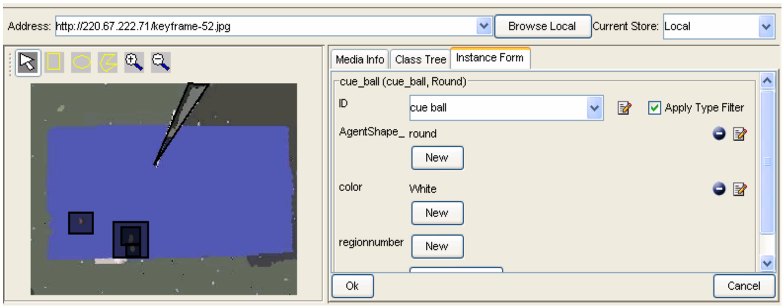


Fig. 7. Specific key-frame(#52) region annotation

Firstly, we load the owl file from our local server which was already defined, then, we import the key-frame(#52) of billiard game video using the local server directory too. When these two elements are well prepared, we begin to annotate the objects that are displayed in the key-frame by specifying the regions of the objects. For example, if we want to annotate the object of "cue ball" and we just choose the rectangle drawing bar to highlight it and the object's corresponding properties will appear on the right side like the figure 7 shows. So, the "instance form" in the figure, we can choose the properties for this object which are already defined in the former ontology, and the same methods to other objects in this key-frame. Therefore, the annotation can be finished semi-automatically assisted by the billiard game ontology.

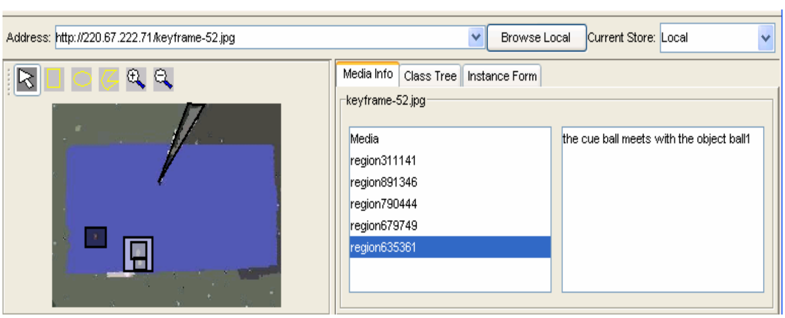


Fig. 8. Specific key-frame(#52) content representation

We specify five significant regions: player, cue_ball, object_ball1, object_ball2, and meet (cue_ball, object_ball1). By associating the cue_ball with the object_ball1's properties, we annotated the fifth region (region635361). We called "the cue_ball meets with the object_ball1". Figure 8 demonstrated the results of key-frame annotation using the action of "meet". The key frame content was annotated with the ontology concepts. After that, we can link the key-frame to the billiard video shot that was obtained from the segmentation in aforementioned section for video event annotation. To simply view the RDF/XML syntax of the annotations, select Windows View RDF(like the figure 9 shows). The RDF output from the image markup performed for key-frame annotation on the Semantic Web.

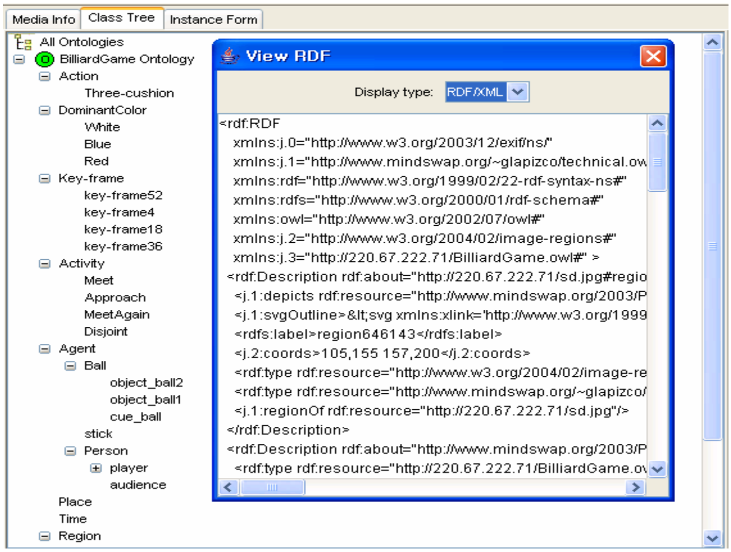


Fig. 9. Annotation for key-frame component

5 Analytical Results for Video Content Retrieval

For video content retrieval, the RDF validation is a prerequisite. We validate it through the "Driver RDF Browser". Then the RDF file was parsed into triple style: "subject", "predicate" and "object". Like the figure 10 shows below, the component lays at the top of the arrow is called "subject" and the bottom of arrow is called "object', the component between them is what we called -" predicate".

We got total 400 triples of data model, 126 nodes and 101 literals in the RDF graph. Following that, we convert them to the relational model based on our "billiard game" ontology. The figure 10 shows a snapshot of a hierarchical model for expression of inheritance-relationship between RDF classes that describes the video content annotation for one action-"meet" which was one participant in the billiard game event-"the three-ball". If we want to find the action - "meet", we should focus on this relational model but not to consider other information such "disjoint" or "audience applause" information that there is of no use for the users' retrieval.

We do the experiment by comparing the ontology-based with key-word retrieval. The following figure 11 shows the process for video retrieval base on billiard game ontology. For example, suppose the user want to retrieve as this: *I want to find "the three cushion" participated by William?* After parsing, we extract the semantic

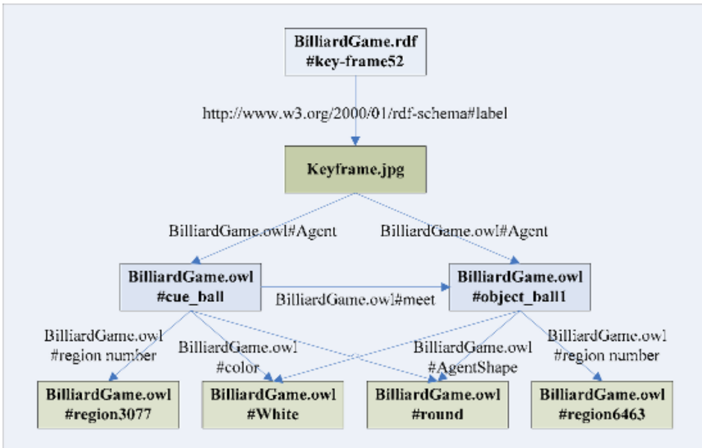


Fig. 10. RDF graph for billiard game key-frame annotation content

information(Player*: William,* Action: *the three cushion*; Parameter mapping: *rdf: Agent, rdf: Event*). Next step is to compare the semantic information parameters with the RDF relation model which contains RDF metadata.

After the retrieval, we evaluate our experiment results, based on this relational model. We adopted an effective method of retrieval which is usually measured by the following two quantities, recall and precision

$$recall = \frac{Number\ \ of\ \ retrieval\ \ relevant\ \ object}{Number\ \ of\ \ relevant\ \ objects} \qquad Precision = \frac{Number\ \ of\ \ retrieval\ \ relevant\ \ objects}{Number\ \ of\ \ retrieval\ \ objects} \tag{1}$$

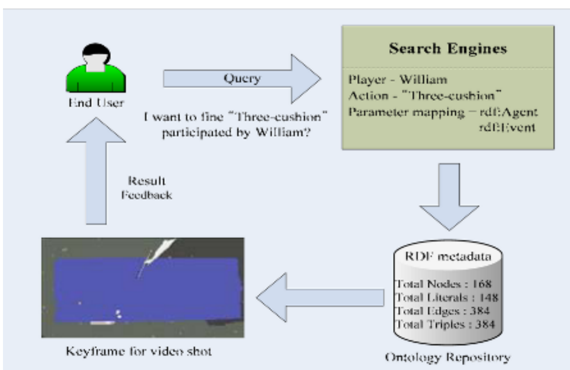


Fig. 11. Ontology- based query processing

A relevant object is an object of use to the user in response to his or her query. Let us assume that *Rel* represents the set of relevant objects and *Ret* represents the set of retrieved objects. The above measure can also be redefined in the following manner.

$$Recall = \frac{|Rel \cap Ret|}{|Rel|} \qquad Precison = \frac{|Rel \cap Ret|}{|Ret|} \tag{2}$$

The Fig 12 displays that we got higher accuracy results based on our relational mo del than just by single key-word retrieval does. Our model can prune the unnecessary information effectively when user retrieves based on conceptual information.

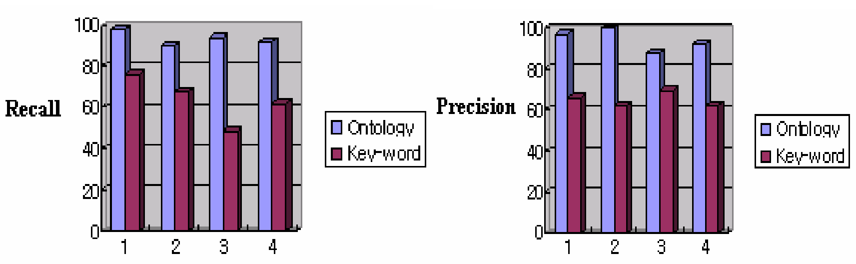


Fig. 12. Recall and precision of ontology-based and key-word based research

6 Conclusions

In this paper, we proposed a novel method for video content analysis and description on the fundamental of the knowledge domain ontology. In this work we have presented a generic, domain independent framework for annotating and managing digital image content using the Semantic Web technologies. The adaptive billiard ontology not only helps us overcome gap between the low-level features and high level semantics, but combining these two aspects in the most efficient and flexible (expressive) manner. The proposed approach aims at formulation of a domain specific analysis model facilitating for semantic video content retrieval. In the experimental part, it demonstrated that the method achieved a higher average rate of use's retrieval based on semantic ontology than using only key-word.

Our future work includes the enhancement of the domain ontology with more complex model representation and especially, the video object description, we try to use the more complex spatio-temporal relationships rules to analyze the moving features. We will also do more technical work (improve our retrieval system) to intensify our retrieval part function.

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An Ontological Infrastructure for the Semantic Integration of Clinical Archetypes

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Abstract. One of the basic needs for any healthcare professional is to be able to access clinical information of patients in an understandable and normalized way. The lifelong clinical information of any person supported by electronic means configures his Electronic Health Record (EHR). There are currently different standards for representing EHRs. Each standard defines its own information models, so that, in order to promote the interoperability among standard-compliant information systems, the different information models must be semantically integrated. In this work, we present an ontological approach to promote interoperability among CEN- and OpenEHR- compliant information systems by facilitating the construction of interoperable clinical archetypes.

1 Introduction

One of the basic needs for any healthcare professional is to be able to access clinical information of patients in an understandable and normalized way. The lifelong clinical information of any person supported by electronic means configures his Electronic Health Record (EHR). This information is usually distributed among several independent and heterogeneous systems that may be syntactically or semantically incompatible. There are currently different standards for representing electronic healthcare records (EHR). Each standard defines its own information models and manages the information in a particular way. This implies that clinical information systems of different clinical organizations might differ in the way electronic healthcare records are managed. Hence, exchanging healthcare information among health professionals or clinical information systems is nowadays a critical process for the healthcare sector. Due to the special sensitivity of medical data and its ethical and legal constraints, this exchange must be done in a meaningful way,

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avoiding all possibility of misunderstanding or misinterpretation. Two main problems arise when pursuing that objective. On the one hand, many hospitals do not have a unified information system. Health data is distributed across several heterogeneous and autonomous systems whose interconnection and integration is difficult to achieve. This may be resolved by setting up a new and integrated information system for all the organization but it would represent a great economic cost, a traumatic upgrade of existing applications and a difficult adaptation of current users to the new system.

On the other hand, a clinical information system may lack a comprehensive semantic definition of the information which it contains, up to the point of making impossible a semantic interoperability between different systems. Due to the complexity and constant evolution of health domain this has not an easy solution. As stated in [6] not only is medicine domain big, it is open-ended because new information, finer grained details or new relationships are always being discovered or becoming relevant. As a consequence, no fixed enumerated list of medical concepts can ever be complete. This implies that a traditional information model will never be completely adapted to the clinical requirements and its continuous evolution.

The main techniques that have traditionally been applied to obtain integration and interoperability at application level are adaptors and exchange formats, whose success has not been very significant to date. Therefore, alternative approaches are currently making use of semantic technologies to facilitate integration and interoperability [4; 9; 10]. An advantage of using semantic approaches is the fact that they do not require to replace current integration technologies, databases and applications, but add a new layer that takes advantage of the already existing infrastructure [5]. Amongst the different available semantic technologies, ontologies are considered a basic technology to promote semantic interoperability between independent and heterogeneous systems [7]. An ontology, which represents a common, shareable and reusable view of a particular application domain [11], gives meaning to information structures that are exchanged by information systems. This paper presents a semantic approach to facilitate the interoperability of EHR information models. This work has been focused on two EHR standards: CEN ENV13606 and OpenEHR. Both information models have been analyzed and semantically represented by means of ontologies. Then, the ontological models have been integrated into a common ontological infrastructure, which will be the core for developing model-independent systems.

Finally, the structure of this paper is the following. In section 2, models for representing electronic healthcare records are discussed. Section 3 describes the role ontologies can play in integration and interoperability issues. Then, the ontological infrastructure developed for this work is described in section 4. Section 5 describes the process for constructing the ontologies of the different information models. Section 6 contains an example of archetype modelling using the ontological infrastructure. Finally, some conclusions will be put forward.

2 Electronic Healthcare Records

A healthcare record is the set of non-redundant, ordered, and complete information concerning the relation between an individual and any healthcare centre. Healthcare records can be queried in different situations and due to different reasons, and they can play different roles in the healthcare process. Their main use is to support clinical care. In the last years, different working groups have been actively working in the definition of architectures and information models for electronic healthcare records. Each model implies a working environment in which the meaning of data varies. This requirement is fulfilled by semantic technologies, which make the description of the nature and logical context of the information to exchange possible, allowing each system to remain independent. An Electronic Healthcare Record (EHR) is a healthcare record digitally stored in one or more information systems.

The OpenEHR consortium has developed the dual model architecture approach [1] for electronic healthcare records. This architecture is based on the metamodelling of healthcare records, and it is based on the separation of concepts in two levels: (1) reference model (RM), and (2) archetypes, which are formal models of clinical concepts. The information system is based on the RM and the valid healthcare records extracts are instances of this reference model. This methodology was tested in the Good Electronic Healthcare Record project (GEHR) in Australia and by the European Synex project. It is also used in the new version of HL7 and in the CEN norm for the communication of healthcare records.

The reference model represents the global features of the annotations of healthcare records, how they are aggregated and the context information required to meet the ethical, legal, etc requirements. This model defines the set of classes that form the generic building blocks of the electronic healthcare record and it contains the non-volatile features of the electronic healthcare record. However, the reference model needs the complement of domain knowledge: archetypes. An archetype models the common features of types of entities and, therefore, defines the valid domain structures. Archetypes restrict the business objects defined in a reference model, bridging the generality of business concepts defined in the reference model and the variability of the clinical practice. They provide a standard tool to represent this issue. Archetype instances are expressed in an archetype definition language (ADL) and they are therefore related to formal archetype model, which is formally related to the reference model. Although both ADL and archetype models are stable, the individual archetypes can be modified in order to be adapted to clinical practice.

The work developed in projects such as the previously mentioned GEHR and OpenEHR suggest that the formalisms for defining archetypes must be based on the following main technical principles: (1) each archetype is a different and complete domain concept; (2) archetypes are expressed as restrictions on the reference model; (3) the granularity of an archetype corresponds to the granularity of a business concept of the reference model; (4) each business concept can be considered a descriptor of a domain ontological level; and (5) archetypes have partonomic and taxonomic components. Having introduced how electronic healthcare records can be represented at conceptual level, let us describe the two current EHR standards that are based on a dual model approach: CEN/TC251 EN13606 and OpenEHR on which we are focusing in this research work both at information level (reference model) and knowledge model (archetypes).

2.1 CEN

The CEN/TC251, Technical Committee 251 of the Normalization European Committee [12] is in charge of developing standards in the field of medical informatics. The activity of one of its working groups is devoted to the standardization of the architecture and information models for electronic healthcare records. The overall goal of this standard is to define a rigorous and durable information architecture for representing the EHR, in order to support the interoperability of systems and components that need to interact with EHR services: as discrete systems or as middleware components, to access, transfer, add, or modify health record entries, via electronic messages or distributed objects, preserving the original clinical meaning intended by the author, reflecting the confidentiality of that data as intended by the author and patient.

This standard will have five parts: (1) generic information model for communicating the electronic healthcare record of any one patient (reference model); (2) generic information model and language for representing and communicating the definition of individual instances of archetypes (archetype exchange specification:); (3) a range of archetypes reflecting a diversity of clinical requirements and settings, as a “starter set” for adopters and to illustrate how other clinical domains might similarly be represented (reference archetypes and term lists); (4) the information model concepts that need to be reflected within individual EHR instances to enable suitable interaction with the security components (security features); and (5) a set of models built on the above parts and can form the basis of message-based or service-based communication (exchange models).

This model makes use of the dual approach for communicating the electronic healthcare record. Here, an archetype is defined as a computable expression of a clinical domain concept based on a reference model. It is defined through a set of structured restrictions. Archetypes share the same formalism, but they can be of different types. Definitional archetypes are part of a standardized, shared ontology. Non definitional archetypes are locally used and defined by particular institutions to fulfil particular clinical needs. However, clinical organizations should agree on common definitions in order to exchange clinical information efficiently. Therefore, obtaining the mappings between these archetypes might be of interest.

2.2 OpenEHR

The OpenEHR Foundation [13] is a non-profit organization. Amongst its objectives, the following ones can be pointed out: promote and publish the formal specification of requirements for representing and communicating electronic health record information, based on implementation experience, and evolving over time as health care and medical knowledge develop; promote and publish EHR information architectures, models and data dictionaries, tested in implementations, which meet these requirements; and manage the sequential validation of the EHR architectures through comprehensive implementation and clinical evaluation.

The openEHR architecture [2] specifications consist of the following components: (1) Reference Model, which provides identification, access to knowledge resources, data types and structures, versioning semantics, and support for archetyping; (2) Service Model, which defines the basic services in the health information environment, centred around the EHR; and (3) Archetype Model, which describe the semantics of archetypes and templates, and their use within openEHR.

All of the architecture specifications published by openEHR are defined as a set of abstract models. Among the global requirements of EHRs and EHR systems supported by openEHR, the following can be pointed out: life-long EHR; priority to the patient / clinician interaction; technology and data format independent; facilitation of EHRs sharing via interoperability at data and knowledge levels; integration with any/multiple terminologies; support for clinical data structures: lists, tables, time-series, including point and interval events; compatibility with CEN 13606, Corbamed, and messaging systems.

3 Ontologies for Integration and Interoperability

The most important factors that make the integration and interoperability between systems difficult are the semantic and structural heterogeneity, as well as different meaning information has in different systems. Hence, our interest is focused on how semantic technologies, in particular ontologies, may support and promote interoperability among electronic healthcare records systems.

An ontology can be seen as a semantic model containing concepts, their properties, interconceptual relations, and axioms related to the previous elements. Furthermore, ontology has a standard reference model to integrate information known as knowledge sharing. In practical settings, ontologies have become widely used due to the advantages they have (see for instance [3]). On the one hand, ontologies are reusable, that is, a same ontology can be reused in different applications, either individually or in combination with other ontologies. On the other hand, ontologies are shareable, that is, their knowledge allows for being shared by a particular community. In the context of integration, they facilitate the human understanding of the information. Ontologies allow for differentiating among resources, and this is especially useful when there are resources with redundant data. Thus, they help to fully understand the meaning and context of the information. This is important for our objective of achieving semantic interoperability among electronic healthcare record systems built on top of different information models. For our purpose, the information model semantics is formalized by means of ontologies and represented by using the Ontology Web Language (OWL) [18].

Ontologies have already been used for integration and interoperability purposes in medical domains. In [8], ontologies were used to promote integration and interoperability between information systems for three medical communities by combining data with HL7 [14] and terminologies such as UMLS [15], MEDCIN [17] and SNOMED [16]. So, terminologies are integrated by using ontologies. Our approach is different because EHR standards have a different nature and the components defined in clinical archetypes can be linked to different terminologies. Therefore, our work can benefit from terminological integration approaches such as [8] in order to simplify the management of different terminologies at EHR level. Another example is the joint effort made by the ONTOLOG [19] forum, the Medical Informatics department of Stanford University and the Semantic Interoperability Community of Practice (SICOP) [20] to integrate and make the Federal Health Architecture and the National Health Information Network interoperable. They defined an three level ontological architecture. The medium level ontologies were FEA-RMO (Federal Enterprise Architecture- Reference Model Ontology) and HL7

RIM, and different domain ontologies were obtained from the Federal Health Architecture. This effort was carried out in the context of HL7, so different EHR models were not targeted as we do in this work.

4 The Ontological Infrastructure

In this section, the ontological infrastructure to facilitate the interoperability between CEN- and OpenEHR-based information systems is described. In this work, the following versions of the CEN and OpenEHR specifications have been used: CEN (release 09/2004) and OpenEHR (release 09/2005). A set of components will be described, as well as their use and the relations among them. The information models have clear differences related to how information items are organized and taxonomic depth in specific issues. However, they do not present inconsistencies so that the quality mappings between both models are likely to be achieved.

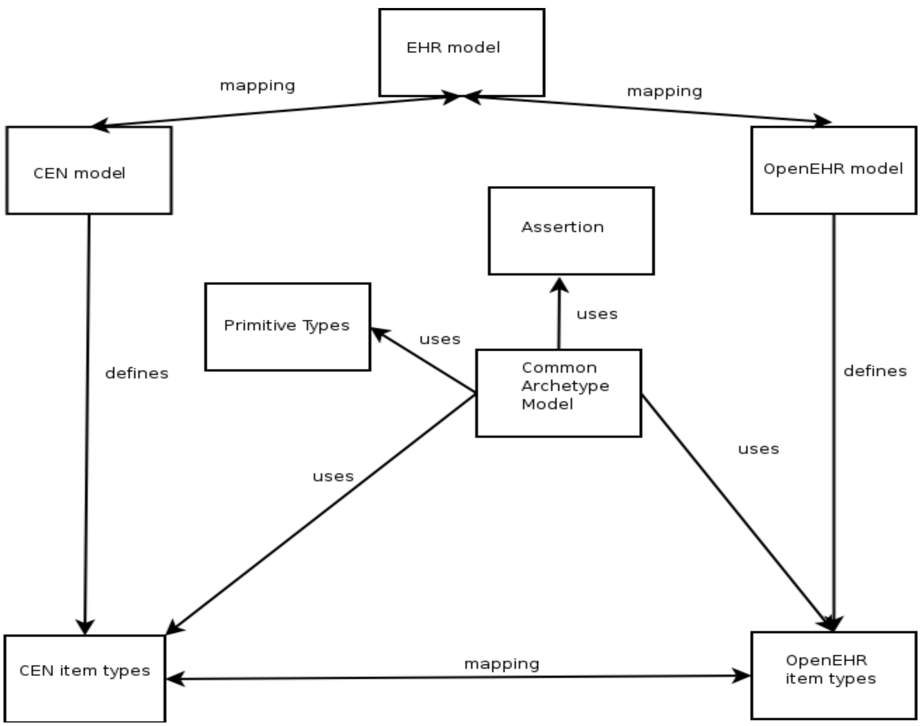

Fig. 1. The ontological infrastructure

Figure 1 shows the set of ontologies that configure our ontological architecture to solve this problem, as well as the relations existing among them. This figure has three main areas. The left and right areas contain specific information of each reference model (i.e, CEN, OpenEHR). Each one defines a healthcare record information model, including a set of types of items. For instance, clusters and elements are types of CEN items. The OpenEHR is richer in terms of types of items. The definition of mappings between types of items is possible, although some semantic processing is needed. These items define the nature of clinical actions that can be represented by clinical archetypes. The central part of the figure represents the common parts to both standards. The global reference model is located on top of the figure. This model will allow us to translate information between both models. The archetype model is located in the central part of the figure. This is common for both standards, and it makes use of the ontologies of assertions and primitive data types, which are semantically equivalent for both standards. Furthermore, the archetype model will be used to build archetypes, and these will be used to generate the archetype instances (one per patient). These instances are contained in the extract of the electronic healthcare record of the patients. The lower part of the figure refers to the types of clinical items defined in both models.

Hence, two major mappings have to be made between: (1) the types of items in order to be capable of translating archetypes to a different model; (2) the concepts that describe the electronic healthcare record in order to translate EHR extracts. This architecture facilitates different actions, such as:

- Model-independent definition of electronic healthcare records
- Model-independent definition of clinical archetypes
- Automatic translation of EHR extracts from CEN to OpenEHR and viceversa
- Automatic translation of archetypes from CEN to OpenEHR and viceversa
- Semantic interoperability between CEN-based and OpenEHR-based systems

5 From Information Models to Ontological Representation

Our work was mainly focused on the reference and archetype models of both CEN and OpenEHR standards. Each model was represented using OWL to obtain its ontological representation. Then, the ontological information and archetype models were compared in order to find similarities and differences among the CEN and OpenEHR representations. It is more appropriate to perform this comparison at ontological level due to different reasons. First, ontologies are formal models so that formal reasoning can be performed on both models. Second, representing both models using the same formalism provide a common representation framework for the comparison process. Third, if we want to come to an integrated model, it is more appropriate to have the components represented with the same formalism and at the same granularity level.

Hence, let us discuss the conclusions drawn from the analysis of the information and archetype models. First, the representation of the information models is more oriented to the transmission via a communication network rather than to representing contents semantically. In fact, the different model diagrams provided in the documentation of both standards has little semantic information; they are similar to UML class diagrams. This can be observed in the archetype model defined in the CEN [12] or OpenEHR documentation [13]. For instance, there are some references to elements belonging to different classes modelled by string attributes. This representation may make it harder to understand the underlying semantics. Therefore, it would be more appropriate to model this reference through a relation between the corresponding classes. In our ontological approach, referential semantics is modelled through semantic relations between the concepts. Moreover, the UML-like representation is not suitable for performing formal reasoning at conceptual level, so that, better use of the information contained in the model might be made. This process was performed in two steps: reference model, and archetype model.

Both archetype models contain the same type of information: translations, audit details descriptions, ontological section, and constraints. The ontological section and the constraint are the most important parts since they contain the definition of the archetype terms, which are instances of some specific type of concepts belonging to the respective (CEN/OpenEHR) reference models. However, the archetype model does not structure appropriately or represent formally this information. So, what we have done is to remodel this archetype model by using as modelling focus the archetype terms. Our first goal was to develop an ontology that would represent an integrated view to the CEN and OpenEHR archetypes models, that is, the commonalities were identified, and the differences were kept to allow building archetypes for both reference models. According to our approach, an archetype has general information as it is specified in the standard models. This general information encompasses the auditory details, the archetype description, assertions, translations to other languages, and a set of available terminologies. Furthermore, an archetype contains the definition of a concept (i.e., heart rate pulse), is a specialization of another archetype, and it contains a set of archetype terms. An archetype translation to a specific language is comprised of the set of

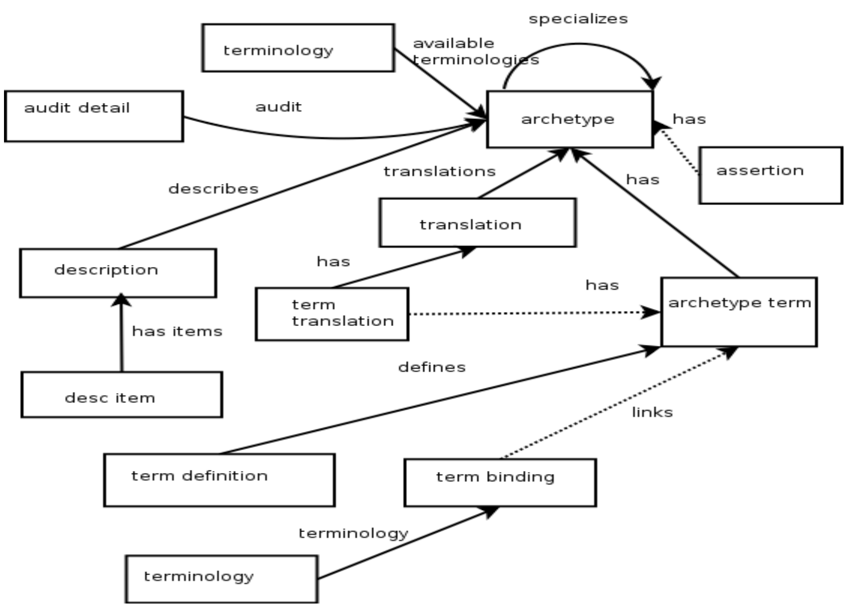

Fig. 2. Ontological representation of the archetype model (archetype concept)

translations of archetype terms to such language. Therefore, each archetype term has a set of translations associated. Each archetype term has also a definition, and a set of term bindings to the available terminologies. Figure 2 shows a part of the ontological representation of the archetype model. This part of the ontology reflects common information to CEN and OpenEHR. Archetype terms can refer to restrictions and conceptual entities. Conceptual terms (called ontology terms) are divided into concepts (e.g., heart rate), complex terms (e.g., list, history), simple terms (e.g., position, device), or values (e.g., sitting, lying). A simple term has a set of values associated. Each complex term is comprised of a set of complex and simple terms. Values are of a particular datatype, which is given by the reference model (CEN / OpenEHR). Both standards use the same basic datatypes, but have different simple and complex terms.

This part of the ontology is shown in Figure 3. Besides the modeling of this integrated archetype model, the reference model of the CEN and OpenEHR standards have been ontologically modeled. For this purpose, the procedure was similar to the one followed for the archetypes model. They were analyzed in order to detect semantic representation flaws and OWL schemes were developed. Then, both ontologies were semantically compared in order to look for mapping between both standards to develop an integrated model for the electronic healthcare records. The main difference is the richness for defining types of clinical data. The CEN model makes use of folders, sections, entries,

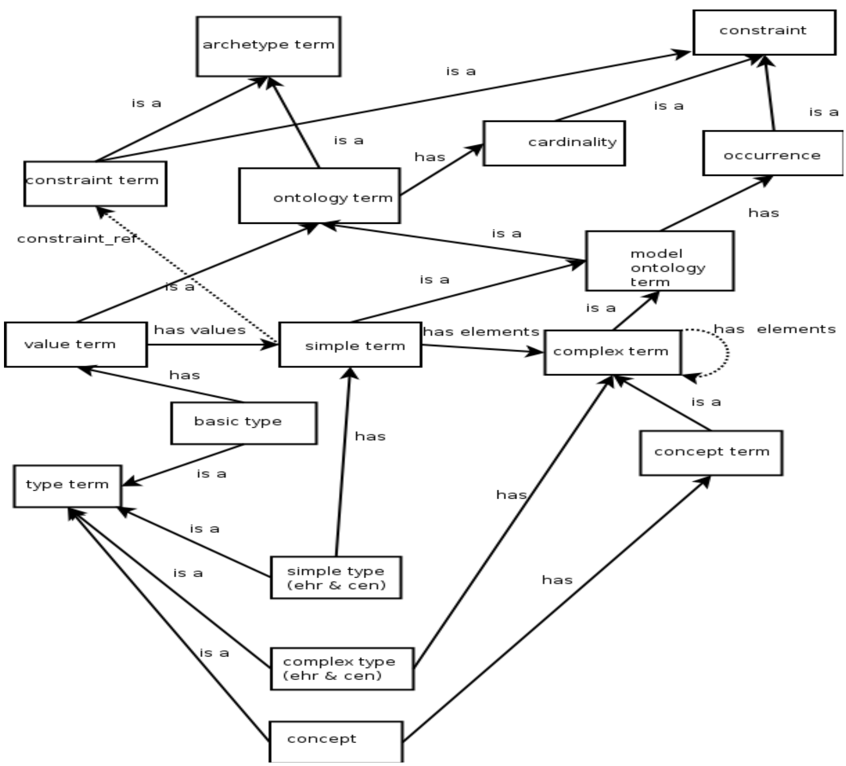

Fig. 3. Ontological representation of the archetype model (archetype terms)

items, clusters and elements, whereas the OpenEHR model uses a wider range of types, including some such as history, item list, item structure, and so on. We are currently completing this mapping, which would allow to transform automatically CEN electronic healthcare records and archetypes into OpenEHR ones and viceversa. Our research group has been working of the modelling of the different standards and definition of the mappings for the last year. The set of OWL ontologies and mappings obtained through this research project are available at http://klt.inf.um.es/~poseacle.

A "problem" has a "structure" and a "protocol". The structure of a problem has a description of the problem, a "date of initial onset", "age at initial onset", "severity", "clinical description", "date clinically recognised", "location", "aetiology", "occurrences or exacerbations", "related problems", "date of resolution", and "age at resolution". These archetype terms must be assigned a type of term. For this purpose, a set of types are available, those belonging to OpenEHR and CEN. Provided that CEN types are a subset of OpenEHR ones, the latter ones can be used as the ones proposed to the archetype builder and then, these can be easily mapped onto CEN types by considering complex OpenEHR types as CEN Cluster and the singles ones as CEN Element. Let us consider the definition of the "protocol". A protocol is comprised of a set of "references", having each a "reference" and a "web link". The following code of the protocol is shown in ADL, where ITEM_TREE, CLUSTER, and ELEMENT refer to the corresponding OpenEHR types., at00xx stands for the terms associated to the entities.

```
protocol matches {
   ITEM_TREE[at0032] matches { -- Tree
      items cardinality matches {0..*; unordered} matches {
          CLUSTER[at0033] occurrences matches {0..1} matches {      -- References
             items cardinality matches {0..*; unordered} matches {
           ELEMENT[at0034] occurrences matches {0..*} matches {   --
   Reference
                     value matches {   TEXT matches {*}          }      }
             ELEMENT[at0035] occurrences matches {0..*} matches { --
   Web link

                     value matches {   URI matches {*}                       }}}}}}}
```

Therefore, our approach would associate an ITEM_TREE to "protocol", a CLUSTER to "references", an ELEMENT to "reference" and to "Web link". These types are mapped onto the same types in OpenEHR. In the case of CEN, the CLUSTER and the ELEMENTs are mapped onto CLUSTER and ELEMENT but the ITEM_TREE is mapped onto a CLUSTER too. In general, any OpenEHR complex type is mapped onto a CLUSTER in CEN. The corresponding occurrences and cardinality constraints are defined similarly in both models.

6 Conclusions

Healthcare professionals need to access the complete healthcare record of their patients in order to perform more efficient healthcare processes. However, this information is usually distributed across heterogeneous sources and systems. Therefore, there is a need for solutions that allow for integrating the information contained in the different sources and systems, and these solutions should ideally be transparent for users. In this paper, this issue has been tackled by applying a semantic approach. Most of the scientific community agrees on the role and importance of the use of semantic technologies. However, a part of the community says that there is currently too much diversity and low standardization in how to work with these technologies. Our semantic approach aims at facilitating the integration and interoperability between CEN and OpenEHR compliant clinical information systems. The key semantic technology to achieve this goal is the ontology, which can be viewed as a conceptual model containing a set of interrelated elements whose existence is accepted by a particular community. Ontologies acquire more importance when they cover particular domains, because once achieved the semantic control of a domain, data integration or linking systems would be easier. In this paper, the effort has been put on generating ontological models of the CEN and OpenEHR reference models, as well as developing an integrated archetype model.

The model proposed in this work would facilitate the interoperability of those information systems that makes use of different EHR models, since the model defines an ontology-based common syntax and semantics. We are currently addressing the mapping between the ontologies corresponding to the CEN and OpenEHR reference models in order to obtain a global EHR model, so that, systems might work with data coming from both standards. The next step will be the development of a model-independent archetype management system, capable of managing both CEN and OpenEHR archetypes by using the ontological infrastructure. This system will provide us qualitative information about this infrastructure.

Acknowledgements

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Improvement of Air Handling Unit Control Performance Using Reinforcement Learning*

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Abstract. Most common applications using neural networks for control problems are the automatic controls using the artificial perceptual function. These control mechanisms are similar to those of the intelligent and pattern recognition control of an adaptive method frequently performed by the animate nature. Many automated buildings are using HVAC(Heating Ventilating and Air Conditioning) by PI that has simple and solid characteristics. However, to keep up good performance, proper tuning and re-tuning are necessary. In this paper, as the one of method to solve the above problems and improve control performance of controller, using reinforcement learning method for the one of neural network learning method(supervised/unsupervised/reinforcement learning), reinforcement learning controller is proposed and the validity will be evaluated under the real operating condition of AHU(Air Handling Unit) in the environment chamber.

1 Introduction

Although modern control theory has been rapidly developing, most industrial controllers of air conditionings and refrigerators, etc use the controller type of PID(Proportional Integral Derivative). In spite of having a simple structure, PID controller is the most used for industrial processor control because it is well-functioned with stability and tenacity of the goal following, invasions from the outside and the process variables. In addition, it experimentally extracts dynamics of the plant by using several tuning methods. It is able to design the controller by searching variable for the optimum control[1,2,3].

However, it cannot estimate control performance in advance if there is uncertainty of process model or a change of operation environment. It is necessary to have an

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exact estimate of control environment that changes at any time and automatic tuning function, especially, in the case of automatic building control that only operates by typical non-linear structure. In order to choose the parameter of PID controller to get this optimum control function, there have been a lot of studies about tunings of PID controller such as the Ziegler-Nichols[4] tuning in 1942 and the tuning by relayed experiments by Astrom and Hagglund, etc, and a few methods which had improved from the Ziegler-Nicholas tuning are used[5,6,7,8,9].

Therefore, this study has designed the optimum building cooperating controller by using Q-Learning to solve these problems above and improve control function of the controller. Q-Learning was developed by free model reinforcement learning on the based of probable dynamic programming. It has applied to the building cooperating system of artificial climate laboratory inside where it is able to control freely outdoor temperature artificially.

2 Reinforcement Learning

There are actor-critic structure by Sutton's Temporal Difference(TD) and Watkins' Q-learning etc. These methods estimate reinforcement signals and learn when there is no immediate reward at the present. Therefore, reinforcement learning suits the case which exists various models and environments because the controller itself learns the right control signals by using evaluated signals from the environment of controller's behaviours even though a human does not involve the learning and is adaptable like a human even if the environment changes.

The Q-learning method used in this study had developed as one of the methods of free model reinforcement learning which is based on probable dynamic programming. This makes the system with learning ability on the Markovian environment operates the optimum.

In order to use this Q-Learning, if let's say S for a state set and A for an action set of scattered environment, basic Q-Learning algorithm is the same as Fig. 1.

① For all environments s and actions a, $Q(s,a)$ initializes an optional value (generally 0).

② recognizes present environment s.

③ chooses action a according to the rule of environment-action.

④ operates action a on the environment given and then puts s' for the environment and r for immediate reward.

⑤ renews the rule of environment-action from s, a, s' and r.

$$\Delta Q_\pi(s_t,a_t)=\alpha_t[R(s_t,a_t)+\gamma \max_{a'\in A} Q_\pi(s_{t+1},a')-Q_\pi(s_t,\mathrm{a}_t)]$$

α_t : learning rate, γ: decrease factor between 0 and 1

⑥ goes back to step ②.

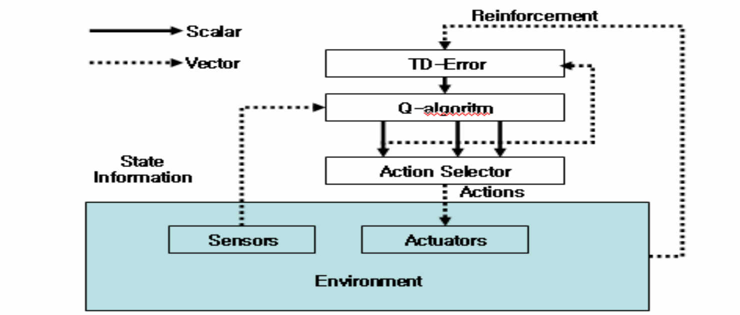

Fig. 1. Reinforcement learning architecture

Fig. 2. shows the summary that combines the structure of reinforcement learning with PI control algorithm. As we studied from Fig. 1. and Fig. 2., reinforcement learning achieves on-line study through two structural elements. The actor by the given environment acts suitable action to the environment and the environment by the given action sends a judgement on that if the changed state and action were right to the actor with reinforcement signal that is a reward for the output of PI controller.

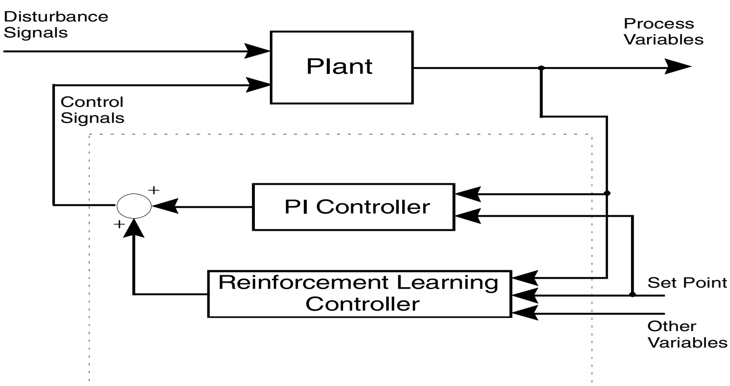

Fig. 2. Combination of RL and PI controller

3 Experimental Devices

3.1 Test House

I built a test house in the artificial climate lab building in order that I could experiment overall such as the load of air-conditioning and heating of the building, the efficiency of air-conditioning and heating, thermal environment, energy saving, heat transfer of the building structure, Wall thermal mass effects, HVAC control, Access floor control, and so on.

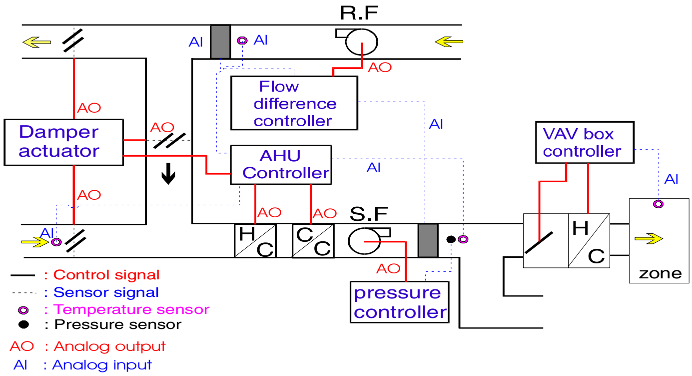

Fig. 3. Configuration of VAV AHU

Fig. 3. shows a composition of cooperating automatic control system which was installed at both the non-hypocaust of the test house and well-equipped lab in the way of variable air volume(VAV). The cooperating system installed was designed to oper ate with a cooperating machine according to the condition of the outside air and in-door. Air-supplier or ventilator are able to do variable voltage variable frequency (VVVF) control, so they can perform economical efficiency and energy saving evaluation. And a variable air volume(VAV) was installed to save energy and control the volume of air which is supplied to each indoor by the load change of inside building. Operations and information collecting about all equipments of the building performs in the automatic control system.

3.2 System Embodiment

Supervisory control of cooperating system achieves at the supervisory control of the main computer and local loop control.

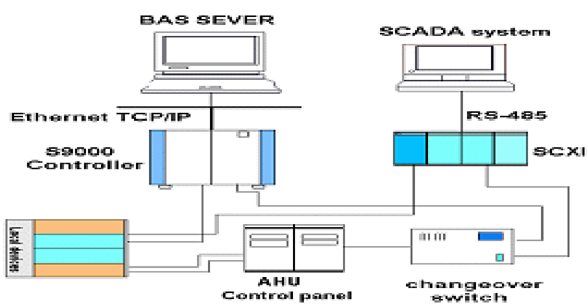

Fig. 4. System realization

Fig. 4. shows the composition of supervisory operating control system for automatic operating of cooperation system of the test house. The system is composed of established supervisory operating control system and supervisory operating control system for control algorithm performance experiment separately. Established supervi-

sory operating control system makes supervisory control of the main computer and local loop control perform real-time data supervisory and operating control through data interface with Ethernet TCP/IP, but it is limited to experiment performance of actual various control algorithm. So, supervisory operating control system has been embodied which can compare and analyse performance specifics through control algorithm development and application, and controller corroborative experiment by composing independent data interface and supervisory control system and performing automatic control.

4 Result of Experiment

In order to compare and analyse control performance specifics by corroborative experiment of reinforcement learning controller, it performed performance experiment by using VAV AHU in the test building compared to established PID controller. In the performance experiment, heating coils' the control performance experiment of heating coils for supplied air temperature control has been performed to examine application possibility on the real system before it is applied to whole system. Here are the conditions for the experiment: the temperature of the outside air was -1℃ ~ 0℃, temperature change of mixed air temperature of the test building and supplied air temperature was 22℃ < Tma(temperature of mixed air) < 28℃, 33℃ < Tsa(temperature of supply air) <43℃. With these conditions, the system was operated and it performed the controller performance experiment. Before performance experiment, in order for the system to operate more stable and précised control, it used the optimum control variable of PI controller, that are a comparison element Kp, an integral element Ki, by using the tuning method of Ziegler - Nichols[3] and testing various types of loops. Reinforcement learning controller was added to PI controller, then it used the PI controller that has a comparison element Kp=1.9, an integral element Ki=7.5 to remove heating coils and designed the controller by operating control performance experiment and using output reward control signal of reinforcement learning controller.

It decides 7 of scattered output signals: [-2, -1, -0.2, 0, 0.2, 1, 2] as output reward control signals of reinforcement learning(RL) and sends them with output control signals of PI controller. Each input variable of 3 divided into 8 of space limits and 3-demention input space has been fixed 7^3(343). Each input space stores 7 scattered input signals at Q-value. This is a reinforcement learning equation as below.

$$R(t) = (T_{sa}(t)^* - T_{sa}(t))^2 \quad T_{sa}(t)^* \text{ : a set point, } T_{sa}(t) \text{ : a observed value}$$

Fig. 5. shows the control performance specific of the heating coils of the case that it sent a random optional output signal according to input state in the condition of RL controller added to PI controller for the online study for the RL controller.

Fig. 6. presents the control performance specific of the heating coils both in the case of PI controller which has the optimum control variable: Kp = 1.9, Ki = 7.5 with little overshoot through the tuning process and in the case of RL controller added to PI

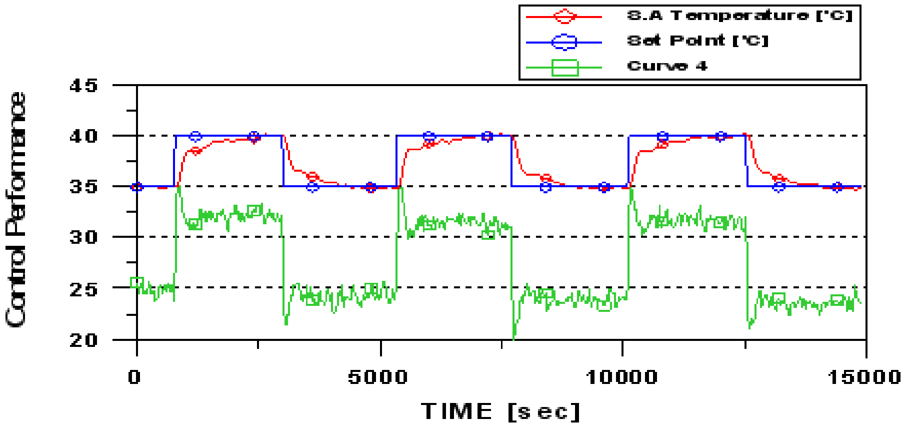

Fig. 5. Control performance when the selected action of RL agent is added to PI controller

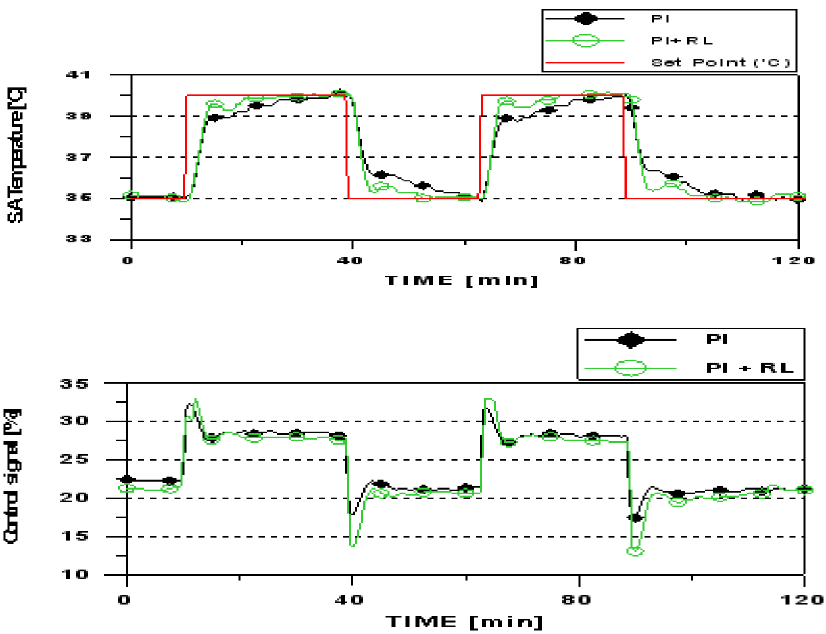

Fig. 6. Control performance with combined PI and RL controller (optimal gain)

controller after completing learning. The optimum controller with complete learning, that is, if RL controller is used, there is a big decrease of normal state error compared to PI controller when a set point for the supply air temperature changes according to the change of outside environment, and an improvement of controller's performance that has quick respond.

Fig. 7. shows the control performance specific of the heating coils both in the case of using PI controller which has control variables Kp= 1, Ki= 4 with increased rising time

a bit and the case of applying PI and RL controller. It is clear to be seen there is a improvement of control performance like normal state error decrease and quicker respond than PI controller when supply air temperature changes according to environment change. Also, the more times of learning routine, the less performance lowering of learning errors, it is certain that the optimum control of heating coils is possible.

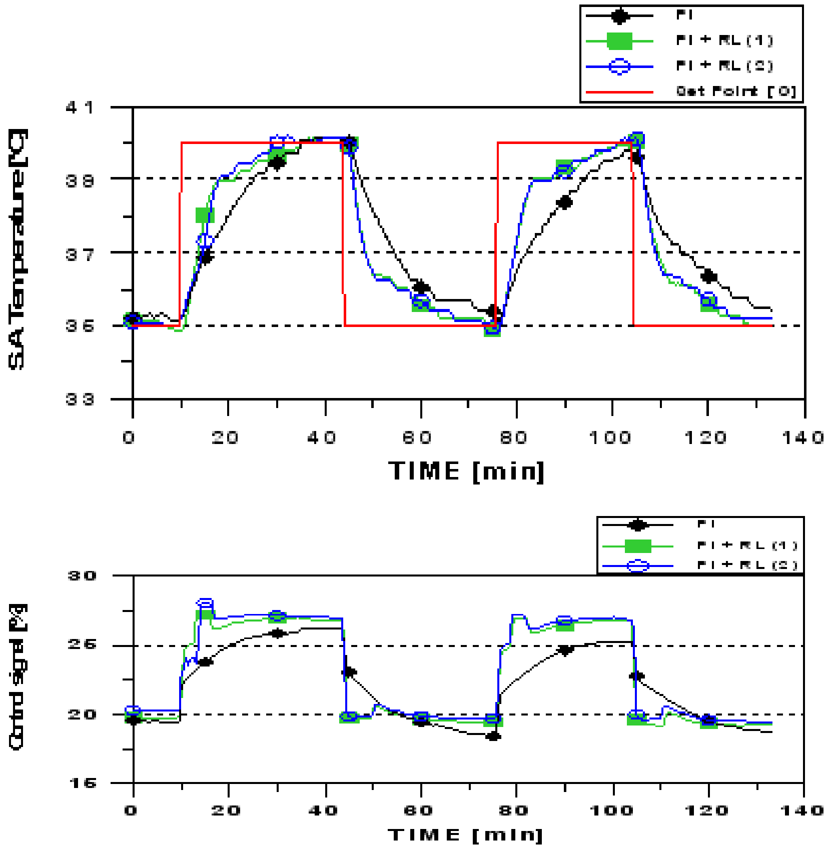

Fig. 7. Control performance with combined PI and RL controller (random gain)

Fig. 8. shows when it used a RL controller with learning error and a PI controller, if you compare the performance, the respond is a bit improved. However, normal state error increased far more than using only PI controller because shaking status quo on the output control signal of heating coils happened by the matter of convergence near the boundary value of the input variable for learning.

To apply the controller which RL controller is applied to actual system through this experiment, first, there would be enough learning, appreciate selection of input variables according to environment change, a boundary range for each variable, and effective selection of output reward signal value of each system to develop the controller with optimum performance.

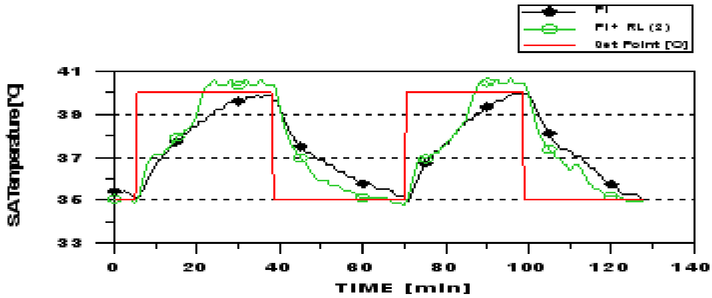

Fig. 8. Performance comparison of controller as learning error

5 Conclusion

As the result of experiment that PI controller and Reinforcement Learning controller applied to actual tuning system, the more increasing times of learning routine, RL controller increases or decreases output of PI controller when the temperature value of supply air changes according to the change of outside environment. It does not decrease normal state error between a set point and a temperature of supply air. However, it is clear that it has a rather quick respond so that output control signal of heating coils improves considerably as it following-controls a set point.

In order to apply the controller which RL controller connects to actual system, there should be enough learning, appropriate selection of input variables, space range of each variable and establishment of control signal value of output reward of each system effectively. Otherwise, there could cause a place where the boundary section condition of variables or no learning achieved, or would not converge because of the happening of shaking status from learning error. Therefore, it could cause deterioration of controller's performance. However, it could be the controller with optimum performance on the purposes of each system if there would be appropriate input variables, reward output signals, and the range of learning times.

The controller with Reinforcement Learning control algorithm has a quick adaptability to environment changes so that it is able to improve the performance of controller.

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Optimizing Dissimilarity-Based Classifiers Using a Newly Modified Hausdorff Distance*

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Abstract. The aim of this paper is to present a dissimilarity measure strategy by which a new philosophy for pattern classification that pertaining to Dissimilarity-Based Classifiers (DBCs) can be efficiently implemented. DBCs, proposed by Duin and his co-authors, is not based on the feature measurements of the individual patterns, but rather on a suitable dissimilarity measure between them. The advantage of DBCs is that since it does not operate on the class-conditional distributions, the accuracy can exceed the Bayes' error bound. The problem with this strategy, however, is that we need to measure the inter-pattern dissimilarities for all the training samples such that there is no zero distance between objects of different classes. Consequently, the classes do not overlap, and therefore, the lower error bound is zero. Thus, to achieve the desired classification accuracy, a suitable method of measuring dissimilarities is required to overcome the limitations based on the object variations. In this paper, to optimize DBCs, we suggest a newly modified Hausdorff distance measure, which determines the distance directly from the input gray-level image without extracting the binary edge image from it. Also, instead of obtaining the Hausdorff distance on the basis of the entire image, we advocate the use of a spatially weighted mask, which divides the entire image region into several subregions according to their importance. For instance, in face recognition, important regions could include eyes and mouth, while the rest is considered unimportant regions. There could also be the background region that contains no facial parts. The present experimental results, which, to the best of the authors' knowledge, are the first reported results, demonstrate that the proposed mechanism could increase the classification accuracy when compared with the "conventional" approaches for a well-known face database.

1 Introduction

[illegible]

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dissimilarity measure

[1]

all.

Random *Random_C* *KCentres* T

prototypes Y

$|Y| \leq |T|$

Y

L_p

$L_{0.8}$

[1] The idea of the zero-error bound is based on the fact that dissimilarities may be defined such that there is no zero distance between objects of different classes. Consequently the classes do not overlap, and so the lower error bound is zero. We are grateful to Bob Duin for providing us with insight into this.

2 Dissimilarity-Based Classification

Foundations of DBCs: T $\{\boldsymbol{x}_1, \cdots, \boldsymbol{x}_n\} \in R^p$ n p T T c $\{T_1, \cdots, T_c\}$ T $\bigcup_{k=1}^{c} T_k, T_i \cap T_j$ $\phi, \forall i$ / j *training data* $\boldsymbol{z}$ T_i ω_i T_i $\{\boldsymbol{x}_1, \cdots, \boldsymbol{x}_{n_i}\}, n$ $\sum_{i=1}^{c} n_i$ [2] Y_i Y_i $\{\boldsymbol{y}_1, \cdots, \boldsymbol{y}_{m_i}\}, m$ $\sum_{i=1}^{c} m_i$ d d $\boldsymbol{x}_i, \boldsymbol{y}_j$ $\boldsymbol{x}_i$ $\boldsymbol{y}_j$ d [3] d $\boldsymbol{x}_i, \boldsymbol{y}_j$ $\geq$ d $\boldsymbol{x}_i, \boldsymbol{y}_j$ $\boldsymbol{x}_i$ $\boldsymbol{y}_j$ d $\boldsymbol{x}_i, \boldsymbol{y}_j$ d $\boldsymbol{y}_j, \boldsymbol{x}_i$ T Y $n \times m$ $D_{T,Y}$ i, j $\boldsymbol{x}_i \in T$ $\boldsymbol{y}_j \in Y$ $\boldsymbol{x}_i$ d $\boldsymbol{x}_i, \boldsymbol{y}_1$ $, d$ $\boldsymbol{x}_i, \boldsymbol{y}_2$ $, \cdots, d$ $\boldsymbol{x}_i, \boldsymbol{y}_m$ ^{T}, $\leq i \leq n$ $D_{T,Y}$ [4] *dissimilarity space* p $\boldsymbol{x}$ m δ $\boldsymbol{x}, Y$ $\boldsymbol{x}$ $\boldsymbol{x}_i$ δ $\boldsymbol{x}_i, Y$ i^{th} $D_{T,Y}$ δ $\boldsymbol{x}, Y$ δ_Y $\boldsymbol{x}$ m $\boldsymbol{x}$ p

Dissimilarity Measures Used in DBCs: [5] $L_{0.8}$ L_p p , , ∞

---

[2] Rather Y_i may be created or selected from T_i, and its computation may also involve the other sets, $T_j, j \neq i$.

[3] Note that $d(\cdot, \cdot)$ need not be a *metric* [7].

[4] Here, the subscripts of D represent the set of elements on which the dissimilarities are evaluated.

[5] The details of the binary, categorical, ordinal, symbolic and quantitative features are omitted here, but can be found in [7].

Max-Min

Median
Cosine

Classifying Steps in DBCs:

Y T
RandomC *KCentres*
$D_{T,Y}$

z δ_Y z

δ_Y z

$D_{T,Y}$

3 Spatially Weighted Gray-Level Hausdorff Distance

The Classical Hausdorff Distance: *max-min*

A
$\{a_1, \cdots, a_p\}$ B $\{b_1, \cdots, b_q\}$

$$H\ A, B \quad max\{h\ A, B\ , h\ B, A\ \},$$

$h\ A, B$

$$h\ A, B \quad \underset{a \in A}{} d\ a, B \quad \underset{a \in A\ b \in B}{} \|a - b\|,$$

$\|\cdot\|$ A B [6]
B A $h\ B, A$ $_{b \in A} d\ b, A$

The Modified Hausdorff Distances:

[6] The distances, such as the city block, chessboard, and Euclidean distances, are the most popular in pattern recognition and image processing applications. In this paper, we employed the Euclidean distance.

$$H\ A,B \quad max\{h_{WHD}\ A,B\ ,h_{WHD}\ B,A\ \},$$

$h_{WHD}\ A,B$

$$h_{WHD}\ A,B \quad \overline{N_a}\sum_{N_a} w\ a \quad {}_{b\in B}\ \|a-b\|,$$

N_a A $w\ x$

$$w\ x \quad \begin{cases} & x\in R_i \\ w_v \quad < w_v < & x\in R_u \\ & x\in R_b \end{cases},$$

R_i R_u R_b $h_{WHD}\ B,A$

A B

$$h\ A,B \quad {}_{a_t\in A}\ d\ a_t,B\ , \quad \le t\le \quad ,$$

t

$$d\ a_t,B \quad \left({}_{b_{t-1}\in B}\|a_t-b_{t-1}\|, {}_{b_t\in B}\|a_t-b_t\|, {}_{b_{t+1}\in B}\|a_t-b_{t+1}\| \right).$$

a_t $\overline{A}$ b_t B a_t b_{t-1} b_{t+1} B

A Newly Modified Hausdorff Distance:

A B

$$h_{WGHD}\ A,B \quad \overline{N_{a_t}}\sum_{a_t\in A} w\ a_t\ \ d\ a_t,B\ ,$$

$\sum_{a_t \in A} w\ a_t \qquad N_{a_t}$

$$d\ a_t, B \quad \Big(\underset{b_{t-k} \in B}{} \|a_t - b_{t-k}\|, \underset{b_{t-k+1} \in B}{} \|a_t - b_{t-k+1}\|, \cdots, \underset{b_{t-k} \in B}{} \|a_t - b_{t-k}\|, \cdots, \underset{b_{t+k} \in B}{} \|a_t - b_{t+k}\| \Big) .$$

k t k a_t b_{t-2} b_{t-1} b_{t+1} b_{t+2} a_t b_t

4 Experimental Results

& & × × × & [7]

---

[7] We experimented with the simpler 50×50 matrix here. However, it should be mentioned that we can have numerous solutions, depending on the representative selection, the dissimilarity measure, and the design of classifiers in the dissimilarity space. Especially, regarding the dissimilarity measure, it is possible to construct the dissimilarity matrix rapidly by employing a computational technique. From this perspective, we are currently investigating how the experiment with the full 400×400 matrix can be performed at a high speed.

w x
mean face

n −

n

n

five &

%

k

%

σ

Table 1. A comparison of the averaged classification accuracy rates (%) and the averaged processing CPU-times (seconds) of the Dissimilarity-Based Classifiers (DBCs). The processing CPU-time of the second row is presented as an exponential form. For example, $3.45e3 = 3.45 \times 10^3$. Also, the numbers represented in the brackets of each row are the standard deviations. The details of the table are discussed in the text.

Database	HD	WHD	GHD	WGHD
AT&T	85.00 (5.18) 3.45e3 (1.64e2)	93.00 (4.82) 3.02e3 (1.02e2)	81.20 (10.72) 5.93e4 (2.22e2)	99.00 (1.05) 5.92e4 (2.12e2)

5 Conclusions

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A New Model for Classifying DNA Code Inspired by Neural Networks and FSA

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Abstract. This paper introduces a new model of classifiers $\mathrm{CL}(V, E, \ell, r)$ designed for classifying DNA sequences and combining the flexibility of neural networks and the generality of finite state automata. Our careful and thorough verification demonstrates that the classifiers $\mathrm{CL}(V, E, \ell, r)$ are general enough and will be capable of solving all classification tasks for any given DNA dataset. We develop a minimisation algorithm for these classifiers and include several open questions which could benefit from contributions of various researchers throughout the world.

1 Introduction

A. Hoffmann et al. (Eds.): PKAW 2006, LNAI 4303, pp. 187–198, 2006.

V, E, ℓ, r

V, E, ℓ, r

V, E, ℓ, r

V, E, ℓ, r

V, E, ℓ, r

V, E, ℓ, r

V, E, ℓ, r

2 Preliminaries

$$X \quad \{A, C, G, T\}.$$

X^*
X

3 Main Notion

classifier V, E, ℓ, r

$$V, E, \ell, r \qquad V, E, \ell, r \;,$$

$V \quad \{v_1, \ldots, v_n\}$ E
$G \quad V, E$ e
$\ell\ e$ X $r\ e$

$$\ell \quad E \to X \qquad r \quad E \to \; .$$

state *current state* V, E, ℓ, r

$$s \quad V \to \; .$$

V, E, ℓ, r

V, E, ℓ, r

$$x_1, x_2, \ldots, x_N,$$

$x_1, \ldots, x_N \in X$ $s_0 \quad V \to$

$i \geq$

$$s_i \quad V \to$$

s_{i+1}

$$s_{i+1} \; v \qquad \sum_{w \in V, (w,v) \in E} r \quad w, v \quad s_i \; w \; .$$

$v \in V$

$s_N \; v \; \in$

V, E, ℓ, r $\leq k \leq N$

$\mathcal{K}_k$ $C_1, \ldots, C_k$

C_i $C_i^{(k)}$ i

$\leq i \leq k$

$$s_N \; v_i \qquad \{s_N \; v_1 \; , \ldots , s_N \; v_k \; \}.$$

$k >$ $\mathcal{K}_k$ $\mathcal{K}_{k-1}$

$$C_1^{(k-1)}, C_2^{(k-1)}, \ldots, C_{k-1}^{(k-1)}$$

$\mathcal{K}_{k-1}$ $C_k^{(k)}$

4 Main Result and Verification

V, E, ℓ, r

Theorem 1. *For each set S of DNA sequences and every given partition*

$$S \quad S_1 \cup S_2 \cup \cdots \cup S_k$$

one can find a classifier V, E, ℓ, r

$$C \quad V, E, \ell, r$$

which produces classification

$$\mathcal{K} \quad X^* \quad C_1 \cup C_2 \cup \cdots \cup C_k$$

such that the classes of partition are determined by the classes of classification so that $S_i \quad S \cap C_i$ for all $i \quad , \ldots , k$.

Proof. N $|S|$ S $b^{(1)}, b^{(2)}, \ldots, b^{(N)}$ i $, \ldots, N$ $b^{(i)}$ $b_j^{(i)}$ j $, \ldots, m_i$

$$b^{(i)} \quad b_1^{(i)}, b_2^{(i)}, \ldots, b_{m_i}^{(i)},$$

i $, \ldots, N$ $b^{(i)}$ $S_{\phi(i)}$ ϕ $\underline{N}$ $\underline{k}$ V, E, ℓ, r

$$V_0 \quad \{v_1, v_2, \ldots, v_k\}$$
$$V_i \quad \{v_1^{(i)}, v_2^{(i)}, \ldots, v_{m_i-1}^{(i)}\}$$

i $, \quad, \ldots, N$ v_0 $V_0, V_1, \ldots, V_N$

$$V \quad V_0 \cup V_1 \cup \cdots \cup V_N \cup \{v_0\}.$$

v_0 $v_0^{(1)}, v_0^{(2)}, \ldots, v_0^{(N)}$ i $, \quad, \ldots, N$ $v_{m_i}^{(i)}$ $v_{\phi(i)} \in V_0$ i $, \quad, \ldots, N$

$$E_i \quad \{ \; v_0, v_1^{(i)} \quad v_0^{(i)}, v_1^{(i)} \; , \; v_1^{(i)}, v_2^{(i)} \; , \ldots, \; v_{m_i-1}^{(i)}, v_{m_i}^{(i)} \quad v_{m_i}^{(i)}, v_{\phi(i)} \; \}$$

$$E \quad E_1 \cup E_2 \cup \ldots \cup E_N.$$

s_0 ℓ r i $, \quad, \ldots, N$ j $, \quad, \ldots, m_i$

$$\ell \;\; v_{j-1}^{(i)}, v_j^{(i)} \qquad b_j^{(i)},$$
$$r \;\; v_{j-1}^{(i)}, v_j^{(i)} \qquad .$$

s_0 $v \in V$

$$s_0 \;\; v \quad \begin{cases} \quad v \quad v_0, \\ \end{cases}$$

V, E, ℓ, r $b^{(i)}$ $\leq i \leq N$ j

$$s_j \;\; v \quad \begin{cases} \quad v \quad v_j^{(i)}, \\ \end{cases}$$

$v \in V$

$< j < m_i$ s_{j+1} v

v $v^{(i)}_{j+1}$ E $w, v^{(i)}_{j+1}$ s_j $v^{(i)}_j$

$$
\begin{aligned}
s_{j+1} \; v \quad & \sum_{w \in V, (w,v) \in E} r \quad w, v \quad s_j \; w \\
& \sum_{w \in V, (w, v^{(i)}_{j+1}) \in E} r \quad w, v^{(i)}_{j+1} \quad s_j \; w \\
& r \quad v^{(i)}_j, v^{(i)}_{j+1} \quad s_j \; v^{(i)}_j \\
& s_j \; v^{(i)}_j \\
& .
\end{aligned}
$$

v $v^{(i)}_{j+1}$ $v \;/\; v^{(i)}_{j+1}$ $w \in V$ w $v^{(i)}_j$ $w, v \notin E$ v $w \;/\; v^{(i)}_j$ $s_j \; w$

$$
s_{j+1} \; v \quad \sum_{w \in V, (w,v) \in E} r \quad w, v \quad s_j \; w
$$

$$.$$

$v \;/\; v^{(i)}_{j+1}$ $b^{(i)}_1, \ldots, b^{(i)}_{m_i}$ $b^{(i)}$ V, E, ℓ, r

$$
s_{m_i} \; v \quad \begin{cases} v \quad v^{(i)}_{m_i} \quad v_{\phi(i)}, \\ \end{cases}
$$

$b^{(i)}$ $C_{\phi(i)}$ $\mathcal{K}_k$

5 Neural Networks and Finite State Automata

V, E, ℓ, r

V, E, ℓ, r … V, E, ℓ, r … V, E, ℓ, r

V, E, ℓ, r … V, E, ℓ, r … V, E, ℓ, r … V, E, ℓ, r

6 Main Algorithm

V, E, ℓ, r … V, E, ℓ, r *minimal* … *vertex* …

V, E, ℓ, r

V, E, ℓ, r … V, E, ℓ, r …

… C … V, E, ℓ, r … C … V …

$$V \times V \quad \{ u, v \mid u, v \in V\}$$

… *relation* … V … ϱ … *symmetric* … $u, v \in \varrho$ … $v, u \in \varrho$ … $u, v \in V$ … *transitive* … u, v , $v, w \in \varrho$ … $u, w \in \varrho$ … $u, v, w \in V$ … *reflexive* …

$$\{ v, v \mid v \in V\}.$$

… *equivalence* … ϱ … V … $v \in V$ …

$$v^{\varrho} \quad \{w \mid v, w \in \varrho\}.$$

… v^{ϱ} … ϱ … v … ϱ … v^{ϱ} $v \in V$ … V … ϱ … C … ϱ … C … ϱ … *quotient classifier* C/ϱ …

$$C/\varrho \quad V/\varrho, E/\varrho, \ell/\varrho, r/\varrho ,$$

… V/ϱ E/ϱ … ℓ/ϱ r/ϱ … V/ϱ … ϱ … V … E/ϱ … u^{ϱ}, v^{ϱ} …

$$\ell/\varrho \quad u^{\varrho}, v^{\varrho} \qquad x \in X$$

… $u' \in u^{\varrho}$ … $v' \in v^{\varrho}$ … $u', v' \in E$ … ℓ u', v' x …

$$r/\varrho \quad u^{\varrho}, v^{\varrho} \qquad \sum_{u' \in u^{\varrho}, v' \in v^{\varrho}, (u', v') \in E, \ell((u', v'))=x} r \quad u', v' \quad .$$

… ℓ … r … ℓ/ϱ … r/ϱ …

… V, E, ℓ, r … *-*equivalent* … V, E, ℓ, r …

k

k-equi $\leq k$

V, E, ℓ, r

s t

V, E, ℓ, r C V, E, ℓ, r *-equivalent*

$k \geq$ k

s t V s

k t s t k

$x \in X$ s

x

t x

s t

k $k -$

k

$k -$

V, E, ℓ, r X

$k \geq$

k k

k k

$*$

V, E, ℓ, r

1. V

2. k k

k V

k k

k $*$

3. V, E, ℓ, r

$*$

7 Open Questions

Problem 1. V, E, ℓ, r

Problem 2.

Problem 3.

Problem 4.

Problem 5.

Acknowledgements

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Improvements on Common Vector Approach Using *k*-Clustering Method

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Abstract. In this paper, an advanced common vector approach (CVA) method for isolated word recognition is presented. The proposed method eliminates drawback of conventional CVA method, which is impossibility of being applied to a large number of training voices case, by dividing the training voices into a few small groups where those voices belong to a class of one of the spoken words. The results from using MFCC, LPC, LSP, Cepstrum, and auditory model shows that the proposed method solves the drawback of conventional CVA method. It got better recognition rate of 1.39% without significant changes of amounts of computation.

1 Introduction

A. Hoffmann et al. (Eds.): PKAW 2006, LNAI 4303, pp. 199–206, 2006.

2 Common Vector Approach

R^n n

$\langle x, y \rangle$ x y

$||x||$ x

n $a_1, a_2, \ldots, a_m \in R^n$ $m < n$ a_i i , , $\cdots, m$

a_i x

$a_{i,diff}$ i_{th}

$$a_1 \quad x \quad a_{1,diff}$$
$$a_2 \quad x \quad a_{2,diff}$$
$$a_m \quad x \quad a_{m,diff}$$

$$b_1 \quad a_1 - a_m$$
$$b_2 \quad a_2 - a_m$$
$$b_{m-1} \quad a_{m-1} - a_m.$$

$\{z_1 \ z_2 \ \cdots \ z_{m-1}\}$ $\langle z_i, z_j \rangle$ $\{$ i j $i \,/\, j$ $\}$ $\{b_1 \ b_2 \ \cdots \ b_{m-1}\}$

$$\overline{a}_i \quad \langle a_i, z_1 \rangle z_1 \quad \langle a_i, z_2 \rangle z_2 \quad \cdots \quad \langle a_i, z_{m-1} \rangle z_{m-1}, \ i \quad , \ , \ldots, m \ .$$

$\overline{a}_i$ a_i B a_i $a_i - \overline{a}_i$ a_{common} $a_1, a_2, \ldots, a_m$

$$a_{common} \quad a_i \quad a_i - \overline{a}_i, \ i \quad , \ , \ldots, m$$

3 Common Vectors Using *k*-Clustering Method

k k

k k k n $a_1, a_2, \ldots, a_m \in R^n$ $m \gg n$ a_i i , $, \ldots, m$ a_i k $k < m$ $k \leq n -$ k k a_i %

3.1 k-Clustering Method

a_i k k k a_i k k

Goal. $a_i \in R^n$ i , $, \ldots, m$ k $k < m$ $k \leq n -$

Step 1. r a_i

Step 2. r k

Begin initialize m k u_1 u_2 $\ldots$ u_k

do classify $m -$ samples into k groups according to nearest u_i

recompute u_i

until no change in u_i

return $u_1, u_2, \ldots, u_k$

end

Step 3. r

3.2 Finding First Common Vectors

r j_{th} a_i^j $j \leq k, i$ $, \ldots, t < n -$ j_{th} j_{th}

$$b_1 \quad a_1^j - r$$
$$b_2 \quad a_2^j - r$$

$$b_t \quad a_t^j - r$$

$$a_i{}^j \quad a_{common}^j \quad a_i^j - \overline{a}_i^j \quad r - \overline{r}, \; i \quad , \; , \ldots, t$$

$$a_i^j \quad \langle a_i^j, z_1^j \rangle z_1^j \quad \langle a_i^j, z_2^j \rangle z_2^j \quad \cdots \quad \langle a_i^j, z_t^j \rangle z_t^j$$

3.3 Finding Total Common Vector

a_{common}^j

$$a_{common}^1 \quad a_{common}^{total} \quad a_{common,diff}^1$$
$$a_{common}^2 \quad a_{common}^{total} \quad a_{common,diff}^2$$

$$a_{common}^k \quad a_{common}^{total} \quad a_{common,diff}^k$$

a_{common}^{total} $a_{common,diff}^j$ j_{th}

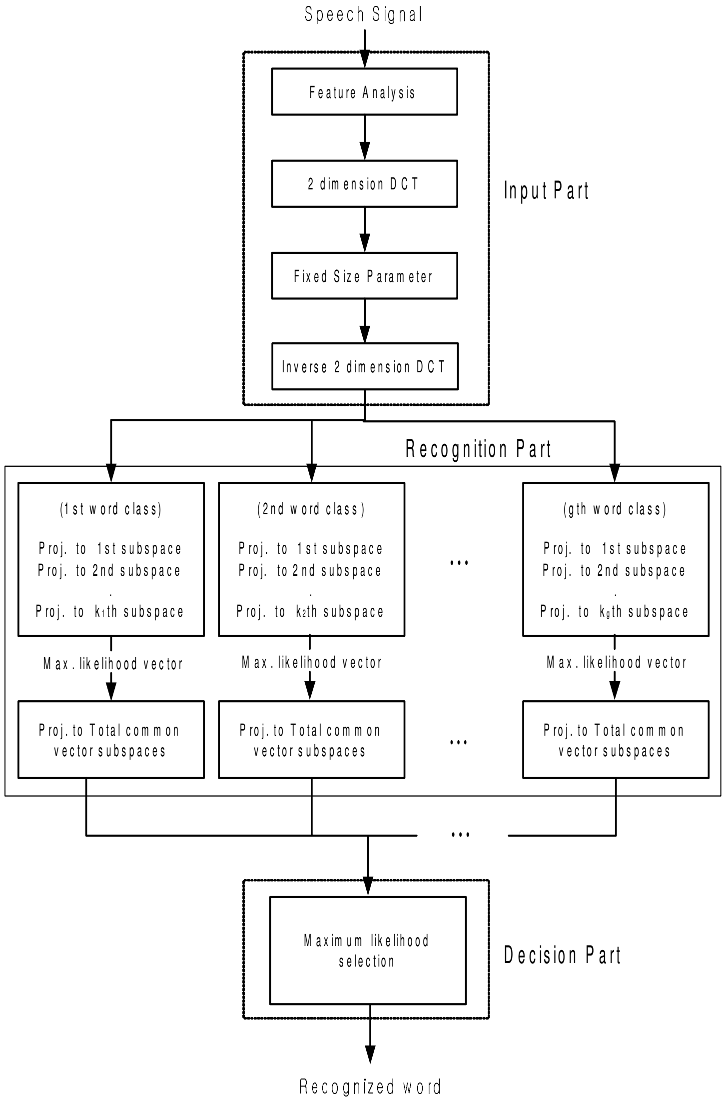

Fig. 1. Block diagram of *k*-clustering method

4 Experiments and Results

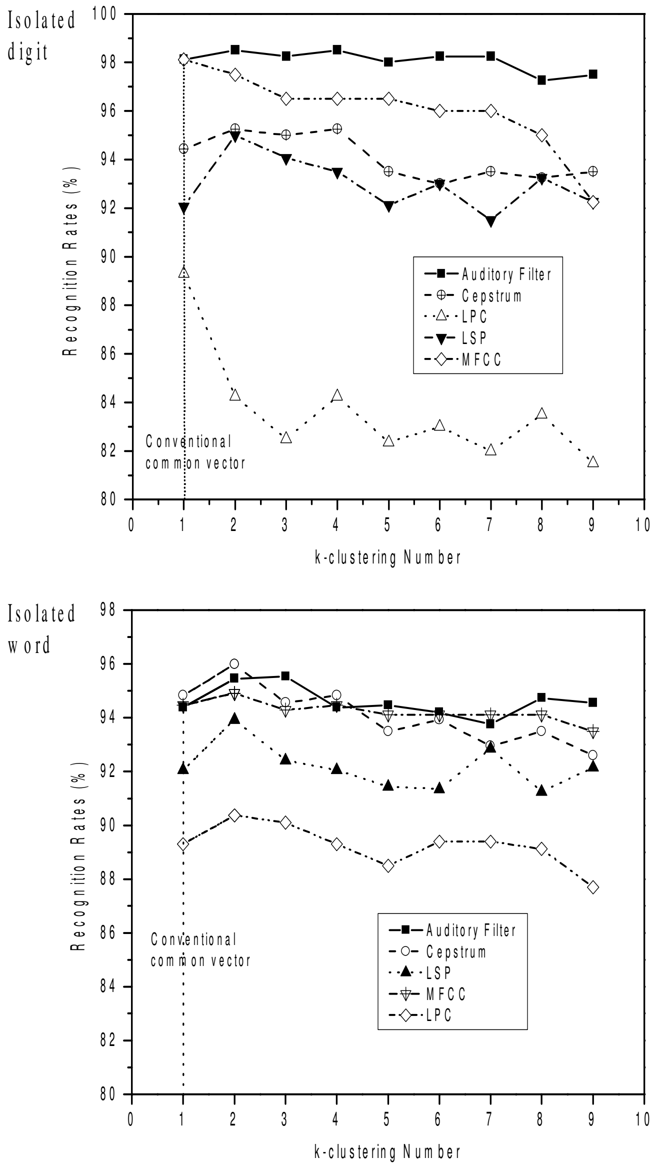

Fig. 2. Recognition rates of variations of the k-clustering number for isolated digit and isolated word

[illegible]

Table 1. Average recognition rates(%) of isolated digit by number of clusters

Method	Conventional CVA(k=1)	k=2	k=4	k=6	k=8
MFCC	98.12	97.50	96.50	96.00	95.00
Auditory Model	98.12	98.50	98.50	98.25	97.25
Cepstrum	94.43	95.25	95.25	93.00	93.25

Table 2. Average recognition rates(%) of isolated word by number of clusters

Method	Conventional CVA(k=1)	k=2	k=4	k=6	k=8
MFCC	94.91	94.47	94.11	94.11	93.49
Auditory Model	94.38	95.45	94.38	94.20	94.74
Cepstrum	94.38	95.98	94.83	93.93	93.49

5 Conclusion

[illegible]

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The Method for the Unknown Word Classification

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Abstract. Natural Language Processing is a hard task. For the real Natural Language Processing, it is a necessary technique to process the unknown words. In this paper, we introduce the method for understanding the unknown words means. Many terms are newly created and we do not find these words in dictionary. Unknown words are generally occurred by reflecting the new phenomenon and technology. Hence, unknown words are dramatically created because of rapid changes in society. However, it is a hard task to define the meaning of all unknown words in dictionary. So, in this paper, we focus on how the machine understands the unknown words means. We propose a method to classify unknown words using the relevancy values between all nouns in the document and their TF values.

1 Introduction

For the real Natural Language Processing(NLP), there are several tasks that we have to solve. One of the significant tasks is to classify the unknown words. The NLP system encounters words that are not in its lexicon frequently. In here, we define the terms as the unknown words which do not exist in the lexicon. As a NLP system will perform well, it should understand the unknown words. Even when the unknown words are not occurred very often, they have an effect on a NLP system quality. For the past several years, the importance of the task for Natural Language Processing systems has been recognized. However, it is a very hard task because the huge unknown words can be created everyday and they cannot be completely registered in the lexicon by the human. Therefore, robust approaches for processing unknown words are needed. [1][2][3] The method presented in this paper allows the automatic detection of the unknown words means. A machine applying our technique can understand the unknown words and it can classify the words automatically instead of the human knowledge engineer. In our approach, several algorithms such as unknown words detection, unknown words understanding and classification are demanded. Our proposed method is using the *Relevancy* values among the terms based on WordNet and their *TF* values.

This paper organized as follows: Section 2 introduces the background technologies and we present our proposed method for understanding the unknown words

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automatically. Section 3 presents the experimental results and evaluation. Finally, we conclude our study in Section 4.

2 Background Knowledge and Our Approach

In this section we describe our approach how to understand the unknown words means. Under this view, unknown word processing is based on the existing techniques.

a) *TF* values
b) *Relevancy* values in WordNet
c) Noun detection

The brief explanation about each technique is as follows.

In this paper, we use WordNet to detect the nouns in the sentences and to get the relevancy values among these nouns. WordNet is a semantic lexicon for the English language. It groups English words into sets of synonyms called synsets and records the various semantic relations between these synonym sets. And English nouns, verbs, adjectives and adverbs are organized into synonym sets in WordNet.[4] Most synsets are connected to other synsets via semantic relations. In our approach, we consider the nouns and two semantic relations (*Hypernym/Hyponym, Holonym/Meronym*) in WordNet for measuring the relevancy values. Second basic technique in our approach is the TF value. Documents are written using huge terms. In this case, it is very hard to determine which words are most important in documents. Until now, for determining the importance of words in document, we generally measure the *TF*(term frequency).[5] And the formula calculating *TF* is as follows:

$$tf = \frac{n_i}{\sum_k n_k}$$

In above formula, $\sum_k n_k$ means the total of all terms, which the document contains, n_i is the number of occurrence of the specific term. And values gained through *TF* formula are the indispensable data with the relations between terms in our approach.

Processing unknown words is a mixture of two above techniques. In order to process document containing unknown words, we use all the nouns contained in the document. In our approach, unknown words are processed following the steps.

STEP 1. Parsing the document to detect unknown word

Unknown words are frequently created because of new theories, technologies, change of the customs and human activities and many manufactures. As we briefly mentioned before, we define unknown words that are not published in the lexical as WordNet. Principle of unknown word acquisition in our approach is as follows:

(1) Detect nouns in document.
(2) Search the unknown words based on pseudo code in table 1. In here, we use the WordNet as the standard lexicon to detect the unknown word.
(3) According to the results of the pseudo code, we are able to detect unknown words.

Table 1. The pseudo code for detecting the unknown word

```
C_i : Set of nouns ;
WN : Nouns in WordNet ;
If (C_i ¬∈ WN)
{
        Unknown_Word = C_i ;
}
Unknown_Word : The results after processing STEP 1
```

STEP 2. Extracting the sentences containing unknown word and all nouns except unknown word in document

In this step, we extract the sentences containing unknown words in document. And then, we detect the all nouns in document except unknown word. In our method, we assume that all nouns in document are related to the unknown word. Moreover, we think the nouns in sentences, which contain unknown word, are closely related to unknown word. Hence, we divide the document into two parts:

- Sentences Part: All sentences containing the unknown word
- Nouns Part: All nouns in document except the unknown word

The processing flow of sentences extraction is as follows:

(1) Use the unknown word detected through STEP 1.
(2) Extract the sentences, which include the unknown word based on pseudo code in Table 2.
(3) Through the STEP 2, we can prepare the input data for our method. For the input data, we analyze the document as we divide into the two parts like Table 3. For example, in this processing, we try to define the meaning of ‘S-Class’, which is an unknown word.

Table 2. The pseudo code for extracting the sentences containing unknown word

```
Unknown_Word : The result through STEP 1
S_i : All sentences in document
If (Unknown_Word ∈ S_i)
{
        {S} = {S} + S_i ;
}
{S} : The result after processing STEP 2
```

Table 3. Extracted sentences containing new word and extracted nouns

Original contents of document	
Origin of S-Class While the exact beginning of the colloquial S-Class expression … it always referred to the most spacio us and largest luxury vehicle … applied to vehicles requiring premium fuel or "Super" due to higher co mpression ratio and output of the top-of-the-line engines. Widely distributed, over time, these cars came to be considered desirable … The S-Class grew out of the modest "Ponton" model, a six cylinder sedan known … The line was introduced with the 220a, 219 (W105), 220S, and 220SE sedan, coupe, … … the W110 featuring a shorter hood and wheelbase for the "economy" models 190c and 190Dc, and t he 300 SE (W112]]), a short time predecessor … … saw the opportunity to build much larger vehicles, including the limited volume 1964 600 limousine … … sedan (still W111) along the new larger (W108/W109). These larger vehicles established the S-Class reputation that continues … … brought aerodynamics to the previously brick shaped cars. The W140 saw the car grow dramatically in its proportions …	
Extracted Sentences containing unknown word	**All Nouns in document**
*Origin of **S-Class*** *While the exact beginning of the colloquial **S-Class** expression … it always referred to the most spacious and largest luxury veh icle … applied to vehicles requiring premium fuel or "Super" du e to higher compression ratio and output of the top-of-the-line e ngines.* *The **S-Class** grew out of the modest "Ponton" model, a six cylind er sedan known …* *These larger vehicles established the **S-Class** reputation that co ntinues …*	Car, sedan, accelerator, gear, seat, break, system, auto, vehicle, carria ge, airbag, space, car, car, person, wheel, sedan, vehicle, passenger, n ews, window, coupe, accident, car … *(in here, we detect all nouns and d o not consider the duplication abo ut nouns)*

STEP 3. Measure the relevancy values and TF values

In STEP 2, we detected the nouns in the document as shown in Table 3. In our approach, we consider the *TF* values of all extracted nouns and the relevancy values among the nouns based on the relations in WordNet. STEP 3 is processed as follows:

(1) Calculate the *TF* values based on pseudo code in Table 4.

Table 4. The pseudo code for calculating the *TF* values

```
N : The nouns in nouns part
TFV : TF values
For (N_i ∈ Nouns Part)
{
    TFV_i = TFV_i + 1;
}
TFV_i : The result after processing TF calculation
```

Using pseudo code in Table 4, *TF* values about all nouns in table 3, for example, are calculated as shown in Table 5.

Table 5. Calculated TF values about sample document as shown in table 3

Synset_ID	TF Value	Words
04207742	11	System
02853224	8	Car
10464998	8	Model
05327145	7	Gear
14401902	3	Sedan
04008331	1	……

Table 5 shows the results of the *TF* values of all nouns in Nouns part. Until now, in previous approaches to understand the unknown words, the *TF* values play the core role. However, it does not support for the complete understanding of unknown words. Hence, we consider the *Relevancy* value between nouns as well as *TF* values for the perfect unknown words understanding.

(2) Measure the *Relevancy* values between noun in Sentence part and noun in Nouns part based on pseudo code in Table 6.

Table 6. The pseudo code for measuring the *Relevancy* value

```
N : The nouns in Nouns part
SN : The nouns in Sentences part
RV : Relevancy Value
For (N_i ∈ N) {
    If (N_i Related to SN)
    {
            RV_i = RV_i + 1;
     }
}
RV_i : The result after measuring the Relevancy value
```

After detecting the nouns, we measure the *Relevancy* value, which means how the nouns are related to the unknown word. In here, we use the semantic relations between nouns defined in WordNet. As we mentioned before, there are many relations in WordNet. However, we just use two relations (*Hypernym/Hyponym, Holonym/Meronym*) for measuring the *Relevancy* value among nouns.

Table 7. Measured *Relevancy* values among nouns about sample document as shown in table 3

Synset_ID	Related Synset_ID and relationship based on WordNet	Relevancy Values
04207742	~ 10720570 ~ 09729204 %p 04410590 %p 04254824 ~ 04008331 %p 03400842 %p 03389509 %p 03228252 ~ 03006338	**9**
02853224	~ 10066029 ~ 09933701 ~ 09908263 ~ 09843239 ~ 09843239 ~ 09819657 ~ 09721227 ~ 09624379 ~ 09608190 ~ 09598437 ~ 09463859 ~ 09385835 ~ 09285577 ~ 09223355 ~ 09145707 ~ 09144663 ~ 09019701 ~ 09013278 ~ 09012224 %p 04916889 #m 07463651 @ 00003226	**22**
08103697	~ 08134364 ~ 08124727 ~ 08120943 ~ 08087842 ~ 08066770 ~ 08063710 ~ 08034339 ~ 07992043 ~ 07982095	**9**
00017572	~ 14254673 ~ 14130483 ~ 14051444 ~ 14051242 ~ 14050897 ~ 14027638	**6**

Table 7 shows the measured *Relevancy* values among nouns based on the relations defined in WordNet.

STEP 4. Defining the unknown words mean

STEP 4 is the core in our approach. STEP 4 exploiting the *Relevancy* values and *TF* values of the nouns is processed as follows:

(1) Use the *TF* value and *Relevancy* value each noun.
(2) Figure out the meaning of the unknown word as we calculate *CV* values about each noun based on pseudo code in Table 8.

Table 8. The pseudo code for measuring the *Relevancy* value

```
N : The nouns in Nouns part
TF : TF Value
RV : Relevancy Value
CV : Concept Value
For (N_i ∈ N)
{
        N_TF_i : TF Value of Ni
        N_RV_i : Relevancy Value of Ni
        CV_i = N_RV_i * N_TF_i ;
}
CV_i : The result after calculating the Concept Value
```

(3) Through the STEP 4, we can determine the meaning of the unknown word. Using the results in Table 9, the unknown word(S-Class) could be classified into the car.

Table 9. CV Results

Nouns (Synset_ID)	Results	
	CV	Concepts
02853224	**798.0001**	**Car, auto, automobile, machine, motorcar**
05394410	352.7999	Arrangement, organization, organization, system
05396456	338.8001	Design, plan
04008331	313.6001	Sedan
07924048	293.9999	System, scheme

Table 9 shows the *CV* results about each noun. In table 9, noun 'car' has the highest *CV* values. So, we could conclude that 'S-Class' is very close to the car. Hence, efficiency of our approach was certified correct.

3 Experimental Results and Evaluation

In example of Section 2, we are sure that our approach is suitable for defining the meaning of unknown words. We have evaluated our proposed method formatively. In order to examine the validity of the method we adopted, the approach was evaluated with some amounts of document resources. Our testing environment is as follows:

(1) Objective: To measure efficiency of our approach.
(2) Materials: WordNet as knowledge source, each 5 documents containing five unknown words – TGV(train), Fanta(beverage), Zindane(soccer player), S-Class(car) and Marlboro(cigarette).
(3) Results: Table 10 shows the results of *CV* values of the five documents respectively.

Table 10. Experimental results

Document 1	CV	Document 2	CV	Document 3	CV	Document 4	CV	Document 5	CV
TGV									
train	8	France	7	France	4	road	24	train	2
Korea	8	travel	6	train	2	train	18	station	2
Pusan	8	pass	4	transportation	2	way	15	Paris	2
route	7	rail	4	rail	2	track	12	Sur	2
South	7	train	4	passenger	2	car	8	rail	2
Fanta									
can	6	Thailand	81	food	48	orange	8	orange	144
mango	5	mango	13	orange	9	company	4	lemon	12
orange	4	product	12	soda	8	war	4	can	6
diet	3	drink	11	product	8	coca	4	flavor	4
lemon	3	orange	11	flavor	7	Germany	2	taste	4
Zindane									
ball	10	France	70	man	12	soccer	6	game	2
cup	5	Paris	30	world	11	world	6	football	2
player	5	world	11	player	7	cup	4	generation	2
name	4	cup	8	cup	7	France	4	trailer	2
French	4	Frenchman	7	game	6	player	3	player	2
S-Class									
sedan	6	car	15	car	24	car	24	sedan	13
car	5	symbol	8	system	18	model	9	price	10
equipment	3	road	8	body	12	system	7	research	8
vehicle	3	coupe	6	time	12	seat	7	car	7
road	2	system	6	control	11	body	4	model	3
Marlboro									
history	14	cigarette	8	cigarette	3	cigarette	35	television	30
advertising	12	brand	5	brand	3	search	9	Cancer	8
life	10	man	3	sales	2	image	7	death	8
marketing	6	Morris	3	world	2	brand	6	man	7
cigarette	5	Philip	3	country	2	man	5	cigarette	4

In the results of the testing, about the tangible unknown words such as *TGV, Fanta, S-Class* and *Marlboro*, the effective classification is possible using our method. However, the results of the testing about the notional unknown words such as *Zindane* have lower accuracy than the tangible words. Based on the testing results, we determine the meaning of each unknown word. Figure 1 shows the classification of the unknown words means using the formula (1).

$$\textit{Unknown Words Means}(= \textit{Highest Value}(C_i)), \quad C_i = \sum W(N_i) \tag{1}$$

where, *W* is the weight value and *N* is the noun in the result. In formula (1), we give the *W* value (*5, 4, 3, 2, 1*) respectively to the each noun in each document by sequence of the *CV* values. And then, we measure the final result using formula (1). Finally, we assume that the word, which has the highest value, is most related to the unknown word. Hence, we classify the unknown words means into the word, which is selected through formula (1).

Through the experimental results in Figure 1, we expect the efficient unknown word classification using our approach. Especially, the results about *Malboro(means Cigarette), TGV(means Train) and S-Class(means Car)* are very satisfied for supporting the performance of our approach. Hence, we certified that the robust unknown word classification is possible using our approach.

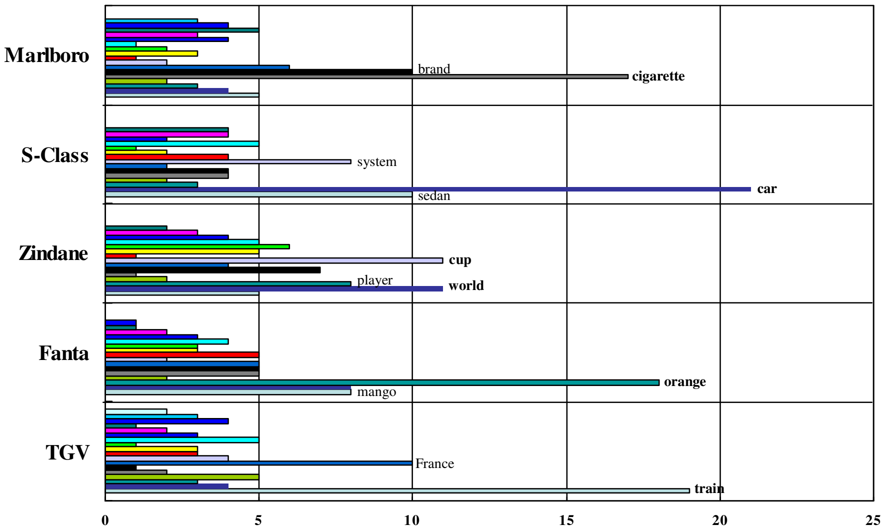

Fig. 1. Experimental Results

4 Conclusion

In this paper, we try to understand the meaning of the unknown words. Nowadays the unknown words are dramatically increasing and study on processing unknown words has been not researched although this task is very important for real Natural Language Processing. In our approach, we assume that nouns in document are related to the unknown word. Therefore, we calculated the *CV* values using the *TF* values and *Relevancy* values of the nouns. Based on the testing results, we assure that the *CV* values strongly reflect the fact which noun is most related to the unknown word.

Acknowledgement

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An Ontology Supported Approach to Learn Term to Concept Mapping

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Abstract. We propose in this paper an approach to learn term to concept mapping with the joint utilization of an existing ontology and verb relations. This is a non-supervised solution that can be applied to any field for which an ontology modeling verbs as relations holding between the concepts was already created. Conceptual graphs are learned from a natural language corpus by using part-of-speech information and statistic measures. Labeling strategies are proposed to assign terms of the corpus to concepts of the ontology by taking into account the structure of the ontology and the extracted conceptual graphs. This paper presents the approach proposed to learn the conceptual graphs from the corpus and the labeling strategies. A first experimentation in the field of accidentology was done and its results are also presented.

Keywords: concept learning, ontology, verb relation.

1 Introduction

[illegible]

[illegible]

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2 Extracting Verb Relations from Corpus

[1] *véhicule diriger vers bretelle (vehicle direct to slip road)* *piéton traverser (pedestrian crossing)* *diriger vers l'opéra (direct to opera)* *c,véhicule (C, vehicle,) ; venir de i (come from i).*

3 Learning Conceptual Graphs

conceptual graph

3.1 Lexical Similarities

R *S* ,*S*

[1] Examples of this paper are translated in English, although they are extracted from a French corpus experimentation.

S T

$$Jaccard\ S,T \quad \frac{|S\bigcap T|}{|S\bigcup T|}$$

S T T S

S T

S T a $a_i..a_k$ b $b_1..b_l$ $a_i \in s$ $b_j \in t$ a_i b_j $i-H \leq j \leq i$ H H $\frac{min(|S|,|T|)}{2}$ s^1 $a^1_1..a^1_k$ s t t^1 $b^1_1..b^1_l$ t s s^1 b^1 i a^1_i / b^1_i T_{s^1,t^1} s^1 t^1 s t

$$Jaro\ s,t \quad - \frac{|s^1|}{|s|} \quad \frac{|t^1|}{|t|} \quad \frac{|s^1|-T_{s^1,t^1}}{|s^1|}$$

P P^1 $max\ P,$

$$Jaro-Winckler\ s,t \quad Jaro\ s,t \quad \frac{P^1}{} \quad -Jaro\ s,t$$

s^1 $a^1_1..a^1_k$ t^1 $b^1_1..b^1_l$

$$sim\ s,t \quad \frac{}{k}\sum_{i=1}^{k} max^L_{j=1}\ sim^1\ a_j,b_j$$

$sim^1\ a_j,b_j$

level 2 function.

3.2 An Iterative Approach to Learn Conceptual Graphs

Verb *Verb,* *Preposition* *verb, preposition*

C *k*

4 Term to Concept Mapping Using the Ontology

R *r* $Range^r$ $Domain^r$ *r* $Domain^r$ $Range^r$

unknown

C *C*

unknown

$$sim\ Cen, C \qquad \frac{}{k}\sum_{i=1}^{k} sim\ t_i, C$$

t_i C $sim\ t_i, C$

t_i C k C

5 Experimentation in Accidentology and First Results

circuler avec (circulate with)

véhicule blanc *inconnu (unknown)*

feu (fire)

inconnu (unknown)

véhicule *véhicule de service*

term, concept

6 Related Work

7 Conclusion and Future Work

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Building Corporate Knowledge Through Ontology Integration

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Abstract. This paper presents an approach for building corporate knowledge, defined as the total knowledge acquired by an enterprise in its business dealings, through integration of its existing ontologies. We propose to represent corporate knowledge as the final merged ontology, defined under our formalism, in which a canon, or common ontology, is used as the standard under which all other ontologies are aligned. The canon is also enriched with knowledge gained during each ontology merging exercise. Our method ensures that all resulting ontologies are semantically consistent, compact and complete, as well as mathematically sound, so that formal reasoning could be conducted.

1 Introduction

Merging businesses usually leads to consolidation of information from different sources and different classification systems. The automation of such processes has the potential to reduce costs and delays, and thus contributes to the success of the merger. However, when information has been structured on the foundation of different ontologies, full automation of the information integration process is rarely achieved. Often, domain experts and knowledge engineers are needed to assist with decision making. The usual method is to first convert or translate one ontology from its current model to the model used by the other ontology, before integrating them. To date, most tools are semi-automatic and vary according to the particular nature of the domain being treated. Tools of a more general applicability, independent from ontology domains, exist, but as a trade-off they are less automatic and rely more on experts and knowledge engineers to assist during their usage. A common note in these techniques is that they are often used by organizations that require ontology merging on an infrequent basis, usually ad-hoc or once-only. It is usually not necessary, or not possible, to transfer knowledge gained from one application to another, apart from improved skills of the people involved and improved overall methodologies. In this paper, we propose a method to merge ontologies, which also captures and accumulates knowledge gained from each application in order to facilitate subsequent

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ontology merging exercises. This would be of particular help for large enterprises with a frequent requirement for ontology merging and enable the building of *corporate knowledge*, defined as the total knowledge acquired by an enterprise in its business dealings and which we represent under our formalism by the final merged ontology, resulting from successive mergings of the enterprise's existing ontologies.

2 Ontology Formalization and Integration

The formalization of canon and ontology in this section is a summary of [5] and could be considered as within the Conceptual Graph Theory [8][2]. However, our proposed ontology merging method is new and does not rely on the Conceptual Graph Theory.

- **Canon**

In simple terms, a canon is a framework for knowledge organization that models the real world through abstract concepts, relations and association rules between them.

Formally, we define a canon $\boldsymbol{K}$ as a tuple $\boldsymbol{K} = (T, I, \leq, conf, B)$ where:

(1) T is the union of the set of concept types T_C and the set of relation types T_R . We assume that each of those sets is a *lattice*, in which every pair of types has a *unique* supremum and a *unique* infimum. This assumption ensures *mathematical soundness* of the structure and is common in lattice theory [10].
(2) I is the set of *individual markers*, which are real-life instances of concept types, e.g. "John" is an individual marker of the concept type "Person".
(3) $\leq$ is the subsumption relation in T, enabling definition of a hierarchy of concept types and a hierarchy of relation types.
(4) *conf* is the *conformity* relation that relates each individual marker in I to a concept type in T_C . It in effect defines the (unique) infimum of all concept types that could be used with an individual marker (called *coreferent concept nodes* in [1]), e.g. the individual marker "John" may be associated through *conf* with the concept type "Man", which is the infimum of other concept types "Person", "Mammal" and "Living Entity", and therefore "John" can be used as an instance of those concepts, i.e., "John is a man, a person, a mammal and a living entity."
(5) B is the *Canonical Basis* function that associates each relation type with an *ordered* set of concept types that may be used with that relation type, e.g., "fatherOf" is a relation type that is associated through the function B with two (identical) concept types: "Person" and "Person", in which the first "Person" is the father and the second "Person" is the child. B must also satisfy the association rule: if two relation types are related (through the subsumption relation $\leq$) then their transformations by B should also be related in the respective order.

- **Ontology**

We define an ontology as a semantically consistent subset of a canon, dealing with a particular domain of discourse. Conversely, a canon could be considered as a *universal* (or *upper*, or *top-level*, or *unified,* etc.) *ontology*, encompassing multiple specialist domains. For example, a classification of diseases written in English could be viewed as an ontology while a general English semantic lexicon (such as WordNet) could be regarded as a canon.

Formally, we define an ontology ***O*** on a domain ***M*** with respect to a canon ***K*** = (*T*, *I*, ≤, *conf*, *B*) as a tuple ***O*** = (T_{CO}, T_{RO}, I_O) where:

(1) T_{CO} (resp. T_{RO}) is a subset of T_C (resp. T_R).
(2) I_O is a subset of individual markers in *I*, that relate to the domain ***M***.
(3) All other relations in ***K*** (i.e., ≤, *conf* and *B*) and their association rules are carried over to ***O***.

Mathematical properties of ontology as formalized above are detailed in [5].

- **Ontology Integration**

Since we define an ontology as a subset of a canon, implicitly a canon must exist before an ontology. However, in reality, in an enterprise, such a canon must be built either from scratch or from successive mergings of existing ontologies. Our paper deals with the latter. Our method ensures that each ontology merging exercise brings new knowledge to the common canon and the common canon is in turn used to make subsequent ontology merging exercises more automatic.

Our method consists of the following steps:

(1) **Step 1 - Input preparation:** In this first step, we ensure that the canon (if exists) and the source (input) ontologies are represented in a format that is suitable for our computational process, i.e., each structure simply needs to be represented as a list of supertype/subtype relationships (such as "conceptA>conceptB"). Note that in most applications, the source ontologies may be legacy systems, not strictly defined under any canon, i.e., they may contain concepts, relations and/or subsumption relations, not existing in the initial canon. For the first ontology merging exercise, we can use a semantic lexicon such as WorldNet as the initial canon.
(2) **Step 2 - Execution of the MultiOntoMerge algorithm:** The core of our method is an algorithm, called *MultiOntoMerge*, which accepts as inputs the above canon and source ontologies and produces as outputs a (draft) merged ontology and a list of concepts, relations and subsumption relations that have been identified as existing in either or both source ontologies but missing from the canon. (If the list is empty, then the process terminates as the canon already contains all the knowledge embedded in the source ontologies and the draft merged ontology is the final merged ontology). We could visualize the merging process by reasoning in a top-down manner with the lattice structures of the source ontologies. The lattices are merged *branch by branch*, starting from the top-level nodes and proceeding *depth-first*, through all their branches. To provide a common starting point, we assume, without loss of generality, that all lattices contain the common "universal" type, which is the fictitious supertype of all types. This lifts the restriction imposed in other previous work ([2][3][7]), which requires the knowledge engineer to specify an entry point for the merging process. During processing, the insertion of any new object (e.g., a new concept type) into the merged ontology is based on its compatibility with other objects already in that

structure. That compatibility is determined by the existing semantics and relations of those objects in the canon. If the new object only exists in either or both source ontologies, and does not exist in the canon initially, then it is noted in a separate list for later verification and validation (Step 3). After validation, that object will be first incorporated in the canon, then in the merged ontology (Step 4). During processing, MultiOntoMerge also performs a number of *consistency checks* on the canon, source ontologies and merged ontology, to ensure that each structure is:

- ➢ Semantically Consistent: The use of a common canon as the upper ontology for all other ontologies being treated, means that all ontologies are semantically aligned with the canon semantics.
- ➢ Semantically Compact: This means that MultiOntoMerge transforms duplicate concepts into *coreferences* (see definition in [8]), in particular when the same concept is used under different synonymous names. The algorithm also consolidates the structure by removing redundant subsumption relations, based on their transitivity property.
- ➢ Semantically Complete: This means that the algorithm ensures that if two concepts (or relations) in the structure are related (as specified by their subsumption relationship in the canon) and that relationship is not already contained in the structure, then it is added to the structure for completeness.
- ➢ Mathematically Sound: This means that the algorithm ensures that the structure is a *lattice*, as per its mathematical definition [4]. In particular, any two concepts (or any two relations) in the structure must have a *unique* supremum and a *unique* infimum, which are also contained in the structure. Note that this property is also invoked in other ontology merging techniques, such as FCA-Merge [9].

(3) **Step 3 - Validation of missing data in the canon:** The list of new objects (i.e., new concepts, relations and subsumption relations) produced by the previous step is then reviewed and validated by a domain expert. This validation is based on the semantics of the objects and is essentially manual. This expert may also consider some items on the list as errors in the source ontologies and therefore should not be carried forward into the final outputs (i.e., merged ontology and canon). These decisions are marked on the list and will be executed in Step 4.

(4) **Step 4 - Re-execution of the MultiOntoMerge algorithm:** The MultiOntoMerge algorithm described in Step 2 is re-executed with the additional input consisting of the decisions made by the expert in the previous step (in the form of a list of new objects missing from the canon, plus any possible errors in the source ontologies). The algorithm then carries out the expert decisions by correcting the source ontologies (if errors were detected there) and by incorporating the missing objects into the canon. Finally, it performs the ontology merging task as in Step 2 again. In most cases, unless further inconsistencies are detected as a result of the previous (incorrect) decisions by the expert, after this step, the output list of data missing from the canon should be empty, and the canon, the source ontologies and the merged ontology should be consistent as per our formalization (i.e. all ontologies are finally subsets of the final canon) and the processing terminates.

Notes

(1) One notable feature from our method is that, as the canon is constantly enriched after each application of MultiOntoMerge, in subsequent ontology merging exercises, missing data identified in Step 2 would be less and less significant and manual intervention in Step 3 would be less and less required. The ontology merging process therefore becomes more and more automatic after each usage.

(2) With regard to other ontology merging theories and techniques (such as Prompt, FCA-Merge, Chimaera, etc.), most of them, if not all, are semi-automatic and require interactions with knowledge engineers and experts during the construction of the merged ontology. However, unlike our method, none of them explicitly leverages knowledge gained from earlier ontology merging exercises to improve subsequent ones. On the other hand, some of them may complement our method by assisting in the automation of our "validation of missing data" step (i.e., Step 3).

(3) Our method enables discovery of new knowledge during the ontology merging process (e.g., with the identification of missing concepts and creation of new concepts in the merged ontology). This is similar to some other techniques, such as *Formal Concept Analysis* [10] and *Simple Conceptual Graph* [1] (see its "lattice-theoretic interpretation").

Example

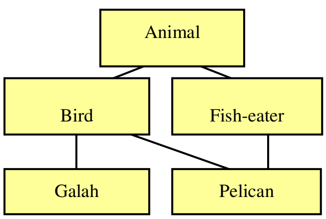

Fig. 1. Input Ontology 1

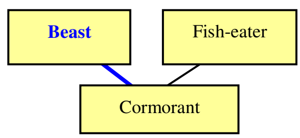

Fig. 2. Input Ontology 2

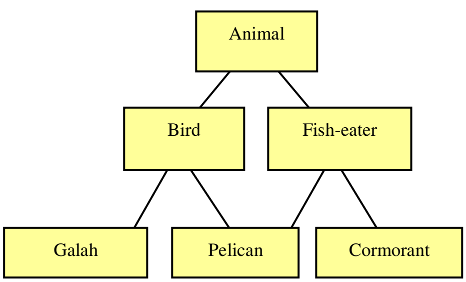

Fig. 3. Merged Ontology (after Semantic Compaction)

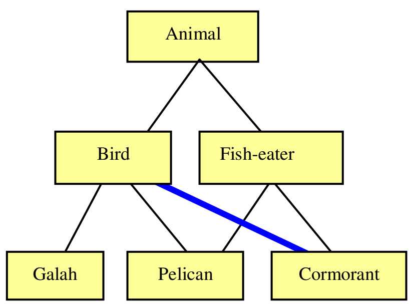

Fig. 4. Merged Ontology (after Semantic Completion)

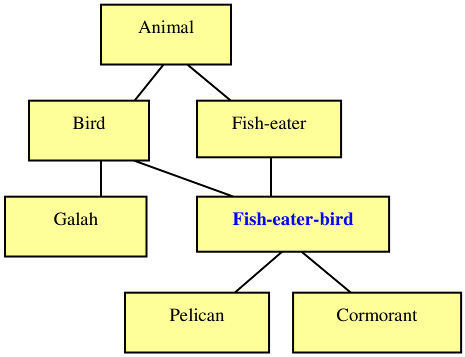

Fig. 5. Final Merged Ontology (after ensuring Mathematical Soundness)

Above is an example of merging two simple ontologies represented by Fig. 1 and 2 (with WordNet used as the initial common canon). Fig. 3 shows the merged ontology after *semantic compaction*, with “animal” and “beast” forming the same concept and the redundant relation “animal>cormorant” removed (based on the canon). Fig. 4 shows the merged ontology after *semantic completion*, with the new relation “bird>cormorant” (taken from the canon) added. Fig. 5 shows the final merged ontology after ensuring *mathematical soundness*, with the new concept type “fish-eater-bird” (taken from the canon) added (as it is the *unique* supertype of the concepts “pelican” and “cormorant”). A prototype MultiOntoMerge is available [6].

3 Conclusion

This paper presents a general domain-independent method to merge ontologies. In addition to producing the merged ontology, our approach enables knowledge contained in the input ontologies to be accumulated inside a common canon. It also ensures that all resulting structures are semantically consistent, compact and complete, as well as mathematically sound, so that formal reasoning could be conducted. For an organization with a frequent need for ontology merging, the use of such a common canon permits a consistent enterprise-wide classification of knowledge across the diverse business units of the organization. The final merged ontology represents the total knowledge of the organization and can be leveraged to improve the organization’s business, e.g., to know which aspects of knowledge the organization is dealing with and where corporate business strengths reside.

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Planning with Domain Rules Based on State-Independent Activation Sets*

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Abstract. In AI planning community, planning domains with derived predicates are very challenging to many planning system. Derived predicate is a new application of domain rules and domain knowledge acquisition. In this paper, we propose an approach to planning with derived predicates: defining activation sets of a derived predicate which are unrelated to any specific state and computing them in the preprocess phase through the instantiation rule-graph; replacing a derived predicate with one of its activation sets in relax-plan to extract action sequences. And we also implement the proposed approach in a new planner, called FF-DP, which shows good performance in our experiments.

Keywords: Deterministic planning; Domain rules; activation sets.

1 Introduction

Domain Rules are referred as particular domain knowledge and new knowledge is often deduced from known knowledge base by applying these rules. Domain rules, or domain axioms, are always the hotshot problem in AI planning community. Given an operator file and a problem file, an intelligent planning problem is intended to require a sequence of actions so that the original state can be transferred into the goal state by applying these actions in turn. The International Planning Competition (IPC), which is held biyearly since 1998, is referred as the most top-level academic conference and planning systems competition in this field. Derived predicate is one of two new features of PDDL2.2 language [1], the standard competition language in International Planning Competition 2004 (IPC-4). In classical planning, predicates are divided into two categories: basic and derived. While basic predicates may appear as effects of actions, derived ones may only be used in action preconditions or goal state [2]. So, derived predicates are not affected directly by domain actions, and their truth in the current state is inferred from that of basic predicates via domain axioms. PDDL2.2 introduces two benchmark domains containing derived predicates: PSR-Middle, and PROMELA (Philosophers and Optical-Telegraph) [3]. There were 19 planners that joined the classical track in IPC-4; however, only four planners (LPG-td, SGPlan, Marvin, and Downward) attempted to solve those domains containing derived predicates.

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Therefore, the lack of the ability of dealing with derived predicates actually blocked most planners to solve more competition problems.

Some methods have been used to deal with derived predicates in different planning system; however, their feasibility and efficiency are limited. Compiling them away is firstly proposed, but is recently proved to involve a worst-case exponential blow-up in the size of the domain description or in the length of the shortest plans [2]. And Gazen and Knoblock propose a pre-processing algorithm which transforms domain axioms into equivalent 'deduce' operators, but this may lead to inefficient planning [4, 5]. Also, LPG-td planner presents an approach to planning with derived predicates where the search space consists of particular graphs of actions and rules, called rule-action graphs [5]. However, the calculation of possible activation sets of a derived predicate in a rule graph is often enormous and boring because activation sets have to be recalculated as soon as the current state changes. So we attempt to find state-independent activations sets of a derived predicate, computing them only once in preprocess phase. We implement our idea on a new planner, called FF-DP (FF-Derived Predicate), which is a modified version of FF2.3 [6].

In the rest of this paper, we first introduce the definition of state-independent activation sets of a derived predicate. Then, we discuss how to calculate state-independent activation sets in a rule-graph and use them in relax-plan. Finally, we examine FF-DP in some specific benchmark problems.

2 Rule Graphs and State-Independent Activation Sets

As we know, the truth value of a derived predicate is determined by a set of domain rules in the form: if Φ_x then P(x), where P(x) is the derived predicate, x is a tuple of variables, the free variables in Φ_x are exactly the variables in x, and Φ_x is a first-order formula such that the negated normal form (NNF) of Φ_x does not contain any derived predicate in negated form [1]. For example, Fig. 1 shows a classical derived predicate "above" in the blocks world: A block x is above y, if x is on y, or it is on a third block z, which is above y.

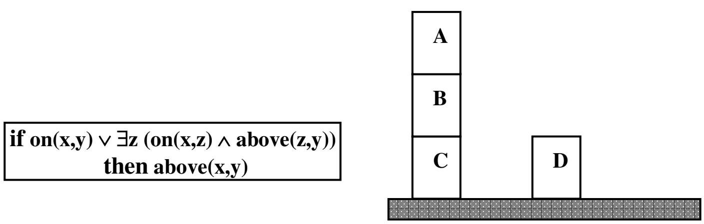

Fig. 1. Derived predicates in the blocks world

Given a rule r = (if Φ_x then P(x)) and a tuple of constants c ($|x| = |c|$), we can derive an equivalent set R composed of grounded rules (contain no variables) by applying the transformations mechanism (more detail in [5]). The set R can only contain basic facts or derived facts, for instance, on(A,B) and on(B,C) are basic facts, while above(A,B) and above(B,C) are derived facts. The set R that consists of grounded rules can be transformed into an AND-OR graph, which LPG-td calls "rule-graph": AND-nodes (fact-nodes) are either leaf nodes labeled by basic facts, or nodes labeled by derived facts; OR-nodes (rule-nodes) are labeled by grounded rules in R. For a rule-node, its in-edge (only one) is from the derived predicate deduced by itself, and its out-edges (often more than one) point to triggering conditions of this rule. For example, in Fig.2, the derived predicate "above(A,B)" can be inspired by rule r1,r2, or r3, and the triggering conditions of r2 are on(A,C) and above(C,B).

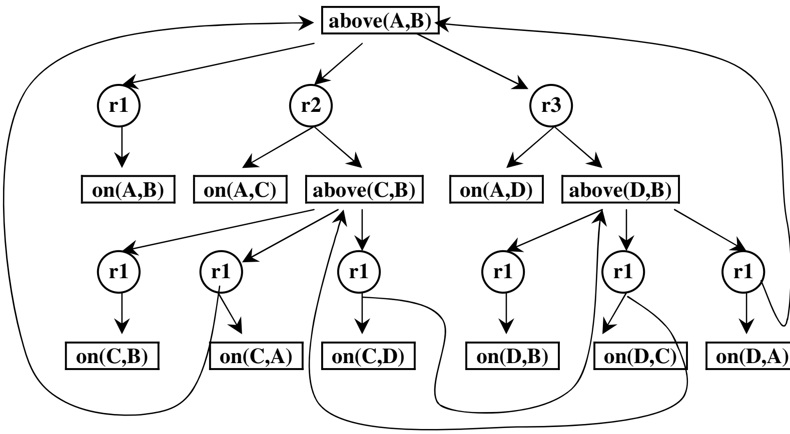

Fig. 2. A portion of the rule graph for a blocks world domain

In LPG-td, an activation set is defined as follows:" Given an unsupported derived precondition node d at a flawed level l of a RA-graph, an activation fact set for d is a minimal set F of basic facts such that $S(l) \cup F \models^{R} \Psi_d$, where Ψ_d is the derived fact represented by d." [5]. Here, S(l) means the current state. Because of the limitation of "minimal set", an already supported basic fact in the level l doesn't belong to any activation set, even if it is a triggering condition of d. Therefore, an activation set of a derived fact is composed of unsupported basic facts in the level l. The notation " $\models^{R}$" means that the derived fact Ψ_d can be deduced from the set $S(l) \cup F$ under the rule set R. So, we can see the reason of introducing activation sets is that, because that derived facts can't appear as any effects of actions but basic ones can, we may replace the derived facts with some basic facts in order to select actions to support them so that the unsupported derived precondition node becomes supported.

We can denote the set of all activation sets with $\sum$. For example , in Fig.2 , the set $\sum_{LPG}$ of the derived predicate "above(A,B)" in the state depicted in Fig. 1 is {{on(A,C), on(C,B)} , {on(A,C), on(C,D), on(D,B)} , {on(A,D), on(D,B)}, {on(A,D), on(D,C), on(C,B)}}. However, suppose that if we stack the block A onto the block D, the state becomes the set {table(C), table(D), on(B,C), on(A,D)} and the set $\sum_{LPG}$ for "above(A,B)" is turned into{{on(A,B)}, {on(A,C), on(C,B)} , {on(A,C), on(C,D), on(D,B)} , {on(D,B)}, {on(D,C), on(C,B)}}. Thus an activation set defined in [5] is closely related to the current state, and once the state changes the activation sets have to be recalculated. Actually, in relax-plan of LPG-td, there exists a great many of time-consuming recalculation. Therefore, we redefine activation sets which are state-independent, as follows:

Definition 1. Given a rule-graph derived from the rule set R, a **state-independent activation set** (short for **SIAS**) for a derived predicate d is a minimal set F of basic facts such that $F \models^{R} \Psi_d$, where Ψ_d is the derived fact represented by d.

3 Calculate State-Independent Activation Sets and Use Them in Relax-Plan

In our definition, an activation set of a derived fact consists of basic facts which can deduce the derived fact under the rule set R, regardless of any current state. Then, we present a depth-first algorithm (depicted in Fig. 3) to identify the set ∑ which consists of all the state-independent activation sets (SIAS) in a given rule-graph.

```
Algorithm 1
SIAS-search (d, A, Path, Open)
Input: A derived fact (d), the state-independent
activation set under construction (A), the set of AND-
nodes of R on the search tree path from the search tree
root to d (Path), the set of nodes to visit for A (Open);
Output: The set of all state-independent activation sets
(∑).

For each successor r of d do
    { Open ← Open ∪ {r};
      While Open ≠ ∅ do
       { x = first_element (Open);
         If x is a rule node Then Open ← Open ∪ {first_successor (x) };
         Else If x is a basic fact Then
           { A ← A ∪ {x};
               If the antecedent of x has other unvisited successor x'
               Then Open ← Open ∪ {x'}
               Else  ∑ ← ∑ ∪ {A};
           }
         Else If x is a derived fact Then
    If x ∉ Path Then
    {  SIAS-search (x , A, Path ∪ {x} , Open);
         If the antecedent of x has other unvisited successor x'
```

Fig. 3. A depth-first algorithm to identify all possible SISA

```
16.            Then Open ← Open ∪ {x'};
17.     }
18.       }
19.For each x' in A which is the successor of r Do
20.       A = A - {x'};
21.}
```

Fig. 3. (*continued*)

The algorithm in Fig.3 performs a complete search on the rule graph. The function first_element gets the first element x in Open table. If x is a rule node, then one triggering condition of x enters the Open table. If x is a basic-fact node, then it becomes an element in A immediately. Until a triggering condition is totally supported by basic facts, the set A becomes an element in $\sum$. When x is a derived-fact node and doesn't emerge in the Path table, the search goes forward recursively by the line 14, otherwise, it should be pruned off to avoid cycle search. At last, to find all activation sets, the set A should maintain possible members (line 19~20). For example, we can get the set $\sum_{SISA}$ of the derived fact "above(A,B)" on the rule graph in Fig.2 by this algorithm, as follow: {{on(A,B)}, {on(A,C), on(C,B)} , {on(A,C), on(C,D), on(D,B)} , {on(A,D), on(D,B)}, {on(A,D), on(D,C), on(C,B)}}. Here, {on(A,B)} is also a activation set in $\sum_{SISA}$, however, it belongs to the current state and hence doesn't appear in the set $\sum_{LPG}$. Next, we present a forward-search algorithm (depicted in Fig. 4) for the relaxed-plan in the domains with derived predicates, where the state contains not only basic facts, but also plenty of derived facts deduced from domain rules.

```
Algorithm 2
Extend-relax-plan (I, G)
Input: The initial state (I), the goal state (G);
Output: The set of actions or fail.
  1. S ← I ∪ D(I, R);
  2. level ← 0;
  3. For each action a which is applicable in S Do
  4.       S' ← S ∪ Add(a);
  5. level ← level + 1;
  6. S'' ← S' ∪ D(S', R);
  7. If S'' doesn't contain G , Then S ← S'' , GOTO 3
  8. Else π = extract-relax-plan(I, G);
  9. If π= ∅ Then return fail;
  10.Else return Aset(π).

  Extract-relax-plan (I, G)
  Input: The initial state (I), the goal state (G);
  Output: The set of actions in relax-plan (Act).
```

Fig. 4. An algorithm to relax-plan with state-independent derived predicates

```
1. For each derived fact d in G Do
2.     G ← (G - {d})∪ best-SISA(d);
3. Act ← ∅;
4. select an action set A in the (level -1) layer in
   the relaxed plan graph, and A is a minimal set whose
   members can support furthest the basic facts of G ;
5. G ← (G- {add(a) | a ∈A}) ∪{pre(a) | a ∈A};
6. Act ← Act ∪ {A};
7. level ← level - 1;
8. If the level > 0 Then GOTO 1;
9. If G contains I Then return Act;
10.Else return ∅.
```

Fig. 4. (*continued*)

The algorithm in Fig.4 is composed of two phases: to extend the plan graph and to extract a plan solution. D(I, R) is the set of derived facts which is the closure of the set I under the rule set R (more details in [2]). Add(a) is the set of positive effects of an action node a, and pre(a) is the set of preconditions of an action node a. In the pre-process phase, we can first calculate the set $\sum$ for every derived fact d by the function "SIAS-search (d, ∅, ∅, ∅)" and store it in a lookup table. And in relax-plan phase, each derived fact is replaced by its best state-independent activation set (SISA). By the way, a best SISA can be defined as an activation set which has the minimal actions set that can reach all basic facts from the initial state. By building a Lookup table to save state-independent activation sets, we can avoid spending a lot of time in calculating those state-dependent activation sets.

4 Experiments with FF-DP

These algorithms are implemented on a new planner, called FF-DP. We examined our planner in the benchmark domains: "PSR-middle" and "PROMELA-Optical Telegraph". And the experiment environment is CPU(Pentium Processor 1.2G) + RAM (512M) + Redhat9.0 Linux, with the compiler gcc 3.0. Actually, we find that the performance of FF-DP is satisfactory in most specific problems. In Fig.5[1], when the problem is relatively simple, FF-DP performs a little worse than LPG-td, for the time spent in preprocess phase by the former is a little more than the recalculation spent by the latter. However, when the problems become more and more complex (that is, contain more derived rules), such as pfile39, 41, 45 or 49, the time of plan by FF-DP is much shorter than that by LPG-td. Also, we are confused that why SGPlan performs so erratically. On the other hand, in Fig.6, we can see that the performance of LPG-td is very bad because of some unexpected errors in the program when in IPC-4 events, while the performance of FF-DP is competitive with the Downward planner, which introduces artificial actions and facts to compile derived predicates away. From these results, we can see that our idea of state-independent activation sets and the corresponding algorithms are effective and promising.

[1] On the x-axis we have the problem name (abbreviated by numbers). On the y-axis, we have CPU-time (log-scale).

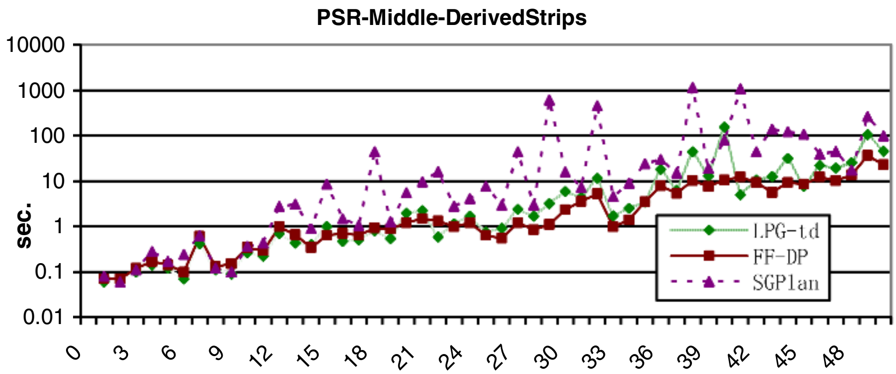

Fig. 5. Performance of FF-DP in the domain PSR-Middle

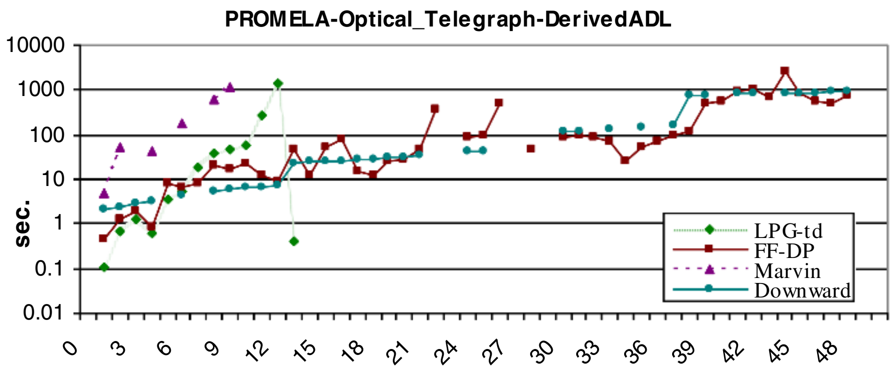

Fig. 6. Performance of FF-DP in the domain PROMELA-Optical Telegraph

5 Conclusion

Handling derived predicates efficiently in modern automated planners is an important problem with a lot of recent practical interest in the AI planning community. Derived predicates can't appear in any effect of action and their truth value can only be deduced from domain rules. In this paper, we propose state-independent activation sets to avoid a number of calculations when the current state continuously changes. Two algorithms are presented: one for calculating the set of state-independent activation sets of a derived predicate in a given rule graph; and the other is to use these activation sets to replace derived predicates in a relaxed plan. We implement these algorithms on a new planner, called "FF-DP", and find good results in the domains containing derived predicates. Future work includes further defining the best activation set and discussing how it will affect on selecting solution sequences.

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Elicitation of Non-functional Requirement Preference for Actors of Usecase from Domain Model

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Abstract. Requirement engineering plays a vital role in the development of the software. The quality of the software being developed depends on the non-functional requirements, which are still not derived effectively due to the conflicts between them. This paper presents an approach to identify the non-functional requirements for a given usecase description from the domain model such as Unified Modelling Language class diagram and goal based questionnaires. This approach makes use of the domain model to find out the behaviour of the system and possible constraints for actors in the system. The non-functional requirement taxonomy and the user preferences are used to analyse the conflicts, which is resolved based on trade-off analysis by prioritizing the preference. The prioritization depends on the dominating non-functional requirements from the inference engine.

1 Introduction

The objective of this system is to provide a support to requirements engineering to identify non-functional requirements of the actors with their preference. This procedure analyses the events triggered from the use case description to find out the variants in the requirements. This is performed using usecase diagram, domain model and taxonomy of non-functional requirements along with actor's preferences. The proposed methodology is explained in section 2. Our implementation and results are explained in section 3. The conclusion and future work is contained in Section 4.

2 The Proposed System

Haruhiko Kaiya [8] discusses the elicitation of the non-functional requirement performed by comparing the existing usecase to derive the invariants related to the non-functional requirements and the stakeholders involved. The system does not focus on the internal description of the usecase as well as the quality requirements are not prioritized. The system proposed in this paper considers the usecase description to identify the system interaction by comparing it with the domain model; also trade-off analysis is used to prioritize the quality requirements. In the earlier works [3][4][7][9][10], domain modeling and extracting information from usecase models

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have done separately. We have suggested a method of combining both, and extracting the variants in usecase and combining with domain model and non-functional taxonomy to derive the actor's preference. The system architecture is shown in Fig. 1.

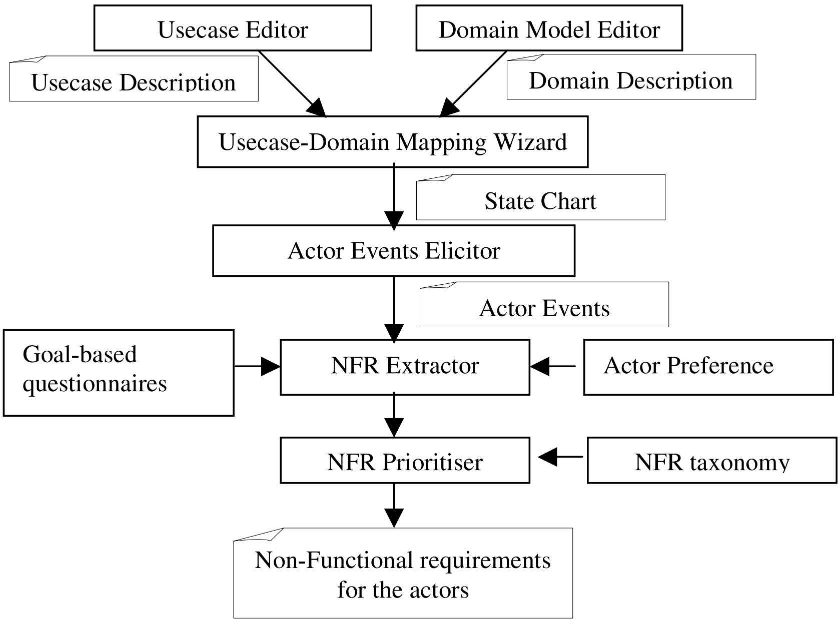

Fig. 1. System Architecture

Usecase and Domain model are structured using the XML editor to the Data Type Definition (DTD) format. The editor checks the syntax of both the usecase and domain model with the specified structure. They are represented with specified notations for easy traceability of the usecase description with the domain model. The syntactic structure of the usecase description is validated using natural language processing. The various syntactic structures used in usecase and domain model are listed in the Table 1.

The Usecase-Domain Mapping Wizard extracts the entities, which are not present in the domain model from the usecase description by mapping the usecase with domain model. The usecase follows the below structure.

Title: a label that uniquely identifies the use case within the usecase model. *Primary Actor*: the actor that initiates the use case. *Participants*: other actors participating in the use case. *Goal*: primary actor expectation at the successful completion of the use case. *Precondition*: condition that must hold before an instance of usecase can be executed. *Postcondition*: condition that must be true at the end of a 'successful' execution of an instance of the use case. *Steps:* Sequence of steps involved in the usecase along with extension. Extensions: a set of step extensions that applies to all the steps in the use case.

Table 1. Syntactic Structure Used in Usecase and Domain model

Statements	Syntax	Sample	Description
simple	[Determinant] entity[1] verb value	User identification is valid	The value of the entity 'user identification' is 'valid'
complex	NO/NOT simple	Not User identification is valid	The value of the entity 'user identification' is 'not valid'
	[NO/NOT] simple AND/OR [NO/NOT] simple	User identification is invalid AND User number of attempts is equal to 4	The value of the entity 'user identification' is 'invalid' and the value of the entity 'user number of attempts' is 'equal to 4'
ANY statement	"ANY" "ON" entity [*]	ANY ON user*	This refers to all the conditions with "User" as the entity (e.g. "User is logged in"), but does not include conditions like "User Card" or "User identification" which are different entities associated with User
	"ANY" "ON" entity	ANY ON user	This refers to all the conditions with "User" as the entity (e.g. "User is logged in"), also includes conditions like "User Card" or "User identification" if present.
Operation declaration	action_verb [action_object]	Validate user identification	"validate" is the action verb and the action object is "user identification" which is an attribute of concept "User".
	[delay_specification] [condition_statement] [determinant] entity operation_reference	BEFORE 60 sec, USER enters pin	'Before 60 sec' is the delay specification,'User' is the entity ,'enters pin' is the operation_reference
		ATM asks user validation to the Bank	ATM is an entity. 'asks user validation to the bank' is operation_ reference
operation_reference	conjugated_action_verb[2] [(binding_word[3])+] action_object [action_participant]	asks user validation to the bank	'Validation' is the conjugated action verb, 'to' is the binding word, 'bank' is the action_object
condition_statement	"IF"simple/complex "THEN"	IF User Identification is valid THEN, ATM displays operation menu	The simple statement 'User identification is valid' is taken as the condition
branch	[delay_specification] [condition_statement] "GOTO"["STEP"] step_reference	Go to Step 2	Control transferred to step number 2

[1] An *entity* consists of one or more words specified as $Word_1, \ldots word_n$. The sequence of words must correspond to a concept, an attribute of a concept in the domain model, an instance of a concept, or a reference to an attribute of an instance.

[2] conjugated_action_verb is the action_verb used in the concept operation declaration in the present tense.

[3] binding_word may be a possessive adjective, article or preposition.

Also it captures the non-existing actors, operations and conditional statements. Then updates the domain model using the reverse engineering wizard supported by the UML plug-in. The wizard uses the structured usecase and domain concept. Usecase editor and domain editor are used for this purpose.

'Actor Event Elicitor' maps the Usecase with the domain model based on the pre-conditions of the usecase. On successful completion the precondition states are withdrawn. The state chart for the entities, which are mapped with the domain model, is generated then. The state chart contains entries like "*1 ---[insert card]--> 2*", meaning that from state 1 it goes to state 2 on performing the event 'insert card'. From the state chart the events related to the actors alone are identified.

'NFR Extractor' generates the non-functional requirements for the actor events with the help of the actor preference and goal-based questionnaires. Actor preference is a matrix of actor versus event. The matrix entries tell whether the actor can perform the specified event or not. In goal-based questionnaires all the events are embedded with possible questions, which helps to identify the quality requirements. Sample actor preference matrix and goal-based questionnaires are shown in the Table 2 and Table 3 respectively.

Table 2. Actor Preference Matrix

Events	Patient	User	Doctor	Nurse
Triggers alarm	Yes	No	Yes	Yes
Press logout button	Yes	Yes	Yes	Yes
Enter vital signs	Yes	No	Yes	Yes
Insert Card	Yes	Yes	Yes	Yes
Connect cables	No	No	Yes	Yes

Table 3. Goal-based questionnaires

Events	Preference	NFR
Insert card	Card Expired	Security
Enter pin	Invalid pin number	Security
Enter pin	Provide proper human computer interface	Usability

'NFR Prioritizer' prioritizes the identified non-functional requirements based on the trade-off analysis. The results are shown in Fig. 2. This is done by the inference engine, which in turn makes use of the NFR taxonomy. In NFR taxonomy, all the NFRs are associated with other conflicting and dependable NFRs. The NFR taxonomy looks like,

Usability#Simplicity+#Accessibility+#Installability+#Operability+#Maintainability-

It states that simplicity, accessibility, installability and operability are directly proportional and maintainability is indirectly proportional with usability.

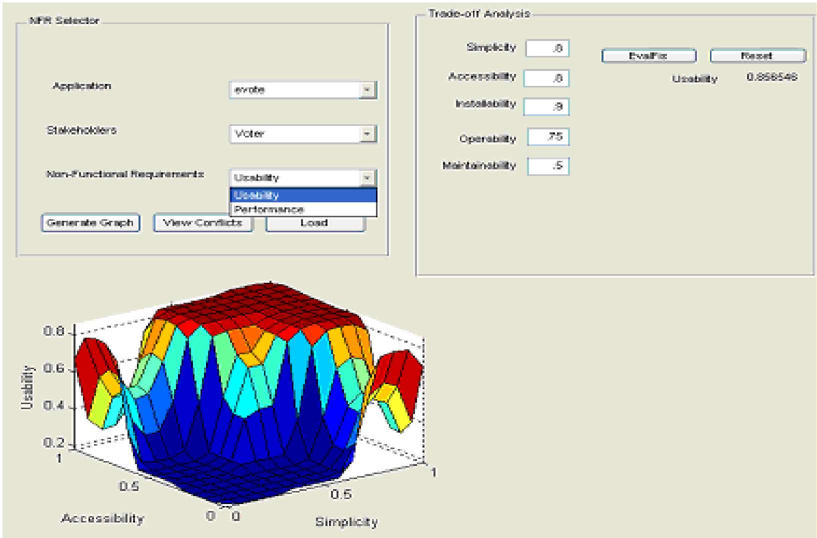

Fig. 2. Trade-Off Analysis

3 Implementation and Results

The system has been implemented using JAVA and a plug in to eclipse for reverse modelling. UML interface 'nsuml' is used to generate the state machines. This is used to synthesize the user behaviour of the system. The editor is created for generating both use case description and domain model description. The system is tested for the following domains ATM, Retailing system, Patient Monitoring System and E-voting system. The system will act according to the user's preference given in the non-functional requirement taxonomy.

The usecase and domain model makes use of XML editor to create data type definition (DTD) to store the model. The XML reader and writer are used to import and export the files for processing. The use case and domain model make use of structured text, which has been checked for the syntax. The wordnet is used as an interface to check for valid parts of speech.

Domain model makes use of UML diagram descriptions. The reverse engineering wizard is used to check usecase and domain maps. Workbench.jar, jface.jar, jdom.jar, runtime.jar are all used to implement the domain mapping and extracting. The prioritization of the non-functional requirement is mapped to goal questions, which are stored in Microsoft Access database. The conflicts are stored in a separate data file. The conflicts are resolved using inference engine created in matlab. The inference engine calculates the preference from the given user weights for each non-functional requirement.

The inference engine is designed to perform trade-off analysis for the non-functional requirements such as usability, performance, maintainability, security, correctness, authorization, reliability and availability.

4 Conclusions and Future Work

This paper presents an approach for deriving non-functional requirements by comparing usecase description with the domain model. This system takes a usecase written in a restricted form of natural language and generates a state model that integrates the behaviour specified by the usecase. The invariants and its initiators are captured from the usecase and domain model. The conflicting non-functional requirements are derived from the NFR taxonomy and they are prioritized using trade-off analysis. The system can be extended to automate the trade-off analysis by using an intelligent system.

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Enhancing Information Retrieval Using Problem Specific Knowledge

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Abstract. In the recent past, information retrieval techniques have improved significantly and it is now possible to access massive text corpora using some of the most popular search engine tools like Google, Yahoo, PubMed[1] (popular search engine for medical literature), etc. Considering that such search engine tools are normally trying to retrieve information from massive text corpora, a number of search results they need to display might be in hundreds or even in tens of thousands. Normally it is not possible or practical to browse through a very large collection of search results, and often a typical user needs further assistance in focusing on the search results that might best meet his/her requirements.

In this paper we present a new technique that allow a user to interactively express problem (task) specific knowledge (which is otherwise not possible using search engine tools like Google, Yahoo, PubMed, etc) and later use this knowledge to help a user to interactively and quickly focus on search results they might be interested in. The system presented in this paper integrates some of the techniques from the field of Natural Language Processing and Visualisation.

Keywords: Intelligent Systems, Information Retrieval, Knowledge based Information Retrieval.

1 Introduction

In this digital age it is now possible to access massive amounts of information available online from almost anywhere in the world. The challenge now is to get the most relevant information quickly and easily. To address this challenge, in the recent past information retrieval techniques have improved significantly and we now have access to some of the most popular search engines like Google. Yahoo, PubMed (popular search engine for medical literature), etc. However, considering that such search engines are normally trying to find relevant information from a very large database(s), often they return a large number of relevant documents for a given query. Normally these documents (returned hits) are ranked based on their relevance to the

[1] http://www.pubmed.gov

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query and displayed in non-increasing order. Search engines typically return thousands or even hundreds of thousands of relevant documents for a given query, and it is then up to a user to browse through a large collection of relevant documents and look for documents that meet her/his criteria. Users normally browse through the first few pages of the high-ranking documents (say 2 or 3 pages of search results, each page with 10 search results) and if they do not find what they are looking for, they quickly start losing interesting in the search results. We believe here a user needs some assistance to quickly and easily focus on the search results that might meet his/her requirements.

In this paper we present a new technique that acquires problem (task) specific knowledge from a user, and later uses this knowledge to help the user to interactively and quickly focus on search results that might be of interest. The rest of the paper is organized as follows: Section-2 briefly outlines some of the relevant features of the current Information Retrieval (IR) systems. Section-3 describes our approach and discusses how it could enhance Information Retrieval. Section-4 describes experimental results and discusses how our approach could enable a user to quickly focus on search results that are of interest. In Section-5 we present our discussion and conclusions.

2 Information Retrieval Systems

Information retrieval activity typically starts with an *information need* of a user. A user then expresses his/her information need in terms of a *query* in order to find relevant documents. The query expressed by the user may not be the best articulation of the information need, however it is usually the only clue that the search engine has concerning the user's goal [2]. Recently, search engines have tried to address some of these problems by using a technique known as query expansion [3]. In this technique, similar or related terms are also considered while looking for relevant documents. For example, a search engine could find synonyms using a thesaurus or related terms using a domain dependent ontology [10] or from other relevant documents (also known as relevance feedback) [4]. Once the query terms are finalized, a search engine tries to find relevant documents based on the query terms and usually displays results in non-increasing order of relevance.

In the above traditional view of IR, a user is limited to expressing his/her information need in terms of keywords that best describe the requirements. However, it is possible that for a specific retrieval task (problem), the user expects the required keywords to be at or near the beginning of the document, or may be at the middle or at the end of the document. This would be particularly true if a user roughly knows the structure of a document(s) he/she is interested in. For example, a user might be searching for a tutorial on prolog. Based on the past experience, the user knows that a typical page would have the words "prolog" and "tutorial" at or near the beginning of the document. However, the user might not be sure about the sequence in which they might appear. For example, it could be "Prolog Tutorial" or "Tutorial on Prolog" or more importantly it might be divided into more than one lines like: two lines "Week-12 Tutorial" and "Prolog" separated by say 1 or 2 lines, at or near the beginning of the document. Unfortunately the current IR systems are not able to effectively use such problem (task) specific knowledge. They do offer features like searching keywords in the Title, URL, etc. However, these features do not cover the types of cases we outlined above.

In general, it is fair to say that the current IR systems are primarily focused on improving retrieval algorithms, and they pay less attention to the task of properly acquiring information need of a user in the first place [1, 5, 6, 7]. We believe that future IR systems should be knowledge-driven where an information retrieval process is enhanced by properly acquiring information need and problem specific knowledge from a user.

Most of the current IR systems use very similar (and one could even say traditional) form based user interfaces [1]. Considering that many users today have access to powerful machines, we believe more advanced interactive user interfaces should be explored in order to improve IR experiences. However, there are very few systems [8, 9] today that try to use such advance user interfaces in order to improve IR experiences.

3 Using Problem Specific Knowledge to Enhance Information Retrieval

In this section we describe the system that addresses some of the problems discussed in the previous section. Fig 1 shows the overall system architecture.

Search Engine Module: A user starts using the system by initially providing a (traditional) query and a search engine name to the system. The "Search Engine" module simply executes the query on the nominated search engine; fetches search results; and later fetches the corresponding documents from the Web. It is obvious that a user can use all the available advance features of a nominated search engine here.

Problem Specific Knowledge (PSK) Module: In addition to a (traditional) query, a user can also ask the system to generate problem specific attributes from the documents obtained by the module "Search Engine". For example, a user can ask the system to find the first occurrence of the word "tutorial" (say ignoring case) in every document retuned by the module "Search Engine". Similarly, we can also ask the system to find the first occurrence of the word "prolog" (again say ignoring case), and so on. The module named "Problem Specific Knowledge (PSK)" allows users to interactively specify such problem specific attributes. Currently this module support the following positional attributes:

- First occurrence of a word (in token, sentence and/or paragraph number)
- Last occurrence of a word (in token, sentence and/or paragraph number)
- First occurrence of a group of words (in sentence and/or paragraph number)
- Frequency of a word

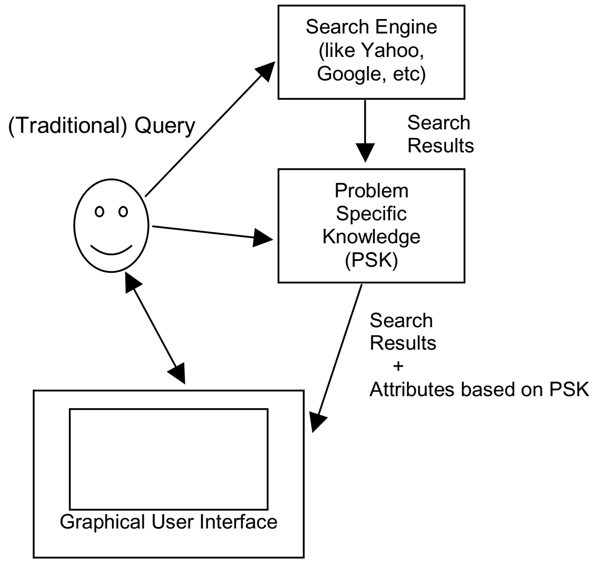

Fig. 1. Overall System Architecture

In the near future, we plan to extend this list by including more commonly used attributes from the field of Natural Language Processing (NLP) [2]. However, as discussed in the next section, we believe the above attributes are powerful enough to significantly enhance IR experiences for a large number of problems.

The module PSK uses GATE[2] to generate (calculate) NLP related attributes. GATE (General Architecture for Text Engineering) is a widely used and very popular (free) open source framework (or SDK) that is successfully used for all sorts of language processing tasks.

Graphical User Interface Module: The problem specific attributes generated by the module PSK, along with the corresponding documents are sent to the "Graphical User Interface" module. The aim here is to plot charts based on the values of the problem specific attributes. For example, we can plot a chart where an X-axis represents first occurrences of the word "tutorial" and Y-axis represents first occurrences of the word "prolog". By plotting such charts, a user can locate documents where these values are either say very small or very large (depending on the requirements). Alternatively, a user may not be interested in documents where one value is say small and another say high, and so on. The module allows a user to quickly plot such charts to view documents in a variety of ways. Each point on a chart represents a document, and it has a hyperlink to the corresponding document. In other words, a user can simply click on a point in a chart and the corresponding document will be displayed in a browser window. This would allow a user to interactively browse through a large collection of search results, using problem specific attribute values.

[2] http://gate.ac.uk/

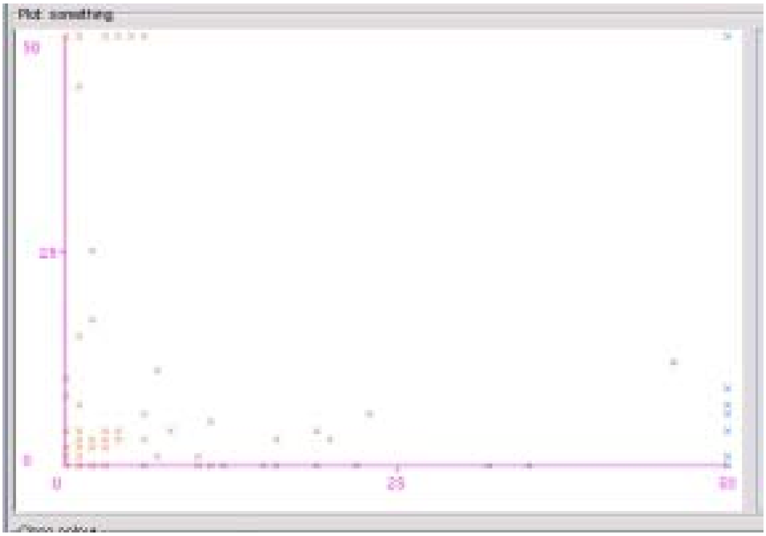

Fig. 2. Chart outlining the relationship between two problem specific attributes: prolog-1p (X-axis) and tutorial-1p (Y-axis)

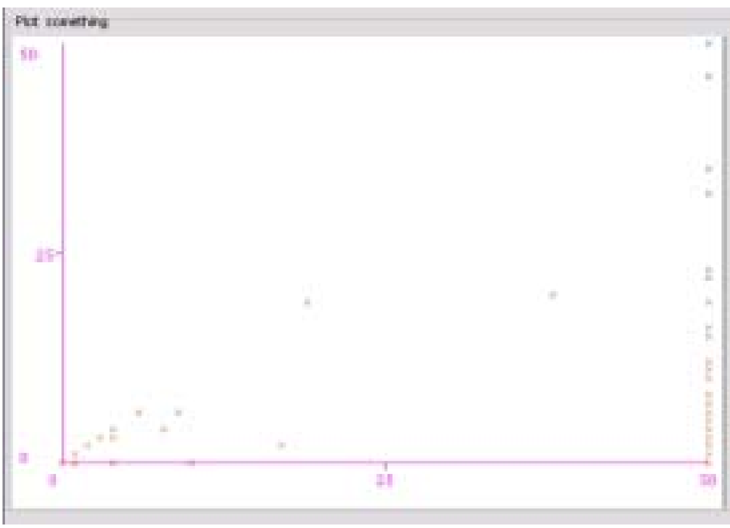

Fig. 3. Chart outlining the relationship between two problem specific attributes: prolog-tutorial-1p (X-axis) and prolog-1p (Y-axis)

It should be noted that here the whole process is knowledge-driven. A user defines problem specific attributes and he/she also selects attributes for charting a graph. This is different to classical clustering methods (which are data-driven) where documents are grouped together using predefined clustering criteria. In this paper we will only focus on knowledge-driven explorations. Here we simply note that if required, it is also possible to cluster documents based on their problem specific attributes for data-driven explorations. The module uses Weka's Visualisation tool[3] to display charts. Considering that Weka offers tools for popular data mining techniques, it would not be difficult to also include data-driven approaches in the future. However, in this paper we want to emphasis knowledge-driven approaches that are often neglected in IR literature.

4 Experimental Result

In this section we present experimental results that demonstrate how problem specific attributes could be used for knowledge-driven explorations of retrieved documents. For the following query, we use Yahoo search engine, retrieve the first 100 results, and restrict our search to `edu.au` (to avoid possible advertisement material).

Let's first continue our previous example where we were interested in searching for a prolog tutorial. For this task, we created the following attributes:

- Paragraph number where the word "prolog" (ignoring case) appears first time in a document, let's call it **prolog-1p**
- Paragraph number where the word "tutorial" (ignoring case) appears first time in a document, let's call it **tutorial-1p**
- Paragraph number where both the words "prolog" (ignoring case) and "tutorial" appear first time in the same paragraph, in a document, let's call it **prolog-tutorial-1p**

The form-based graphical user interface allows a user to create the above attributes. After calculating the above attribute values, the system sends these attribute values along with document references to Weka's Visualisation tool (which is appropriately modified for the system). Initially the system displays thumb nails for possible charts. Here a user can quickly examine different thumbnails to look for possible interesting patterns (relationships) between problem specific attributes. By clicking on a thumbnail, a user can display the corresponding chart. Fig 3 shows such a chart for the attributes prolog-1p and tutorial-1p. Similarly, Fig 4 shows relationships between attributes prolog-tutorial-1p and prolog-1p.

Given that we are looking for a prolog tutorial, we might be more interested in exploring documents that are close to the origins (bottom-left corner) of these charts. We could also infer other useful information from theses charts. For example, in Fig 3, documents that appear on the diagonal axis or close to the diagonal axis have both the attributes appearing first in the same paragraph or nearby paragraphs, increasing the likelihood of them being prolog tutorial. Alternatively we could say that in Fig 3 documents with low x-value (prolog-1p) and high y-value (tutorial-1p) might be referring to some other material on prolog (like lecture notes on AI). Similarly, we

[3] Weka is an open source software for data mining and visualisation, available at http://www.cs.waikato.ac.nz/ml/weka/

could say that documents with high x-value (prolog-1p) and low y-value (tutorial-1p) might be referring to tutorials on other topics (again say AI tutorials).

In the charts there are some documents with attribute values 50. In this experiment, if we cannot find the required term in the first 10,000 words (or there is a parsing problem), we assign 50 to that attribute. This is to indicate that the corresponding value is too high for our purposes. We did this to simplify chart displays. Also note that, a paragraph index starts with 0 and a Yahoo rank starts with 1.

We manually checked all the 100 documents returned by Yahoo! for their relevance to our task and marked them as a relevant or not. Out of the 100 documents retrieved, there are 35 (35%) relevant documents for the task. Based on the Yahoo Ranking, 70% of the top 10 documents are relevant, 65% of the top 20 documents are relevant and 53.3% of the top 30 documents are relevant.

In Fig 2, there are 26 documents on or near the diagonal axis. Out of these 26 documents where an absolute difference between the paragraph indexes is less than 1, there are 16 relevant documents, that is 61.5% relevant documents. 11 of these 16 relevant documents have Yahoo ranks greater than 30. In other words, these 11 relevant documents would not appear in the first three pages of the search results. This is useful because a user can browse the top ranking Yahoo hits (say first few pages) and then use charts to look for more relevant documents, or vice versa.

In Fig 3, there are 20 documents that appear near the origin. In other words, these are the documents where both the words appear in one paragraph at or near the beginning of the documents. Out of the 20 such documents, 65% of the documents are relevant. Out of these 20 relevant documents, there are 5 documents with Yahoo ranks greater than 30.

5 Discussion and Conclusions

Popular search engines like Yahoo do use word proximity as one of their retrieval criteria. However, the final ranking is based on multiple criteria and hence it is not easy to identify documents with a specific structure or that satisfy a specific criterion. The approach presented in this paper enhances a retrieval process by combining problem specific knowledge with the underlying strength of a given search engine. In the experiments presented above, the criterion used in Fig 2 is more relaxed than Fig 3, and therefore we believe there are more relevant hits for Fig 2. This might also be the reason why there are more relevant documents in Fig 2 with Yahoo ranks greater than 30.

In summary, we believe that the current IR systems do not consider a role of a user very seriously in defining information need, and later navigating through possible solutions. More research is need to design and develop innovative approaches that keep users in the loop and actively seek more domain (problem) specific knowledge that could be effectively used in narrowing the search space or improving matching criteria. The system presented in this paper is just the beginning of a bigger goal of building a smart interactive information retrieval system.

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Acquiring Innovation Knowledge

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Abstract. There are few possibilities for acquiring knowledge related to innovation. Firstly, acquiring knowledge using machine learning typically requires structured and classified data and/or cases, and lots of them. Secondly, manual acquisition of knowledge requires human expertise. Both approaches seem impractical when it comes to innovation knowledge. While innovation is recognized as a vital part of sustainability within organizations, there is little assistance with how we can acquire, reuse or share the innovation knowledge that may exist. We suggest a technique and present preliminary results of an evaluation study using this approach.

Keywords: Innovation knowledge, knowledge acquisition.

1 Introduction

Many today would accept that the Western organisation is no longer competitive from the point of view of secondary industry. Although both primary and tertiary industry must be conducted onshore, to attain a global advantage at the quaternary and quinary levels requires innovation. Naturally attaining a competitive advantage is easier said than done for "innovation is… a significant and complex dimension of learning in work, involving a mix of rational, intuitive, emotional and social processes embedded in activities of a particular community of practice" [5, p.123]. We too see innovation taking place as a process whereby knowledge may be gained either through self experience over time or by serving in an 'apprenticeship' with a more experienced innovator who may pass some of his or her expertise on. Nevertheless innovation is not simply a process of trial-and-error rooted in experience, innovation needs to produce timely and ongoing results "involving a complex mix of tacit knowledge, implicit learning processes and intuition" [5, p.124). Given the acknowledgement of the connection between tacit knowledge and innovation knowledge [9], we have turned our research using work-place scenarios to capture tacit knowledge toward the capture of related innovation knowledge.

2 The Approach

The approach carries on and extends our previous work [2, 3, 4] with a narrowing of focus to innovative and creative type knowledge and a change of direction into the

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application of personnel recruitment and training. Acknowledging that innovation is a process we will be looking for emerging patterns of behaviour appropriate to each of the various phases of the innovation process and how these responses correspond to our current understanding of innovation including the various psychological models, instruments and approaches which exist.

Similar to our previous work in developing an IT Tacit Knowledge inventory along the lines of Sternberg *et al.* [11], we have established an inventory with twelve randomly assigned 'innovation' scenarios. We see an example of scenario 12 with corresponding answer 'options' in Fig. 1. For each of these answers respondents select **two** Likert scale values (Extremely Bad through to Extremely Good) for **both** how they would *ideally/ethically* rate the answer option, **and** *realistically* how they feel the answer option is with regard to dealing with the given scenario. We also want our respondents to add innovative scenarios and answer options of their own with a view toward extending the inventory for future use. Finally, we ask our sample population to select the stage of innovation of the scenario along the lines of the Novelty Generation Model (NGM) [10].

You work for an internet company whose founder and chief executive routinely abuses and demoralises people. You and your fellow employees dread coming to work with this tyrannical executive, but you know that he has a great idea that can be packaged for a hot initial public offering in the next 12 months.

Do you:

1) Wait until the company goes public and its stock options vest then get out of there as quickly as possible.
2) Reduce annual leave and join another company. You don't have to take that kind of abuse.
3) Steal his idea and make some subtle readjustments to make it better then start your own internet company. With any luck you'll be able to bankrupt him and make a lot of money in the process.
4) Stay with the company for as long as they'll have you. Company loyalty is always appreciated, and the executive's ideas have merit even if he is a jerk.
5) Approach the chief executive and tell him firmly but politely that you don't appreciate his behaviour towards you and the rest of his staff.
6) Don't take his insults lying down, rise to the occasion and return them with interest.
7) Try to find out what the executive's real problem is. It may turn out to have nothing to do with you and rather be connected to personal problems. In which case, you won't feel that you are incompetent at your job.

Fig. 1. Scenario 12 with associated answers

The NGM is a bio-psycho-social approach, for it recognises that at a genetic level some people are more inclined to look for new problems and able to come up with novel solutions. In the model, the first step is novelty seeking followed by creativity which is broken into novelty-finding and novelty-production. These stages may be divided along the following lines.

Idea generation: Typically a technical insight into a product or process or thought about a service.
Opportunity recognition: An opportunity is identified for developing an idea into a new product, process or service.
Development: Usually involving prototype development and marketing testing.
Realisation: Typically realising how to market the product and introduce it to the customer.

These stages relate to novelty seeking with idea generation being a form of novelty seeking, opportunity recognition comprising novelty finding, and the last two stages representing a form of production from a novel idea. We return to these stages shortly.

Whilst we recognize certain psychological approaches such as the Kirton Adaptation-Innovation (KAI) inventory [8] or the Myers-Briggs Type Indicator (MBTI) creativity index [7] also focus on innovators, we choose to focus more so on the behaviour of individuals who have had successful results rather than on character or personality traits that so typically characterise current psychological research. However, we envisage that such psychometric tests will also play a role in a comprehensive instrument that can be used for the recruitment and development of personnel.

3 An Evaluation Study

As Information and Communication Technology (ICT) is our area of expertise, we will initially focus on innovation in this field. To compare novices with expert innovators, we are using two sample populations. First of all a third year undergraduate 'management theory' class of 75 individuals with a median age of 21 forms our novice population, and secondly approximately a dozen recognized innovators varying from 30 to 80 years of age, who will provide a skilled sample data set to compare against. To be recognised as an innovator, as opposed to merely claiming to be one, infers a process of public scrutiny. The individuals we will be approaching will by definition generally fit within the category of people experienced at what they do. With the incorporation of biographical information into the first component of the inventory, we hope to find differences in the answering of the scenarios on the basis of gender, or employment seniority, LOTE (Language Other Than English), highest formal qualification obtained and amount of ICT experience. Naturally the last two factors will not be high for the novice group given the age group we are dealing with.

4 Results and Findings

We present only a very small selection of our results here to illustrate our technique. Our novice population is 20 to 26 years of age, largely male (only 5 females), overwhelmingly ethnic (where ethnic in the Australian context refers to non Anglo-Celtic) and more specifically concentrated in the Chinese and to a lesser extent, the sub-continental ethnic groups. Finally the novices were generally school leavers (highest qualification was typically completion of secondary school) as one would expect. Analysis of the results revealed that all respondents took the innovation knowledge inventory seriously and none took a neutral ‘Neither Good nor Bad’ Likert scale option all the way through the questionnaire. To maintain concentration and thereby increase data validity, respondents were given only 4 randomly assigned scenarios along with the biographical component of the questionnaire.

Let us briefly examine the results of the answers for part of the inventory, in this case for scenario 12. With regard to answer 1 (“Wait until the company goes public and its stock options vest then get out of there as quickly as possible”), our respondents were ethically generally ambivalent, hovering around neither good nor bad, but realistically this option was considered on the whole to be good idea.

With regard to answer 2 (“Reduce annual leave and join another company. You don't have to take that kind of abuse”), the respondents were ethically positive, but realistically more negative. In other words whilst this option might seem an okay thing to do, our respondents felt in practice this was not such a good idea.

Answer 3 for Scenario 12 (“Steal his idea and make some subtle readjustments to make it better then start your own internet company. With any luck you'll be able to bankrupt him and make a lot of money in the process”) presents the most interesting result. There is clearly a *very* strong skew toward answering this question in the negative from an ideal or ethical point of view, but our undergraduates feel in practice this option is not so bad with a small majority actually considering the idea positive in practice.

With regard to answer 4 (“Stay with the company for as long as they'll have you. Company loyalty is always appreciated, and the executive's ideas have merit even if he is a jerk”), our novice population is evenly spread with regard to this situation from an idealistic point of view. In practice however the novices are inclined toward considering this option a bad idea.

In answering 5 (“Approach the chief executive and tell him firmly but politely that you don't appreciate his behaviour towards you and the rest of his staff”), the undergraduates feel this is a very good idea idyllically speaking. In practice however, they seem a little more reserved, a small minority even considering this an extremely bad idea.

Answer 6 (“Don't take his insults lying down, rise to the occasion and return them with interest”) is taken on the whole negatively by our sample students. What is interesting is that a larger than usual group of ‘fence sitters’ take a neutral stance (‘Neither Good nor Bad’) for this question. Only a small minority consider this option both ideally and in practice to be a good idea.

Finally answer 7 (“Try to find out what the executive's real problem is. It may turn out to have nothing to do with you and rather be connected to personal problems. In which case, you won't feel that you are incompetent at your job”) was interesting insofar as nobody considered this to be an extremely bad idea. People were generally comfortable with answer 7, and while there were some who took a neutral stance on the whole this idea was received positively ideally and in practice.

The actual responses of the novices are not of direct interest to us. We are firstly interested to see if the novices respond like experts, and if not, what is it that the experts do that is different. Scenario 12 used in this example has been developed from one of the case studies recorded in [1]. It is interesting to note that option 1 was in fact what the innovator historically chose, though he comments that this option was not very innovative. Instead he recommends option 3 as the most innovative option. This is very interesting because our novices revealed a strong tendency toward intellectual property theft being a bad idea ethically, but starting ones own internet company and bankrupting the competition being a good one in practice. Clearly our novices and our expert have very different views.

Remember that an important part of our research using the inventory was identifying the novelty generation stage a given scenario was at. In the case of Scenario 12, our management students were somewhat divided with regard to the Scenario's innovation development stage. Five students felt the scenario was focusing on *idea generation*, with one of these believing the scenario was concerned with *opportunity recognition* at the same time. The majority of novices (10 out of 23) felt scenario 12 was about *opportunity recognition*. Two out of 23 felt the Scenario was dealing with the *development* stage. And finally 5 students felt the scenario was dealing with the *realisation* stage of innovation.

5 Conclusion and Future Work

What remains to be done next is to extend the results to examine the remaining 11 scenarios with their respective answer options, and then to perform comparisons with that of recognised innovators. More elaborate data analysis techniques such as our use of Formal Concept Analysis [6] should permit us to achieve finer granularity of result analysis than would otherwise be the case with purely statistical approaches.

Most importantly we need to compare the results we have so far with those gained from recognised innovators. A first step in that direction has seen us contact people such as Professor Gordon Bell [1] after whom 'Bells Law of Computer Classes' is named, who was happy to validate our inventory. The next step will be to find other similarly talented individuals who will be identified through innovation awards and ICT organisations specialising in innovative ideas. We seek individuals who are successful both in a technical as well as an entrepreneurial sense.

The benefits of our approach will be best realised in the HR domain. Once we have developed and validated our innovation inventory, we intend to adapt and extend the tool to allow the scenarios to be randomly assigned to potential and existing employees so that it can be used to identify individuals, and to what extent, they behave similarly to the identified innovators. We will need to devise various algorithms to determine acceptable ranges of behaviour and incorporate the use of weightings to allow some scenarios to be more or less important in generating a score. For personnel selection, the goal would be to provide an innovation index/score ranking applicants to assist with the selection process. The tool may be extended to allow other details regarding other selection criteria to be included to make the process more streamlined.

For training purposes, algorithms will be developed which will provide scores indicating what knowledge is currently lacking in the individual and to propose a training programme for the individual. To achieve this goal we will need to refer to and incorporate other research in the psychology, training and recruitment literature.

We intend to compare our approach to the key psychometric approaches offered for innovation testing. We propose to administer techniques such as MBTI, KAI or other psychology-based techniques in order to correlate our findings with these other approaches and to validate the NGM. For instance, we will test whether certain personality traits and characteristics or motivations correspond to the phases in the NGM.

It can be argued that knowledge only exists when it is inside someone's head. When it comes to tacit knowledge we encounter even greater objections to attempts to capture or measure it as by definition such knowledge is implicit, unspoken and even unspeakable. In seeking to measure and capture innovation type knowledge, we are stepping into even more unchartered and cloudy waters. By building on findings from management and psychology based research, we are hoping to shed light on the nature of innovation knowledge. However, we want to move beyond the debate to look at the behaviour patterns that can be identified in the past successes of innovators and extrapolate from that what it means to be innovative and who has the potential to be so.

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