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Database support for very large hypertexts

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SUMMARY

Current hypertext systems have been widely and effectively used on relatively small data volumes. The potential of database technology is explored for aiding the implementation of hypertext systems holding very large amounts of complex data. Databases meet many requirements of the hypermedium: persistent data management, large volumes, data modelling, multi-level architecture with abstractions and views, metadata integrated with operational data, short-term transaction processing and high-level end-user languages for searching and updating data. To illustrate the potential for the use of databases, a system implementing the storage, retrieval and recall of trails through hypertext comprising textual complex objects is described. Weaknesses in current database systems for handling the complex modelling required are discussed.

KEY WORDS Databases Hypertext Paths Trail management Composite objects

INTRODUCTION

The hypermedium is an information space representing a high-level abstraction of data. It represents an idealized view of the information needs of an area of particular human interest or activity. Information usually amounts to connections between different items to be found in human experience. These may be physical things or they may be ideas.

The significant feature of the hypermedium is the nature of this connection between data. It consists of an ordering but an ordering that is not unique. Many possible orderings may exist. While the computer is an obvious tool for handling and organizing large quantities of data in the hypermedium, straightforward procedural methods cannot cope with the complexity of the organization. The experience of early workers in databases is being repeated in the hypermedium by those engaged in developing hypertext. To progress beyond small simple systems requires the writing of what amounts to a customized database system. However, in adopting a customized solution, there is an immediate loss of generality and of functionality and a deterioration in quality. The hyperbases so developed may only be usable in their home environment whereas a generalized database implementation would provide the basis for the use of the same information for many other purposes [1]. There is the matching and retrieval capabilities of information retrieval systems, the document segmentation and word indexing of free text products, the display of markup languages, the layouts and layers to be found in the Office Document Architecture, the use of metadata for data exchange, and the application of a body of rules as in the field of AI and expert systems.

It therefore seems better to make use of the experience of the database community in building large hyperbases but it cannot be pretended that the benefits of one technology

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to the other are all in one direction. As will be seen later, database technology in its present form has some deficiencies in modelling complex objects and events, the solution of which will be given greater impetus by involvement in new challenging areas. The authors therefore see the relationship between database and hypertext technologies as symbiotic rather than parasitical. The hope is that database technology is both extending the hypermedium and being extended by it.

For reasons of continuity from the old, a fundamental unit of data in the new hypermedium is a document. Present hypertext provides mainly for small, simply structured documents and, in the way that it concentrates on factors at the human–machine interface, it gives good insight into the capabilities needed for a full hypermedium system. Three main types of link are recognized in hypertext systems:

1. explicit inter-document links representing citations,
2. lexical links in which the meaning of words is resolved,
3. conceptual links in which implicit semantic connections are made between one document and another.

The work described later is mostly concerned with symbolic links between one document and another. Lexical links pose greater difficulties in implementation because of frequent ambiguity in finding the definition of a word amongst its many usages in a text. Implicit links have proved to be difficult for the machine to locate automatically but can be entered manually by the user in most hypertext systems and in small-scale applications can provide very rich structures. It is unlikely that such richness can be achieved in large hyperbases where automated authoring is likely to prevail.

In traditional document systems, there is often a very arbitrary division in information [2] because of the rigidity enforced by predefined document sizes. In hypertext systems, this is overcome to some extent through various composition techniques for representing isPartOf relationships. Through such aggregation, logical documents can be defined which are a synthesis of what may be many diverse physical documents. The view of the authors is that these ideas need developing further to represent a document as a complex data object holding information in the form of structured data. The representation of document structures in database models is investigated more fully later.

LIMITATIONS OF CURRENT HYPERTEXT SYSTEMS

Present hypertext systems concentrate on the human–computer interface and rely on semi-automated or manual techniques to represent links between one document and another. This is satisfactory for small, simple document structures but otherwise there are a number of problems:

- The use of symbolic addressing is not fully exploited to cope with pre-existing forms of citation and for automated authoring of large quantities of text.
  - — There is no independent level of control that can test or validate the data and that can track the navigation through documents: the design and construction of maintainable links is a major problem. There is a lack of the concept of referential integrity.
- Methods of management of persistent data are relatively primitive.
  - — It is not easy for a hyperbase to be used concurrently by a number of different

readers or for multiple authorship. Progress in this area is currently being achieved by very active research in the area of Computer Supported Cooperative Work (CSCW).
  - — Access methods, in general, are designed for handling small amounts of persistent data.
- Searching facilities are specialized.
  - — There is an emphasis on browsing through nodes via links rather than on content addressing where the facilities are often quite limited. However, there are exceptions. Hyperties [3] is an early example of a system paying much attention to string searching within a fine data structure. Other workers have used relational database systems to augment searching facilities as mentioned later.
  - — Indexing is based on surrogates such as tables of contents rather than the full contents of a node.
- There is no consensus on the nature of the formal data model which is necessary to provide an integrated framework for data structuring and manipulation. Recent work employing set theory [4,5], Petri nets [6] and Z [7] shows the urgency with which this area is now being tackled. It is important for large complex applications that current hypertext practice involving the use of directed graph (general network) structures, inheritance hierarchies and object-oriented scripts be underpinned by a greater body of theory. A formal storage model using network structures has been developed [8] but this omits many of the activities.
- Node data is WYSIWYG. There is limited opportunity for mapping and indirection between user views and storage structures. There tends to be one fixed view—that of the author—with little scope for the preferences of individual readers.
- Hypertext systems are generally self-contained and cannot be easily integrated with other programs and data. It is difficult for another application to use the hyperbase.

These problems are emphasized with large data volumes, multiple authorship, complex inter-node and intra-node relationships, need for multiple views of same hypermedium, and a desire to integrate the hyperbase with other types of application within the organization.

POTENTIAL OF DATABASE TECHNOLOGY

Database technology has significance as it can assist in many of these problem areas: high-level end-user languages such as SQL can be embedded in standard programming languages to integrate database facilities with other functional aspects; management of large volumes of persistent data, including such aspects as security, integrity, concurrency and optimization of access, is a central tenet of the technology; multi-level architectures with mappings from logical to physical levels provide different views of the same stored data; content-addressing can be integrated with navigation to give facilities as sophisticated as those found in information retrieval systems.

The use of data models requires more detailed discussion. Database technology depends on the development of an appropriate data model for structuring and manipulating the data. It could be argued that the use of any model is reductionist, resulting in a loss of information. However, a data model does provide a rigorous framework within which an application can be developed. It therefore seems necessary, to exploit the full power of

hypertext, to have some machine model expressing semantic detail of the documents held with a full abstract specification of the data-types involved and a multi-level architecture similar to that of a DBMS. A clear problem is the kind of model that is most suitable for representing the architecture of documents and multimedia data and for providing usable query languages. As will be seen later, current DBMS models are inadequate in some respects.

The manner in which cross-references are realized and checked is crucial for a consistent hyperbase. Database systems employing symbolic keys for identification of objects have an inherent advantage over less conceptual approaches in handling text whose content is continuously changing. In first generation hypertext systems with physical node addressing, cross-references must in advance be fully identified as in a network database. In a value-oriented database approach to hypertext, links are made dynamically at run-time using symbolic key matching techniques. Both means provide for display and navigation through documents. The physically oriented approach uses less resources but the early binding of identifier to data is more of a static method which allows less flexibility if, for example, data is being loaded in an uncertain order or key values are being changed or deleted.

The greater flexibility obtained through the dynamic power of lazy evaluation using database technology is not the only advantage in this area. Constraints like referential integrity can be placed automatically on new data entered into the system and on updates to existing records. Potential cross-references in symbolic form are checked against the current database and must succeed for the new or changed record to be accepted without reservation. At the programmer's discretion, errors resulting from dangling cross-references can result either in the new data being rejected or accepted with reservation. Such reservations include a warning message, flagging of the citing field or a setting of the citing field to null.

The various levels of verification of links makes the construction of large hyperbases a very much easier and rigorous process through a multi-stage commit process. During the addition of user data, dangling cross-references, perhaps reflecting the order in which data is added, are flagged in the first pass and only after a second pass to re-check citations is the possibility of rejection considered. In any event, cross-references which cannot be resolved will remain flagged as such so that the system is always consistent with respect to which references are navigable. Finally the concept of referential transparency should be raised. In a database environment, the entire management of the links will be automatically handled by the system to relieve the user of all responsibility for maintaining referential integrity.

RELATED WORK

To enable larger amounts of data to be handled, some hypertext systems have already been augmented by a conventional relational database system as for example with the commercial system OWL [9]. Another attraction of relational systems has been to enhance the searching facilities as with the work by Gallagher *et al*. [10] in storing HyperCard objects in the database system ORACLE. At Texas Instruments, an experimental system, PANORAMA, based on the object-oriented database, ZEITGEIST, has been built to augment navigation facilities with searching functions [11]. These approaches have promise but are restricted by poor complex object modelling with the relational approach

and a complex user interface compared to those in contemporary hypertext systems for PANORAMA.

Work by Raymond and Tompa [12] has indicated the need for an accurate representation of the fine structure of documents to allow fragments of documents to be referenced and treated as objects of data in their own right. Tompa's model [4] satisfactorily treats some aspects of the hypermedia such as multiple readership and symbolic labels through using a 6-tuple structure recording nodes, pages, readers, mapping from nodes to pages, labels and hyperedges. However, there is a major problem with the model for real textual data: all references are between nodes mapped statically to a number of data pages with no scope for dynamic variation of unit size in the source and target objects. The model thus fails to capture the inherent complex object structure of multimedia data including the fragmentation features discussed by Tompa in his earlier work.

AN EXAMPLE DOCUMENT ARCHITECTURE

In order to examine document architectures, the example of English legal statutes will be used in this paper. In England, Parliament enacts statutes and Figure 1 shows related documents which have a bearing on the meaning of a particular section in an Act of Parliament. A section represents the smallest self-contained free-standing unit of text although subsections may be directly cited sometimes. A section is a mere point in the textual hypermedium and can rarely be consulted alone or understood without reference to other documents. For many purposes, sections are grouped together into parts or paragraphs into schedules. As any of the information in the Figure 1 may have a bearing on a section in question, it can readily be seen that advanced hypertext features are needed if all the relevant subject matter is to be available and easily reached in the electronic medium. Our work can be contrasted with that of Yoder and Wettach [13] who have also developed a hypertext system for the law. Their system is very flexible in the forms of data accepted but lacks a formal data model for controlling structures and for providing a general means of manipulating the data.

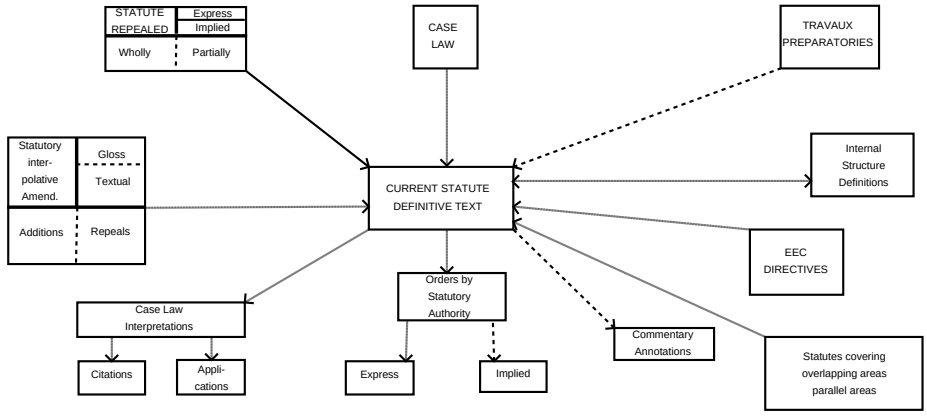


Figure 1. A Section of statute set in the European legal hypermedium

TRAILS AND PATHS

The existence of conceptual paths through textual documents was first recognized by Bush in 1945 [14]. Treu [15] considered the existence of trails through bibliographic citations and thought they should be preserved for a searcher to retrace his steps at a later date. At Newcastle, the need to provide a conceptual framework for the machine to assist the human in his database searching and navigation was recognized in 1987 [16] with a prototype implementation of the recording of trails in database tables as persistent data fully integrated with the hypertext data. The main objective of the trails was to assist the human in communication with the machine by removing the need to memorize backward and forward references, unsuccessful routes through the database, search terms used and the search and navigation strategy. Also in 1987, Conklin [17] identified one of the major difficulties in current hypertext systems as the user becoming "lost in hyperspace" as a result of losing his way along a trail as a result of the demands made during navigation. Zellweger [18] has classified the various kinds of path and emphasized the importance of implementing paths as first-class data. Although the implementation of the paths as scripts is satisfactory for single-user systems, there are problems with sharing of the path data in multi-user environments.

There is general agreement in the work quoted above that path information should be first-class data, replayable with or without variation and an essential part of the user interface. Before considering the required structures in more detail, we will first consider database models for representing the internal structure of the statute.

DATABASE MODELS AND TEXTUAL STRUCTURES

The basic DBMS models such as the relational are not suitable for manipulation of the fine structure of documents mainly due to the problems of normalization and aggregation of textual data [1] which in general terms result from an inadequate representation of complex objects [19]. At least for representing ideas, it is necessary to move on from the classical models to the semantic models because the required emphasis is on capability, expressiveness and abstraction. A range of semantic models incorporating more features and constraints than in the basic models has been proposed in an attempt to model more closely the real world. These include the Entity-Relationship (E-R) Model [20] and Taxis [21], both of which have been employed in this work.

CLASS STRUCTURES

A Chen E-R model of English statutes and the corresponding diagram showing the class structures have been presented elsewhere [1]. Two types of hierarchy are embedded within the class structure:

- An essential inheritance hierarchy to indicate the inheritance of properties (attributes) automatically by lower level objects from higher ones through 'isA' relationships.
- An aggregation hierarchy to indicate potential groupings of data through 'isPartOf' relationships. This hierarchy provides the framework upon which textual units are dynamically aggregated to satisfy varying user requirements.

The aggregation hierarchy has as its root a highly abstract object *node* which has some similarity to a node in hypertext terminology comprising a chunk of data for presentation

to the user. There are thus clear similarities between the two approaches. However, there are important differences:

- in hypertext systems, nodes are static structures at run-time whereas in our approach, a node can be dynamically generated at any time from any of the underlying text objects by aggregation. This dynamic composition is an important feature of the Dexter model [7] mentioned earlier.
- in hypertext systems, the internal structure of the nodes can be left undefined whereas in database technology there is a clearly defined structure for each specific text object at lower levels of the class hierarchy.
- the aggregation of *node* in our approach is always made in the context of symbolic identifiers (see Figure 2) rather than record or card numbers.

```
define AnyDataClass Node with
    ss#: {| ssmin:ssmax |}
    section#: {| sectmin:sectmax |}
    part#: {| partmin:partmax |}
    subp#: {| subpmin:subpmax |}
    para#: {| paramin:paramax |}
    subschedule#: {| subsmin:subsmax |}
    schedule#: {| schmin:schmax |}
    footnote#: {| footmin:footmax |}
    year: {| yearmin:yearmax |}
    chapter: {| chapmin:chapmax |}
  unique
    all.unit.id: (year, chapter, part#,
      section#, ss#, schedule#, subschedule#,
      para#, subp#, footnote#)

define AnyDataClass Text isA Node with
  changeable
    marginal.note.other: string
    crossnotes: string
    omissions: string
    footnotes.old.stats: string
    formatting.attribute1: string
    formatting.attribute2: string ... etc
  unique
    text.id: (year, chapter,
      section#, ss#, schedule#, para#, subp#)

define AnyDataClass XRef with
    citing.text.id: set of Text
    cited.text.id: set of Text
  unique
    ref.id: (citing.text.id, cited.text.id)
```

Figure 2. Taxis-like specification of symbolic key for statutes

SYMBOLIC ADDRESSING FOR HYPERTEXT

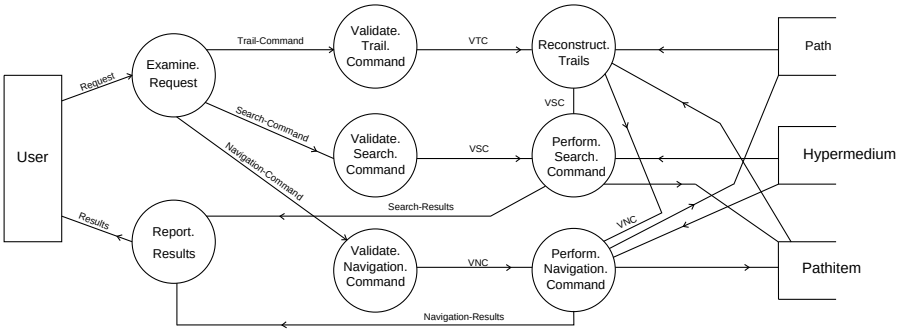
For navigation in the hypermedium, it is important to be able to identify uniquely individual units of text so that cross-references can be resolved. With the complex object structure employed in this study, it has been found that the optimal solution is to employ a generic symbolic key *all.unit.id* for the abstraction *node* as shown in Taxis-like form in Figure 2 [1]. The key *all.unit.id* effectively defines a generic heading which contains an integer value for each possible component of a textual identifier. The form of the key is application-dependent: in our work, nine different components have been identified such as section, subsection and footnote. For a given instance of a text, the values of some components are inapplicable. Such components have a value of zero: all other components have positive values, for example, *section#* would be assigned the value 6 in the heading of the sixth section of an act. This provides a completely general mechanism for addressing all objects in the inheritance hierarchy. The values for the attributes of *node* are constrained by the variables such as *ssmin* and *ssmax* which specify the minimum and maximum values permitted for subsection numbers.

The class *text* is a specialization of *node* representing an abstraction of the main body of text. As shown in the definition of *text.id*, a subset of the components of the generic key *all.unit.id* is required to address the main text. Specific features included in *text* but not in *node* are attributes representing various details of the internal structure of an item of text. Cross-references are represented by the class *XRef* with each citation held in *ref.id* comprising a pair of symbolic identifiers for the citing and cited text units, respectively. The constraint is specified that the citing and cited objects must be members of the set *text*: therefore, the identifiers of the text units must conform to the structure of *text.id* and the text units must be instances of the class *text* to enforce referential integrity.

MODELS FOR EXPRESSING DYNAMIC ASPECTS OF TRAIL MANAGEMENT

Figure 3 shows a Data Flow Diagram (DFD) [22] for the trail management which indicates the control of events required in searching and navigating. The diagram shows an overview of the processes involved and how they reference three types of information: the hypermedium itself, the names of the trails made by each user held in *path* and a complete history held in *pathitem* of each path comprising an initial content-based search followed by a series of navigational commands. Whilst execution of a particular process is not complicated, it is a matter of integrated management of the very large number of processes that are possible and their complex interrelationships. Also shown is a description of the main data flows on the input side to illustrate the nature of the commands passed to the system for action.

Only the top-level of the DFD is shown. This could be decomposed further into lower-level diagrams, each holding more detail of how each process operates. It is interesting to note that such detailed diagrams have similarities to the Petri nets of Furuta and Stotts [6]. Both approaches employ process models: DFD are business-oriented but Petri nets have the better formal basis.




```
Request          = [Trail-command | Search-command |
Navigation-command | System-command]
Trail-command    = [trail.label str | first | last | fwd(n) |
bwd(n) | end]
Search-command   = [find | and | or | not] attr str
Navigation-command  = [[+|-] n | ref | {subobject-id}]
System-command   = SPIRES-command
Subobject-id     = [subsection p | section q |
part r | subparagraph s | paragraph t |
schedule u | footnote v | year w | chapter x]
n..x = integer-value
attr = text-attribute
str = string-value
Abbreviations:
VTC = Validated-Trail-Command
VSC = Validated-Search-Command
VNC = Validated-Navigation-Command
Convention: [..] selection; {..} iteration; (..) optional
```

Figure 3. DFD for trail management in navigation of hypertext

MODELS FOR EXPRESSING STATIC ASPECTS OF TRAIL MANAGEMENT

As companion to the DFD of Figure 3, there is an E-R diagram in Figure 4 to show the relationships between the entities holding the trail information *path* and *pathitem* and other entities relevant to trail management. Each user can hold many paths each of which holds many path items. For branching trails [18], it is necessary to introduce the involuted relationship *cites* to indicate that a single path item can branch to many other path items during navigation through the user backtracking. For linear trails, the relationship *cites* is not required.

The entity-type *Current.Record.Position* has been introduced to explicitly indicate the current selected object. Many users can be active at a given time but it is an assumption at present that each user holds a single current record position at any given time. The entity-type *hypermedium* is in a 1 : N relationship with *pathitem* indicating that each hypermedium object can appear many times as a path item but that each path item refers to only one hypermedium object. The importance of the relationship *item.found.in* for integrity of the trail is described later.

IMPLEMENTATION OF TRAIL MANAGEMENT SYSTEM

The system was implemented on the non-standard SPIRES DBMS run on an Amdahl 5860 of the NUMAC service. The textbase STATLT holding the statutes for England has been developed and refined in a series of projects since 1980 and at the start of the project described here already provided a very detailed definition of the data structure [1], full text-searching facilities, symbolic addressing in the manner of Figure 2 and a multivalued attribute *marg-note-xref* in each text unit to record cross-references made to other parts of the text [23].

The current work is concerned with the implementation of the dynamic aspects shown in Figure 3 and the static aspects of Figure 4. The additional tables created to record the status of navigation will first be described.

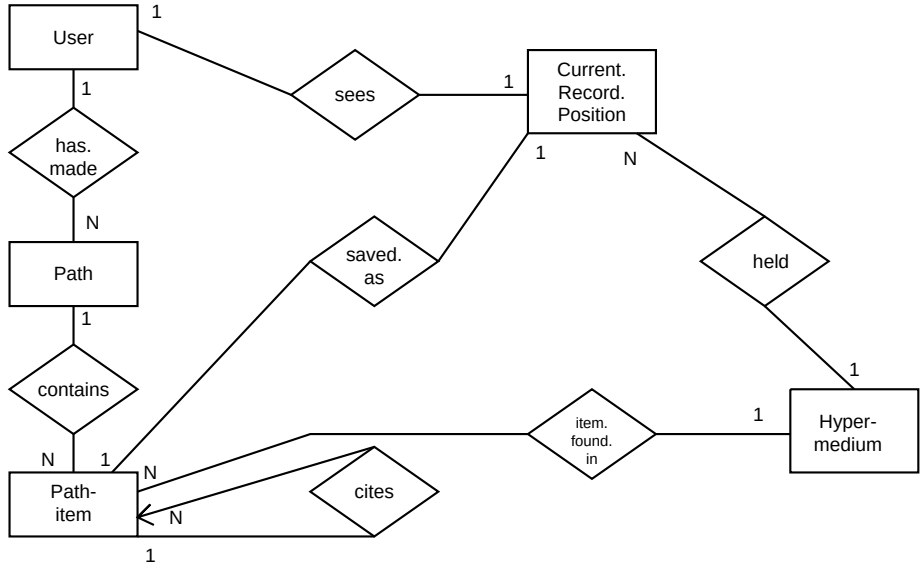


Figure 4. E-R diagram for static aspects of trail management

TABLES TO RECORD THE NAVIGATIONAL STATUS

The entity-types *path* and *pathitem* shown in Figure 4 hold all information on the trails made by users through the textbase. The attributes describing this information are shown below (key attributes in bold):

- path(**user.id, trail.num,** trail.label)
- pathitem(**user.id, trail.num, command.num,** command, citing.text.id, cited.text.id, current.unit, link.status, relevance)

Each trail is labelled with a string *trail.label* for identification by the user. In *pathitem*, *cited.text.id* holds the symbolic key of the current record after the command held in *command* has been both executed and successful. Success or failure is indicated by the value for the logical attribute *link.status*. The current unit size, indicating the extent to which the complex object structure has been aggregated to provide results to the user,

is indicated by the value for *current.unit*. The attribute *relevance* can be used to record the desirability of taking a particular route.

The attribute *citing.text.id* represents the involuted relationship *cites* of Figure 4 and is used as a backward reference point to enable the user to perform backwards and forwards tracking through the text. The attribute pair *citing.text.id* and *cited.text.id* is exactly equivalent to *ref.id* defined earlier in the Taxis-like symbolic key definition of Figure 2. The tables and their attributes are extensively used by the processes described in the DFD of Figure 3.

DYNAMIC ASPECTS AND THE USER INTERFACE

The DFD of Figure 3 was converted to a structure chart [24] by transaction analysis. The process *Examine.Request* was considered to be the transaction centre as it triggers many courses of actions in the system. The functions were implemented using the SPIRES Protocols language.

Two types of command are recognized by the system. SPIRES system commands are passed to the database kernel without modification. Other commands to validate and execute either a search, navigation or trail request are parsed and then sent to the appropriate process. It should be emphasized that the interpretation of users' actions is to some extent context-driven. Thus if the variable *status* holds the value REPLAY, the users' actions will be interpreted as far as possible as involving the recall of a trail. If the value is ACTIVE, the user is thought to be navigating and if INACTIVE (from the navigation perspective) performing an initial search to locate a record on content prior to navigation. However, if it is unambiguous that a user wishes to change his mode of operation from, say, navigation to content search, his status will be changed transparently from, in this case, REPLAY to INACTIVE. This flexibility is very important as it is only by changing mode in the middle of a session that a user can vary an earlier trail to explore the text in a new manner. The facilities available to the user under each status value are as follows:

- INACTIVE: A search command creates an initial result stack of items. This is followed by iterative searching with Boolean logic on the current stack. Navigation can only sensibly proceed when the user has identified a single record as of initial importance from content-searching. The ideal is probably an initial list of ranked records as described by Croft and Turtle [25].
- ACTIVE: Navigation commands available are of three main types:
  - — entering a positive or negative number enables the user to browse backwards or forwards through the text in logical sequence of the textual units. This command is typically used for browsing in either direction through sections within a part or paragraphs within a schedule at a constant textual unit size.
  - — entering the command **ref** directs the system to find the record referenced by the current record. If several records are referenced from a single record, the user will be given a choice as to which one is required. If the reference is to a high-level unit such as a *part*, objects will be aggregated to retrieve a complete *part* for the user. This command can therefore dynamically change the current textual unit size.

— entering values for the identifiers of sub-objects of the symbolic key defined in Figure 2 finds the record with symbolic key with new values for the designated sub-objects and current values for other components. The current textual unit size is adjusted accordingly.

With all three forms of the navigation command, execution results in updating the table *pathitem* defined earlier and, if successful, making the object found the current item.

- REPLAY: for the replay of trails established earlier, the user first provides a string *trail string* for identifying the required trail held in the table *path*. If the trail exists, the first action held for the path in *pathitem* will be executed and the system status will be changed to REPLAY. During the replay of a trail, a user can enter any of the following:
  — *first* finds the key of the record found at the beginning of the selected trail and establishes it as the current record.
  — *last* finds the key of the record found by the end of the selected trail and establishes it as the current record.
  — *fwd[n]* takes the navigation n steps forward from the current position.
  — *bwd[n]* returns the navigation back n steps.
  — *end* causes the status of the system to be changed from REPLAY to INACTIVE.

DISCUSSION

We have used current database techniques to satisfy our requirements. Of particular interest is the availability of both powerful browsing and searching facilities, the recording of all information concerning user trails as persistent data in fully-fledged database tables, and the dynamic variation of text unit size to meet changing user demands.

However, our task was relatively hard in two areas:

1. the dynamic adjustment of unit size; and
2. the integration of dynamic and static models.

In our implementation, aggregation was achieved at run-time through masking out components of the primary key and assembling, using the Protocols language, the series of text objects meeting the criteria implied by the user's current request. Reasonable performance was achieved in this task but the aggregation is being achieved by external operations on the objects rather than by the more conceptual approach of aggregation abstraction: new object classes with aggregation methods are defined to represent the various unit sizes.

Database technology does not provide a completely satisfactory solution to this problem. The definition of abstract data types as in Postgres [19] to represent the various aggregation possibilities may give problems with closure: the return of a multivalued set produces an unnormalized relation. Alternatively, an object-oriented database system such as GemStone [26] could have been employed. This would have modelled well the inheritance abstractions but aggregation is achieved by external operations on objects as in our current implementation.

The dynamic and static aspects have been implemented using different models which are weakly integrated. This lack of integration is found in all conventional database systems in current use [27]. It is an inherent feature of object-oriented databases that

methods form part of the class definition. Some semantic database models such as Taxis also provide this capability and their expressiveness has been examined for text [1]. Although these integrated models are currently at the experimental stage for realistic amounts of data, their usage in future large hyperbase systems seems very necessary. The object-oriented model of hypertext developed using the Vienna Development Method [28] shows the potential of the paradigm in this area.

In addition, there is also a number of areas where further work is required:

1. The interface provided to users. Layered object-oriented techniques employing multi-windowing need to be front-ended onto the present system.
2. Investigation of the semantics of trail integrity. The integrity of trails depends during their existence on no component object being deleted during maintenance of the hypermedia database. There is therefore a need for restrictions on the actions that are permitted on objects that participate in trails. Operations such as deletion on any *hypermedium* object participating in the relationship *item.found.in* should perhaps be constrained. Further work is needed at the conceptual level in this area to determine the exact nature of the constraints required.

CONCLUSIONS

Hypermedia systems are very complex: events have to be controlled over long periods, as in the design, control, maintenance and integrity of linear and branching trails used for navigation; text and graphical information comprises complex data objects with the need for aggregation and inheritance abstractions; and interfaces must employ multi-windowing techniques and be natural according to psychological models. A natural extension of the present work on hypertext at Newcastle is to investigate the use of object-oriented databases with their claimed suitability for large-scale complex applications. In effect, what is required is to place under a contemporary hypertext interface, database models which are very powerful, yet can provide a high level of abstraction to the end-user. It is to be hoped that database technology can be developed quickly enough to meet the imminent requirements for data management in very large hyperbases.

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