Intelligent Information Retrieval from Multiple Databases

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1. Introduction

Modern information technology provides human workers with enormous amounts of information. However, this information is not always tailored to the needs of those working with it. Moreover, it is often necessary to consult more than one database to obtain the needed information. To combine the information from multiple sources, the human user must perform (mental) cut and paste operations [Greenes 1991]. But before arriving at the cut and paste-stage, the user must first be able to find the pieces of information which belong together. If the information is to be obtained from multiple databases, this may cost considerable effort. In short, retrieval of related information from multiple databases can be a troublesome affair.

To diminish these troubles we can use an environment that enables its users to have uniform access to multiple databases, that facilitates finding pieces of information which are in some manner mutually related, and that adapts its retrieval facilities to the needs of the user. The purpose of the Archimedes project is to offer an environment that supports uniform access to multiple databases, and that provides user-customized facilities to retrieve multimedia information.

This environment is the so-called information network, which contains linked information objects pointing to pieces of information stored in multiple databases. The network offers graphical browsing facilities, next to the possibility to formulate queries based upon both types and attributes of information objects and on the semantics of the links connecting them.

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The research for this paper was partly financed by the Foundation for Knowledge Based Systems (SKBS), which seeks to improve the level of expertise in the Netherlands in the field of knowledge based systems, and to promote the transfer of knowledge in this field between universities and business companies.
In connection with the Archimedes project, a set of four applications will be built, which exploit the facilities of the information network. To demonstrate the capabilities of the Archimedes approach, the applications are taken from different domains, to wit a medical, a legal and an economical domain. We will illustrate the uses of the network by taking examples from these domains.

The Archimedes project is a project in progress. This paper describes the design of the information network which is the central topic of the project. In the next section we start the description of the Archimedes approach with a discussion of the information objects. In section 3 we describe how the information objects are connected in the information network. The fourth section is about information retrieval from the network. Then follows an account of the role and nature of user models. And finally, before concluding the paper, we indicate in section 6 how it is possible to include the knowledge of a knowledge system in the information network, so that the knowledge can be integrated with the other information.

2. Information objects

2.1. The purpose of having information objects

One starting point of the Archimedes approach is that uniform retrieval of information from multiple databases should not go at the cost of the original databases. The data should remain in its original form. Since the original form may be different for different databases, and since we want to profit from the advantages of the object oriented paradigm [Parsaye et al. 1989; Roberts 1991], we decided to work with object-like counterparts of the original pieces of information [Akscyn et al. 1988; Noll and Scacchi 1991]. These counterparts are what we call information objects.

In this discussion of the information network and information objects, we approach the network from the user's point of view. The object oriented paradigm can not only be applied to the structure of software, but also to the picture the user is given of an application. (This picture is confusingly also called the 'user model', just as the system's model of the user). When information objects are discussed, we refer to objects in the eye or ear of the system's user. Implementation details are not discussed in this paper.

In using information objects, we hope to achieve the four types of transparency a heterogeneous information environment should provide according to [Noll and Scacchi 1991]. There should be type transparency,
which means that the user should be able to manipulate an object independent of its type. There should be location and source transparency; the user need not be aware of either the distance or the type of the information repository. And finally there should be scale transparency; objects should behave the same regardless their number.

2.2. Types of information objects

Information objects come in three major types. First there are the counterparts of pieces of information which reside in the original databases. We will call these counterparts data objects. Since the original databases are not contained in the information network, they are called external databases. Data objects may refer to data of multiple kinds, such as text, graphics, sound, and animation.

The data objects do not contain the information themselves. Next to the attributes and methods they need to fulfill their role in the network, they have methods to retrieve the data from their original sources and display it. The latter methods vary according to the nature of the external databases. A relational database, for instance, is accessed differently than a database containing unstructured texts, graphics or sound. The methods employed to access the external databases take care of the necessary transformations and may therefore be compared to mediators in the sense of [Wiederhold 1992] (fig. 1).

**Figure 1. The role of mediators**

![Diagram of mediators](image)

Data objects are typed, so that the type reflects the nature of the data the objects point to [cf. Diaper and Rada 1991]. The types of the objects can be used in queries.
Besides data objects there is a number of related concepts. The concepts contain no information, but through their mutual links and their links to other information objects, they facilitate information retrieval from the network and make conceptual retrieval possible. The conceptual part of the information network may be seen as the cement of the network which binds the objects together. We discuss this role of the concepts more extensively in section 3.

Finally the information network contains elements of knowledge. The information network as a whole contains knowledge in two ways. The first way is based upon the types of the information objects and the links between them, which make it possible to draw inferences about the relations between information objects [cf. Diaper and Rada 1991]. The second way is based upon information objects which contain knowledge themselves, such as, for instance, rules. In section 6 we discuss the role of knowledge objects more extensively.

The relationship between the three types of information objects on the one hand, and the external databases on the other hand, is pictured in fig. 2.

**Figure 2. The network in relation to external databases**
2.3. Compound and elementary objects

Information objects are elementary or compound. Compound objects do not contain proper information themselves, but only information about the way in which they are composed out of other objects. The information out of which objects they are composed is stored in the form of links to the compound object's elements.

All three types of information objects can be compound. A compound concept is composed of more abstract concepts in the fashion of [Carnap 1956]. For instance, the concept of ‘man’ might be composed of the concepts ‘animal’ and ‘rational’ (or, for those who doubt the rational nature of man, of the concepts ‘featherless’ and ‘biped’).

A rule is composed of a condition-part, a conclusion- or action-part, and eventually a part with a numeral such as a certainty factor. The condition-part in its turn consists of a number of conditions, which in their turn may be composed of e.g. attribute-value pairs. By decomposing a rule into small elements, it is possible to link rule-elements to other information objects.

From the point of view of presentation to the user, compound data objects are the most interesting. Only elementary data objects refer to data stored in external databases. By combining elementary data objects which refer to different databases into a compound object, it is possible to present data from different places in a single frame [Akscyn et al. 1988].

The role of compound objects is comparable to the role of views with respect to databases. It is for instance possible to combine personal data concerning a patient with an X-ray, the patient’s diagnosis, and a protocol for treatment [Rada et al. 1990] (fig. 3). Another example would be to have a combination of a client’s personal data, the text of the statutory regulation which governs the client’s case, and the headings of important case law regarding that regulation.

Compound objects can be created out of more elementary elements by the system user. In that manner she is able to specify herself in what manner she wants to obtain specific data.

3. The information network

3.1. Link types

The information objects are linked together in a network to facilitate information retrieval. The types of links which are exploited are partly domain-dependent. All domains will have the traditional link types such as ‘is-part-of’, ‘is-a’, etc. and their inverses.
Specific domains will use extra link types, such as, in the law, the link between a legal topic (a concept) and the statutory regulations which deal with this topic, between a regulation and the corresponding case law, between case law and handbook parts etc.

The relation between an elementary data object and the corresponding parts of an external database is not handled by a link of the network. The relevant data are from the user’s point of view the contents of the data object.

3.2. The role of concepts

Although their importance may vary with the domain of the network, concepts will usually play an important role in information networks. This role depends on two functions. First the concepts make it possible to retrieve information on the basis of topics [Parsaye et al. p. 310], instead of for instance inverted files. A corollary of this function is that the user can obtain an overview of the information network by filtering out all objects except the concepts. Such an overview may prevent that the user gets ‘lost in hyperspace’[Conklin 1987; McCracken and Akscyn 1984].

A second function of the concepts in the information network is that they form a thesaurus [Rada and Martin 1987] by means of which many
other objects are indirectly linked to each other. If two objects both have a link to the same concept, their mutual relationship often needs no explicit representation by means of an extra link. For instance, if both a set of symptoms and a protocol for treatment are linked to a certain illness (a concept), there need not be an extra link to indicate that these symptoms indicate this treatment. Or if the data of a particular case are linked to a particular categorization (a concept), and this categorization in its turn is linked to a part of a legal textbook, there need not be an extra link to indicate that this passage is relevant for the case at hand (fig. 4).

**Figure 4. Concepts as the cement of an information network**

![Diagram of concepts and data connections]

4. INFORMATION RETRIEVAL FROM THE NETWORK

The purpose of having an information network is to facilitate information retrieval. In the end, retrieval comes down to making the contents of some data object visible and/or audible, dependent on the type of the object. The difficult part, however, is to select the relevant data object. There are two main techniques to select information objects, data objects included. These techniques are *browsing through the information network* and *formulating queries*.

4.1. Browsing through the network

The user will be able to interact with the information network through a graphical interface which makes the objects and their links visible. By
means of a pointing device, objects can be selected for various purposes, one of which is the display of their contents. If an object is selected, all objects which are directly connected to it by means of a link are made visible. This can imply that the 'window on the network' moves. In this manner it is possible to follow links through the network and browse from one place to another. Of course it is also possible to hide objects, in order to withhold the user from becoming a sorcerer’s apprentice who threatens to drown in the objects he invokes.

4.2. Filters

Since the information network may be huge and since one object may be linked to very many neighbours, there is a serious risk that the user who browses the information network gets lost. One technique to avoid this is the use of filters.

There are filters on object types and on link types. By means of a filter on object types, the user can specify which object types will be made visible while browsing the network, and which types will remain hidden. In this way he can for instance use the information network solely as a legal thesaurus or as a collection of case law. It will be possible to have a filtered network that consists of more than one type of object, such as for instance statutory provisions and (related) articles.

By means of a filter on link types, the user can specify which links are made visible while browsing. Objects connected to the selected object are only made visible if the connection is by means of a visible link [cf. Parsaye et al. p. 262]. It goes without speaking that a link between a visible and an invisible object is invisible.

By combining filters on object types and filters on link types, the user can for instance confine the view of the network to statutory regulations and the pieces of case law which have the interpretation of these regulations as their main topic. The example presupposes of course that there is a link type which specifies this relationship between regulations and case law.

4.3. Queries

The second way to select objects from the network is by means of queries. The execution of a query results in a list of zero or more objects. The user can select objects from this list for any action which is defined for objects (of that type). One action is to navigate to the place of the
selected object in the information network. Another action is to ask the object to display its contents.

There are two types of queries. The first type specifies objects whose type and attributes fulfil certain conditions. The second type specifies the relationship between the presently selected object and the objects which are to be found. This relationship can be defined by means of the type(s) of the selected objects and a sequence of one or more links of (a) specified type(s). For instance, in a medical network it may be possible to ask for the treatments corresponding to the diagnoses which can be drawn up from the record of the current patient.

Often it makes sense to reuse such sequences of links of one or more specified types. Therefore it will be possible to define so-called virtual links, which consist of just such a sequence of 'real' links. Virtual links can be used in queries in the same manner as 'real' links.

4.4. Relevance feedback and the weight of links

If data objects are selected through a query because of their connection to a particular concept, it is possible to adapt this connection on the basis of the relevance of the found objects [Parsaye et al., p. 311f.]. For this purpose, the links between concepts and data objects have a numerical dimension, which indicates the distance between the nodes. The distance between nodes can be used to order the output of a query according to the expected relevance of the objects. Moreover, it is also possible to specify the maximum distance between objects in a query. The distance between nodes can be adapted on the basis the user's explicit preference, or on the basis of the user's choice from the output of a query.

4.5. Entries into the network

Both for queries which start from the selected object, and for browsing the network, the place where the user finds himself in the network largely determines whether, and how quickly, he finds the information he is looking for. Therefore the entry into the network, the place where the search for relevant information begins, is an important issue. We envisage four ways in which the user can be provided with a suitable entry, viz. through the context of an application which uses the network, by means of the thesaurus included in the network, on the basis of a list of previously marked objects, or on the basis of the user-history.

The entry on the basis of the context of an application is discussed in
section 6. Entries on the basis of the thesaurus work with a ‘topic list’. The topics, which are concepts in the thesaurus, are collected in a list which the user can evoke when he starts to interact with the network. This list is comparable to the one which results from a query: the items in it can amongst others be used to navigate to a place in the network.

While interacting with the network, the user can mark objects for later use. The list of marked objects can be used for the same purposes as the result of a query.

The user-history is a record of the user’s interaction with the network. It makes it (amongst others) possible for the user to start her interaction where she left the network last time [Cypher 1986].

5. User models

If we want the information network to cooperate with the user in finding the relevant information, it is necessary that the network environment maintains some model of the user [Wahlster and Kobsa 1989]. User models can vary along different dimensions, as, for instance, the duration of the model, the way in which the information of the model is collected (implicit or explicit), and the size and nature of the group to which it applies (one individual, a group, a role) [Rich 1983; Allen 1990].

In the Archimedes project we make use of user models which both relate to roles and to individuals and which are largely (but not fully) built explicitly. In the previous sections we have already met with some aspects of these models. In the following subsections several aspects of the user models are treated more extensively.

5.1. The role-related model

5.1.1. Role-related models in search. – If an information network is relatively small, the chance is that it is meant for a rather homogeneous group of users. In that case it both makes sense and it is feasible to construct a list of topics which more or less cover the whole network. By making a choice form this list, the user can be sure to be rather near to the information he wants. This situation is depicted in fig. 5. In the default situation an information network disposes of one list during each session with the network. This list is the so-called default topic list.

In the case of larger networks, one list will not suffice to cover concepts over the whole network, unless the list has an unmanageable length.
Moreover, a large network will probably contain information that is useful for users in more than one role. Roles in this sense can be compared to stereotypical users [Rich 1989]. A user which plays a particular role may be assumed to have specific information needs which usually go together.

The presumption that someone who plays a particular role has specific information needs, makes it sensible to have several lists with topics, each list for one role. The information objects corresponding to the needs of a role will constitute a sub-network, which can again be covered by a manageable list of topics. Therefore the user of a large information network is offered the opportunity to select a particular role to which a specific list of topics is connected. By selecting a topic from this role-dedicated list, the user can enter the network on a place which is probably near to the information which is relevant for his purposes.

A role-related user model can also be useful for queries. It is possible to relate types of virtual links to particular roles of the user. Dependent on the role under which he entered the network, the user has various sets of virtual links at his disposal if he wants to formulate queries.

Moreover, the adapted strength of links between concepts and data objects can be coupled to a role. The relevance of particular data in relation to a concept may depend on the use which is made of the information and consequently on the role of the user.
5.1.2. Role-related models for the purpose of presentation. – Role-related models can also be useful outside the context of information search. For instance, the ways in which elementary data objects are combined into compound objects will often be related to the role for which the information is meant. A general practitioner will need a combination of a patient name, the description of a disease and a protocol for treatment, while a hospital administrator wants a combination of a patient name, the dates of entrance and of leave of the hospital and the types of medication that have been applied. Therefore it is sensible to make the presence of particular compound object-types dependent on the role of the user.

5.1.3. Filters vs deletion. – The presence of object-types can be made dependent on user-roles in two fashions. By means of filters, particular types of objects, including compound ones, can be made invisible in the presentation of the network. The links by means of which elementary objects are combined into compound ones are still present, and can still be used in queries, but the compound objects are not shown by the user interface.

It is also possible to delete the compound objects and the links which underly them. In this way the compound objects are not present in the information network and they cannot be used in queries anymore. Just as it is possible to delete objects and links from the network, it is possible to add to the network on the basis of a particular role. In section 5.3 we discuss how the several variants of the network relate to each other.

5.2. The individualized model

The possibilities to delete from and to add to the network are also offered to individual users. Moreover, the strength of links can be incorporated in the individualized user model. This means that the network cannot only be adapted to particular roles, but also to individual users. Each user has so to speak his own information network. The same counts for the use of filters in the user interface.

An individual has the extra possibility to mark a number of objects, to facilitate the return to them after a period of navigation. As mentioned before, marked objects can also be used to enter the network in a new session. The set of marked objects is saved in the user’s model.

The history of an interaction is also saved in the individual user model. This history consists of the sequence of selected objects and the queries and navigations steps through which they were selected. The history can
be used to restore the context of the user’s interaction with the network in case this interaction was interrupted for a long or short period [Cypher 1986].

5.3. How the user models relate to each other

Additions to and deletions from the information network just as the presence or absence of particular filters, are dependent on both role-related and individualized user models. An information network has a default setting with regard to the objects and links which are present in it and with regard to its default list and the filters used in its user interface. To deviate from this default, the user can select a role-model, an individualized user model, or both. In the case of conflicts between these models, the more specific ones precede the more general ones. By choosing such a model, the user adds and/or deletes objects and/or links, changes the default list into a customized one, and – if he selects his individual model – activates a list of marked objects and his history.

6. The roles of knowledge in information networks

6.1. Two roles

An information network counts three classes of objects types, viz. concepts, data objects and knowledge objects. The role of knowledge objects has been paid little attention until now. That is because knowledge objects are not directly meant for information retrieval and therefore play an exceptional role.

The role of the knowledge objects is twofold. First and foremost they are meant as the knowledge source for some inference mechanism. The purpose of knowledge is to be used in a knowledge based system (KBS); the fact that knowledge objects are incorporated in an information network does not detract from this.

The other role of knowledge objects is to provide context sensitive entries into the information network. When a KBS uses a particular knowledge object, the related information in the network can easily be found since the place of the knowledge object is known.

This can be particularly useful if, for instance, the knowledge system tries to obtain the value for a rule condition from the user. Since the rule condition has a place in the network, all kinds of information which is relevant in connection with this condition is, via links, directly available to
the user. Moreover, the user can use the place of the rule condition as a starting point for navigation through the network in order to obtain all information which might be relevant for finding the value of the rule condition. As soon as the user has found all information he wants, he can resume his interaction with the knowledge system. The information network is in this way an extension of the knowledge system.

6.2. The cooperative approach of man-machine interaction

The possibility to integrate knowledge systems and information networks in the manner described above is particularly important if one takes the cooperative approach to man-machine interaction with regard to knowledge systems. This cooperative approach stresses the fact that both man and machine have their own strengths and weaknesses with regard to the available knowledge and knowledge processing capabilities.

For instance, knowledge systems can be provided with large amounts of detailed information on a number of specific subjects. Their reasonings can be very complex, but are on the other hand limited to a small number of reasoning types such as firing production rules, inheritance, or resolution.

Human beings, on the other hand usually do not have much detailed knowledge, nor are they well able to follow complex reasoning patterns. But they do have a large amount of superficial ‘world knowledge’, and they are capable to use reasoning patterns such as establishing relevant analogies, which cannot yet be found in machines.

Hage [1989] argues why the cooperative approach is especially useful for legal knowledge based systems because of the nature of the legal domain. His arguments, however, also apply to difficult steps in medical decision making, when, for instance, the interpretation of laboratorium tests is involved. The same counts for economical decisions, for example, in case it must be estimated how the interest rates in Europe will develop given the fall of the rates in the United States and the reunion of East and West Germany. From these examples follows that a division of tasks and as a consequence a cooperative approach to decision making is suitable in all three domains for which the Archimedes projects develops applications.

For many tasks both the human capabilities and the capacities of knowledge based systems are necessary. To accomplish these tasks, a knowledge based system and its user must cooperate to obtain the best results. Cooperation can be facilitated by adapting the design of the knowledge based system. One such adaptation is to integrate the KBS with something like an information network. By means of the network, the KBS provides
the user with all kinds of data which cannot be processed by the system, but which the user can use to provide the system with the information it needs to continue its task. This approach is similar to the use of helpscreens in a KBS, but supersedes it by incorporating the task division of system and user into the design of the KBS.

7. Summary

This paper described the design underlying the Archimedes project. This project aims to support intelligent information retrieval from multiple databases. To that purpose it makes use of a so-called information network which consists of data objects, concepts and knowledge objects. The links of the network make it possible to navigate in a hypermedia-like manner through the network. Moreover they enable the user to select lists of objects by means of queries. Filters on objects and links withhold the user from getting lost in hyperspace. By means of user profiles for particular roles or individuals the network and its user interface are adapted to (groups of) users. Because of the possibility to have knowledge objects in the network, the retrieval capacities of the network can be closely interwoven with knowledge based systems.

References


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