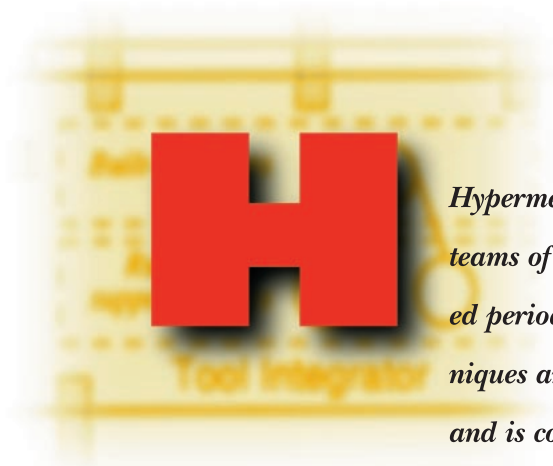
RMM: *A Methodology for Structured Hypermedia Design*



Hypermedia development, especially on a commercial scale, often involves teams of developers who need to be managed and coordinated over an extended period of time. Formal systems development and project management techniques are needed to ensure that the hypermedia product meets its objectives and is completed on time and within budget. However, traditional software industry techniques must be modified to accommodate new requirements.

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Hypermedia projects differ from traditional software development projects in several critical dimensions. First, as Streitz notes in this issue, hypermedia projects may involve people with very different skill sets: authors, librarians, content designers, artists, and musicians, as well as programmers. Second, the design of hypermedia applications involves capturing and organizing the structure of a complex domain and making it clear and accessible to users [9]. Third, multimedia aspects of hypermedia applications raise numerous difficulties [13]. Hypermedia design is therefore a challenging process that is currently more of an art than a science. Finally, the need for prototyping (see Nanard and Nanard in this issue) and intensive testing with users is even more pronounced in hypermedia development than it is with traditional software, because user tolerance to errors in hypermedia applications is very low.

In this article we propose the Relationship Management Methodology (RMM) for the design and construction of hypermedia applications. The name "relationship management'' stems from our view of hypermedia as a vehicle for managing relationships among information objects.

The class of applications for which RMM is most suited exhibits a regular structure for the domain of interest, i.e., there are classes of objects, definable relationships between these classes, and multiple instances of objects within each class. Many hypermedia applications satisfy this requirement. Examples include product catalogs and hypermedia front-ends of traditional database or legacy applications. Since many hypermedia applications in this class have volatile data that requires frequent updating, some means to routinize and automate both the initial development and subsequent update process is needed.

Table 1 illustrates the usefulness of the RMM approach for design and development of hypermedia applications. The two axes representing the structure and volatility of the information are really continuums rather than discrete branches of dichotomy. Applications in the two domains we mentioned—product catalogs and hypermedia front-ends of databases or legacy applications—are highly structured and have high information volatility, making the RMM methodology particularly appropriate. At the opposite end of the spectrum, an artistic work may not have a readily discernible structure and usually remains unchanged over time. In this case, RMM is not applicable. Highly structured applications that remain unchanged over a long period of time can benefit from the RMM methodology during the design and construction phases but do not require much maintenance, so that the updating problem is relatively unimportant and the advantage to be gained by the RMM approach is not as pronounced. Finally, applications that have irregular (or dynamic) structures and high volatility may gain little from the use of the RMM approach. In this case, however, we reserve judgment as it is possible that some parts of the domain may be structured and that the problem of high information volatility can be at least partially addressed.

A number of commercial products, including *Documentum* by Documentum Inc., *PDM* by Xyvision Inc., *RDM* by Interleaf, and *SGML Server* by Information Dimensions, use an approach similar to RMM, in that they provide flexible access mechanisms to documents that are stored in a database. The approaches used in these products are proprietary and have not been reported in the research literature. Moreover, these systems do not provide support for the design process, which is the focus of RMM.

Relationship Management Data Model (RMDM)

A data model is a set of logical objects used to provide an abstraction of a portion of the real world. Data models are necessary to express an application's design. A number of researchers have developed data models for hypertext systems, for example,[18, 24] Dexter [11, 12], HB1 and HB3 [16, 20], Trellis [23]. However, it is important to differentiate a hypertext system from a hypertext application. The former is an environment that facilitates the creation of the latter. A data model for a hypertext system [1, 7, 20, 24] details its internal architecture but is of little value in modeling hypermedia applications. This is because describing the layout of a general purpose engine is quite different from modeling an application domain; a different kind of data model is needed for this purpose. In our case, RMDM provides a language for describing the information objects and the navigation mechanisms in hypermedia applications.

Database models are useful abstractions in database applications, but the peculiarities of hypermedia, in particular the navigation aspect, require new models. Garzotto, Paolini, and Schwabe's HDM data model ([9]; see also Garzotto, Paolini, and Mainetti in this issue) is appropriate for describing the structure of the application domain, and we base our data model on HDM and its successor, HDM2 [8]. HDM and HDM2 describe representation schemes but provide little information on the procedures for using

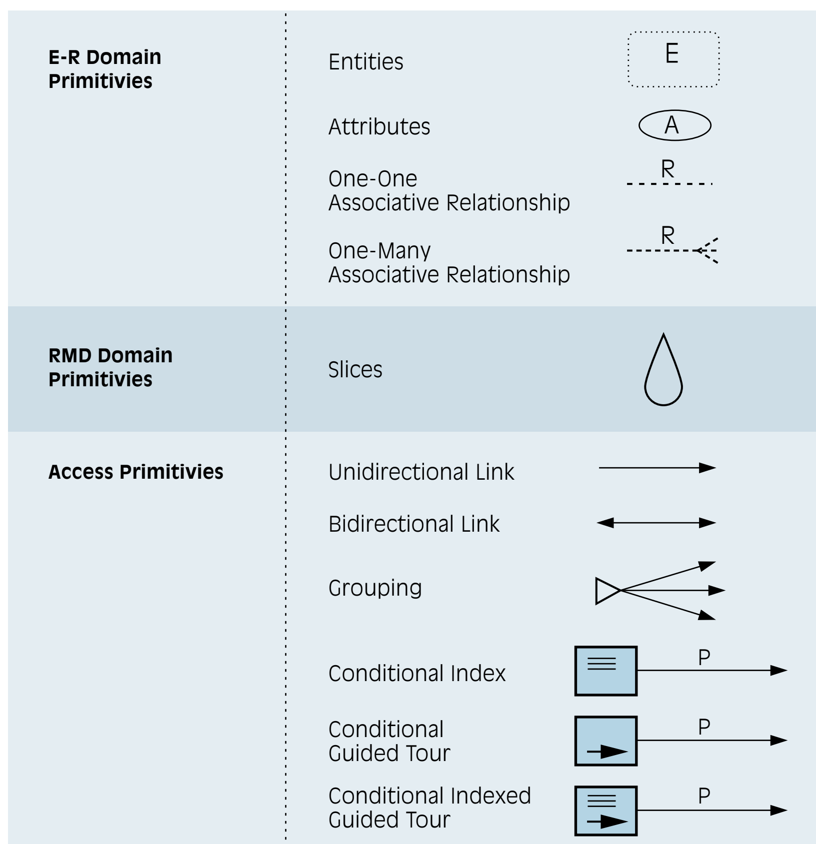


Figure 1. The Relationship Management Data Model (RMDM) primitives. E-R primitives model how information is structured in the application domain. The slice domain primitive models how information is to be presented. The access primitives model navigation.

Table 1. Usefulness of RMM approach

Structure		Volatility of Information: *Low*	Volatility of Information: *High*
Structure	High	Medium usefulness [e.g., Kiosk Application]	High usefulness [e.g., Product catalog, DBMS interface]
Structure	Low	Not useful [e.g., Literary work]	Low usefulness [e.g., Multimedia news service]

those representations in the design process; that is, they do not describe a hypermedia design and development methodology. Lange [15] and Schwabe and Rossi (in this issue and [22]) study object-oriented approaches to hypermedia design. Recent works by us [2] and by Garzotto, Mainetti, and Paolini [10] focus on this problem. The present article represents an update and expansion of [2]. Our methodology differs from that presented in [10] in several dimensions, including the recommended sequence of steps, additional access structure formalisms, increased emphasis on graphic representations, and a more detailed, step-by-step procedure for hypermedia design and development. The proceedings of two recent hypermedia design workshops [14, 21] discuss various other issues arising in hypermedia design.

Here, we describe the RMDM data model which is the cornerstone of the RMM methodology. Figure 1 shows RMDM's modeling primitives. In the upper part of the figure are the *domain primitives*, which model information about the application domain. *Entity* types and their attributes represent abstract or physical objects, such as person or bank account. *Associative relationships*, which can be one-one or one-many, describe associations among different entity types. As in database modeling, a many-many relationship is factored into two one-many relationships.

Because entities may consist of a large number of attributes of different natures (e.g., salary information, biographical data, photographs), it may be impractical or undesirable to present all of the attributes of an entity instance at once. Thus, attributes are grouped into *slices*. For example, a person entity with attributes name, age, picture, and biography may have a general slice, containing name, age, and photograph, and a biography slice, with name and biography. Hence, each instance of the entity "person" will be presented by two slices, and, if the application supports it, a user may choose which one to view. The graphical notation for slices—meant to resemble a pizza slice—appears in the middle of Figure 1.

Navigation is supported in RMDM by the six access primitives shown at the bottom of Figure 1. The unidirectional and bidirectional links are used to specify access between slices of an entity. It is important to stress that these links can be used to navigate only within the boundaries of an entity. RMDM supports navigation across different entities via indices, guided tours, and groupings. An *index* acts as a table of contents to a list of entity instances, providing direct access to each listed item. A *guided tour* implements a linear path through a collection of items, allowing the user to move either forward or backward on the path. There are a number of useful variations on guided tours. For

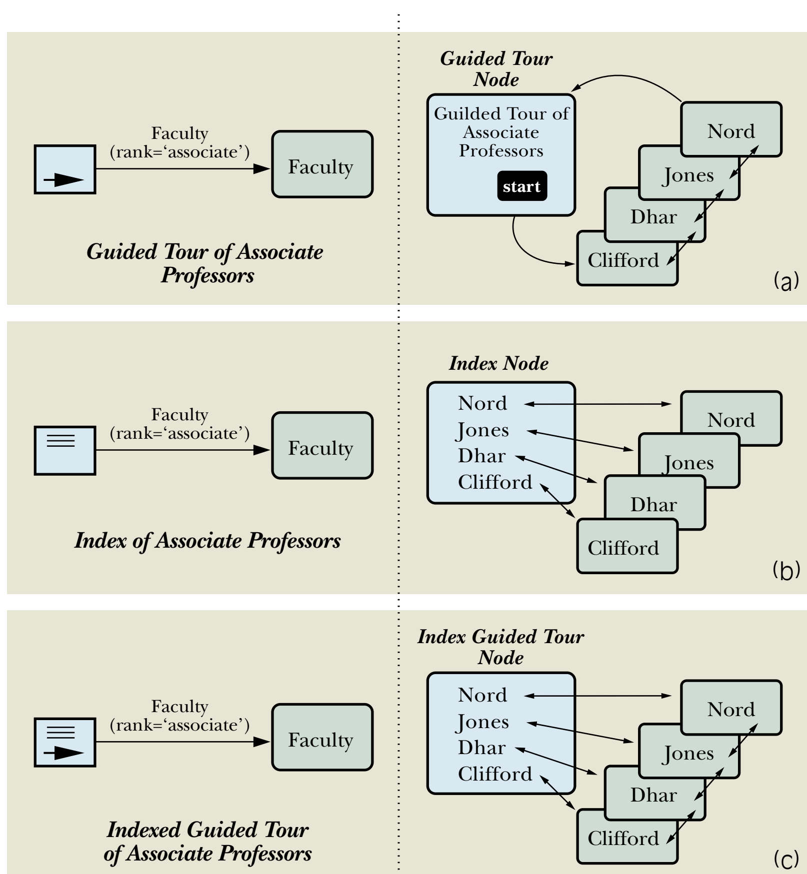


Figure 2. Examples of the conditional RMDM access constructs.

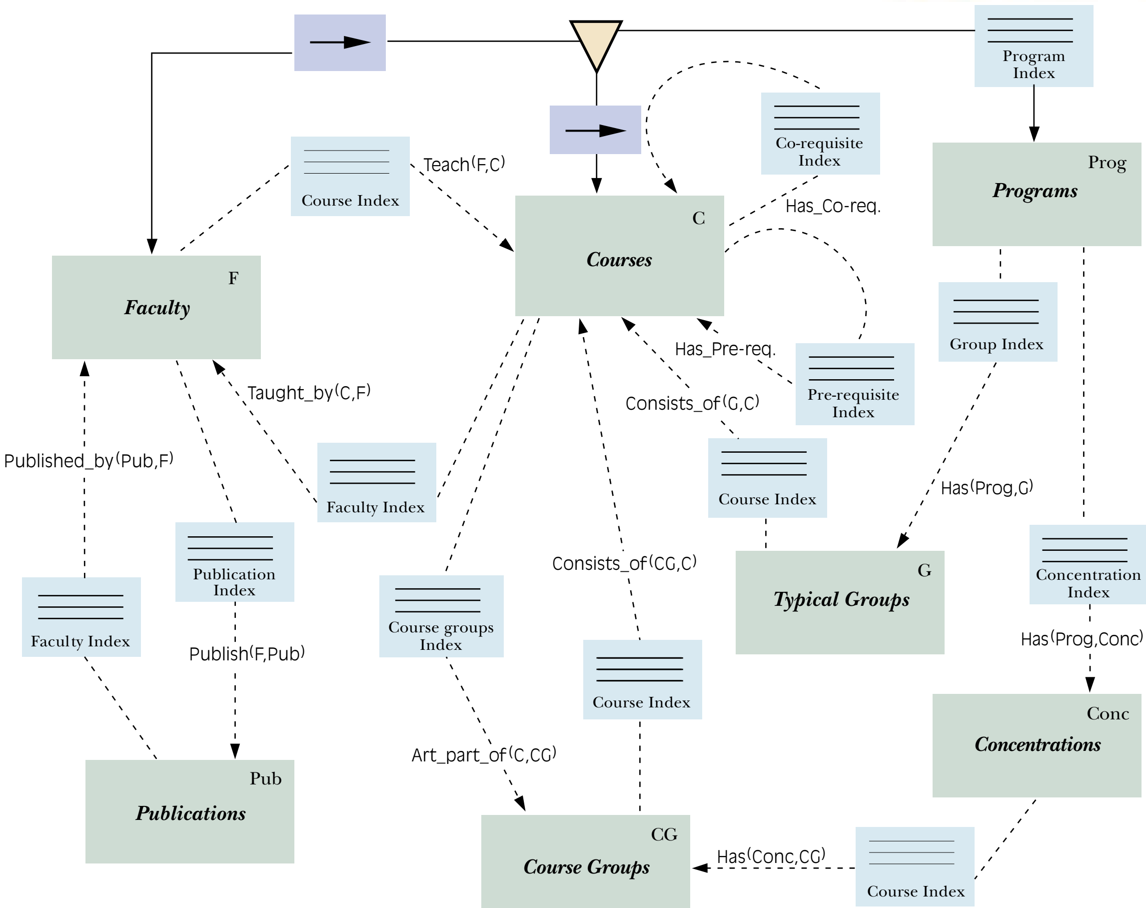


Figure 3. RMDM diagram for the Information Systems Department handbook application represents the final outcome of the three steps of the design process.

example, a *circular* guided tour links the last element back to the first; a guided tour *with return to main* has a distinguished node that contains information about the guided tour itself (e.g., "This is a guided tour of faculty homepages'') and is both the starting and the ending point of the tour; and a guided tour *with entrance and exit* has different entrance and exit nodes. RMDM is capable of accommodating all of these variations on guided tours. However, for the purposes of this article, it suffices to consider a generic guided tour construct, shown in the middle of Figure 1.

The grouping construct is a menu-like mechanism that enables access to other parts of a hypermedia document. A typical example of a grouping is the opening screen of many applications, which serves the purpose of providing access to other features, such as indices and guided tours. Indices are special kinds of groupings. We are currently investigating other useful grouping constructs, such as the multilevel hierarchical structures so common in knowledge classification schemes.

The conditions or logic predicates qualifying indices and guided tours determine which instances of an entity are accessible from the construct. For example, Figure 2a shows a conditional guided tour of all associate professors. The predicate faculty (rank = 'associate') indicates that only those entity instances of faculty whose rank attribute is associate participate in the guided tour. The right part of the figure shows an instance of such a guided tour. Figure 2b is an example of a conditional index web. Here, access is granted via an index-like construct. There are also return links from each participating node to the index, as shown on the right of the figure. Last, conditional indexed guided tour webs combine indices and guided tours to provide a richer access structure.

We will use the Stern School's Information Systems Department's handbook application (ISweb) as a basis for discussion (URL: http://is-2.stern.nyu.edu/isweb). V. Balasubramanian et al. present a different application, also developed with RMM, in this issue. The ISweb handbook contains descriptions of the graduate programs and courses offered by the information systems (IS) department and a list of faculty members in the department and their research interests. We have chosen this application for various reasons: (1) Many readers are acquainted with this domain (2) Its moderate complexity enables an illustration rich in details (3) It illustrates the problems that arise when updates are relatively frequent (semiannual in this case).

Figure 3 shows the complete RMDM diagram for the ISweb application. Note that, in contrast to an entity-relationship diagram that represents the design of a database, an RMDM diagram describes how users will navigate a hypermedia application. To avoid cluttering, slices are not included in Figure 3, and only the key attributes of entities are shown. At the top of the figure the grouping mechanism implements a main menu. Access into the faculty and course information is provided via guided tours; access into programs by means of an index. On choosing the guided tour to the faculty entity, the user can move back and forth among all faculty members (ordered alphabetically). From the faculty entity, there is a conditional index into courses with predicate *teaches(F,C)*. The reciprocal index *taught_by(C,F)* can be accessed from courses. Together, these two indices represent a many-many relationship between faculty and courses.

The *teaches* conditional index allows the user to move from the faculty entity to the courses taught by that faculty member. Had we provided an indexed guided tour for the courses taught by a faculty member, the user would be able to choose which course to visit first and from there, he or she could use the next and previous links to visit other courses taught by the same faculty member.

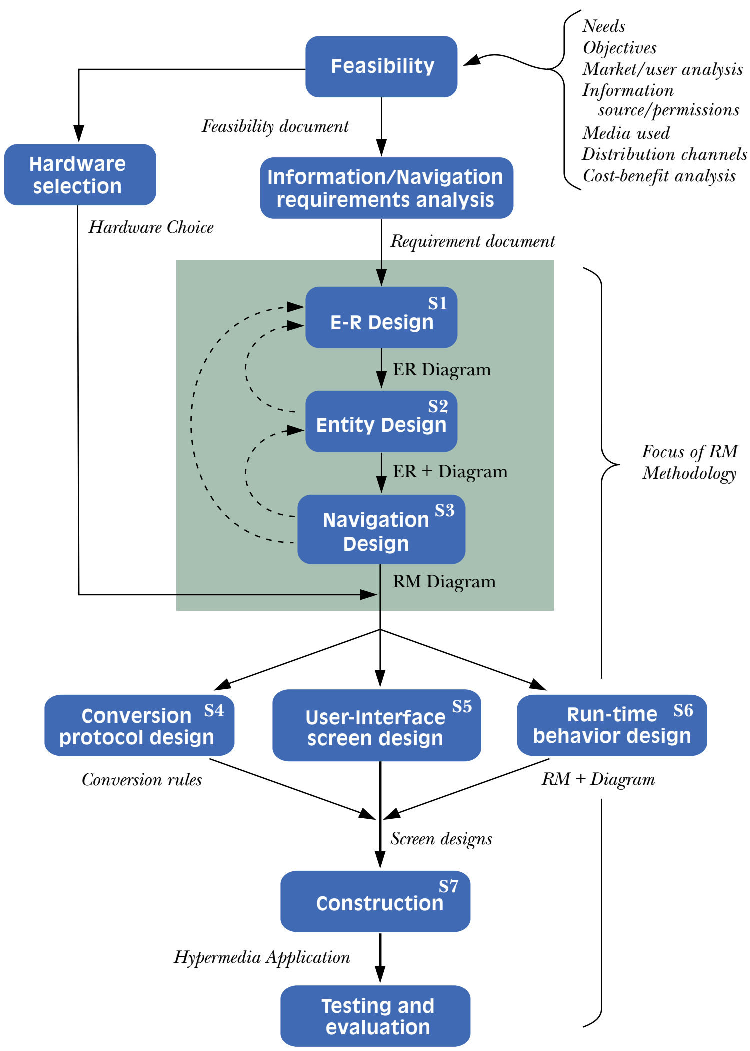


Figure 4. The RMM design methodology. The arrows connecting the various stages are tagged with the objects to be used as input for the next step. Our focus in this article is on the design steps, shown in the shaded area. To avoid cluttering, we show only feedback loops within the design phase (the dashed lines). The remaining feedback loops, although present in RMM, are not shown.

The Relationship Management Methodology (RMM)

The RMM methodology is shown graphically in Figure 4 within the context of the complete software development cycle. RMM focuses on the design, development, and construction phases. In this article we concentrate on the design of access mechanisms, which is achieved through the first three steps of the methodology (shown in the shaded area of Figure 4). Although feasibility, requirements analysis, and testing are undeniably important phases in software development, they are beyond the scope of this article. To evaluate hypermedia applications, one can use techniques like those proposed by Garzotto, Paolini, and Mainetti (in this issue) and by Botafogo, Rivlin, and Schneiderman [3].

The labels on the arrows in Figure 4 represent the various intermediate artifacts generated through the use of the methodology. Although present in the methodology, we do not show the feedback loops among the remaining stages to avoid cluttering the figure. Feedback loops between the RMM design stages are shown by dashed lines.

The RMDM data model provides a strong prescription for choosing the nodes and links in the hypermedia application. However, many design issues must be decided independently by the designer (see Thüring, Hannemann, and Haake in this issue). While our main purpose here is to outline the design methodology, we also discuss some design guidelines for each step.

Step S1: E-R Design. The first design step is to represent the information domain of the application via an

Entity-Relationship (E-R) diagram. The E-R representation has been chosen because it is familiar to system analysts, is well-documented [6], and can model information dependencies in numerous application domains. This stage of the design process represents a study of the relevant entities and relationships of the application domain. These entities and relationships form the basis of the hypermedia application, and many of them will show up in the final application as nodes and links in a hypermedia web. In many situations the E-R diagram might already be available—for example, if the target application is a hypermedia interface to an existing database. In this case it can be reused directly in this step.

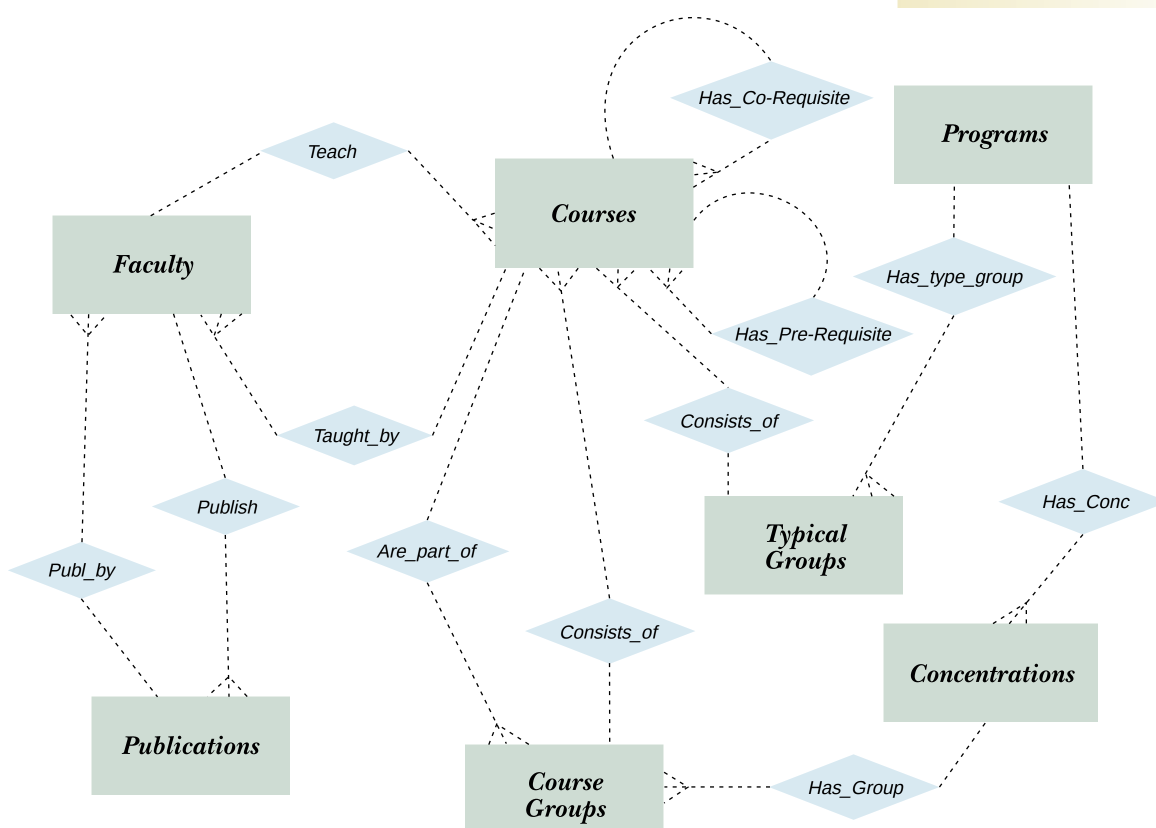
Figure 5 shows the E-R diagram for the handbook application. The entities faculty, courses, programs, among others, are shown in rectangles. The relationships *teaches, taught_by, prerequisite*, and so on, are shown by dashed lines. In RMDM, the relationships that appear in E-R diagrams are called associative relationships, because they represent associations between entity instances. The graphical notation also shows the arity of each relationship. Namely, when an arc opens up into three lines, the arity is many on that side of the relationship. The possible arities of relationships in the E-R framework are one-one, one-many, and many-many. To facilitate design of navigation in step S3, we use standard database design techniques to split many-many relationships into one-many ones. In Figure 5, for example, the two one-many relationships *teaches* and *taught_by* originate in a many-many relationship between faculty and courses. During the navigational design step S3, relevant relationships are identified and are made available for navigation via indices or guided tours.

E-R Design Guidelines

Since E-R design has been extensively discussed elsewhere (see, for example, [4]), we will confine ourselves to but a few remarks here. The objective in the design of hypermedia applications is to make the links between objects explicit, as these are the main paths via which users browse individual items of information. An analysis of the domain using the E-R approach helps identify important relationships across which navigation can be supported. Conversely, if a navigational path across entities is a requirement for the application, a corresponding associative relationship has to be included in the E-R design.

Step S2: Slice Design. This step, which is unique to hypermedia applications, deter-

Figure 5. E-R diagram for the handbook application. Entities appear within rectangles and relationships as dashed lines. Relationship names appear within diamonds.



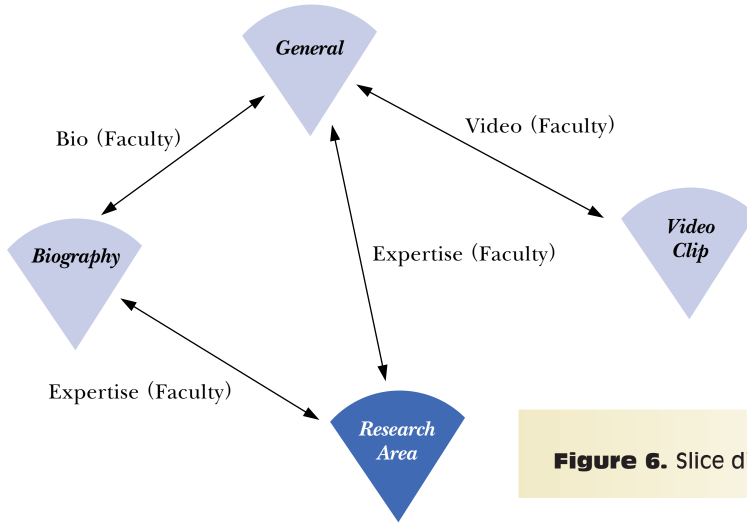


Figure 6. Slice diagram for faculty.

mines how the information in the chosen entities will be presented to users and how they may access it. It involves splitting an entity into meaningful slices and organizing these into a hypertext network. In its simplest form, all the information in an entity can be displayed within one window with scroll bars. Although such an approach is simple for the developer, it is undesirable for a user, who may become disoriented when scrolling within long windows. Alternatively, the information can be divided into meaningful units that can be presented as separate but interrelated wholes. For example, Figure 6 shows the faculty entity subdivided into four slices, containing (1) general information, (2) a short biography, (3) research interests, and (4) a videoclip.

The organization of entities into slices is called the *slice design phase,* and it results in a slice diagram, as depicted in Figure 6. Each slice groups one or more attributes of the entity. For example, the general slice in Figure 6 groups the attributes first name, last name, general description, and rank, while the biography slice contains first name, last name and biography. Each entity has a distinguished slice, its *head,* which is used as a default to anchor links coming in to the entity. In the diagram, entity heads are marked with an asterisk.

The entity diagram also models navigation between slices via uni- and bidirectional links. The labels on bidirectional links name both directions. The up/left direction appears in parentheses. For example, the link joining general and research area is labeled expertise in one direction (from general to research area), and faculty in the other direction. These links, which represent connections between slices, are called structural links. This is consistent with HDM notation. To differentiate them from the associative relationships appearing in the E-R diagram. Structural links differ from associative relationships in that the former connect information pieces within the same entity instance, while the latter interconnect different entity instances

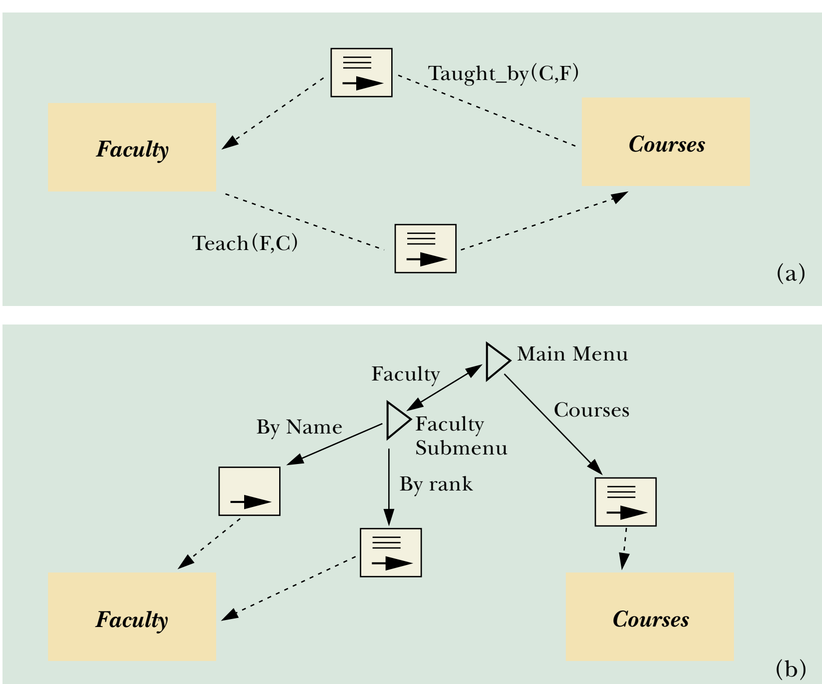


Figure 7. Examples of a Relationship Management Design Diagram. In (a), conditional indexed guided tours implement the associative one-many relationships *teach* and *taught_by*. The use of conditional access structures to provide access beyond that derived from associative relationships is illustrated in (b). Also note the two groupings, which implement a hierarchical menu-like access mechanism.

belonging, in most cases, to different entity classes.

From a navigational point of view, there is an important reason for differentiating among these two kinds of connections. When a user traverses an associative link, the information context changes, for example, from a faculty to a course. However, when a structural link is traversed, the information context remains within the same entity. To support the implementation of different user-interface cues for navigation, structural and associative connections are differentiated graphically in RMM artifacts: Structural connections are drawn with solid lines, whereas dashed lines are used for associative relationships (as in Figures 3 and 5). The concepts of structural and associative relationships also surface under different perspectives in other articles in this special issue. For example, they relate to local and global coherence in Thüring, Hannemann, and Haake's article and to local and global navigation in Kahn's. Together, the entities and relationships obtained in the E-R design step and the slice links make up the structural components defining the application schema described in Bieber and Kacmar (this issue). The output of the entity design phase is an enriched E-R diagram, denoted E-R+, which is obtained from the E-R diagram by filling each entity with its slice design diagram.

Slice Design Guidelines: There are four main considerations: (1) dividing an entity into slices, (2) choosing one slice to be the head of the entity, (3) interconnecting the various slices, and (4) labeling the links. Regarding the first issue, it is important to remember that each slice will represent a *whole* for the system user. Thus, slices should group only related information items but should not contain too much information.

Choosing the head slice and deciding on the interconnections between slices requires an analysis of the domain. In our case, the general slice has been chosen to be head of the faculty entity because it is the most representative of the slices. The links reflect the need to connect more general units, like general, to more specific ones, like biography, research area, and videoclip, and to provide back links to navigate back from these. Finally, choosing appropriate link labels and anchors is a delicate issue as Thüring, Hannemann, and Haake note. In our applications, we picked labels that explicitly highlight the nature of the target slices.

Step S3: Navigational Design: In this step, we design the paths that will enable hypertext navigation. Each associative relationship appearing in the E-R+ diagram is analyzed. If, according to the requirements analysis, an associative relationship should be made accessible for navigation, it is replaced by one or more RMDM access structures. Since the RMM methodology is meant for domains that are updated on a relatively frequent basis, all navigational paths are specified in generic terms. This means that there are no hard coded links between instances of entities; instead, links are specified by referring to properties of entities and of relationships. The three RMDM navigational elements that make this possible are conditional indices, conditional guided tours, and conditional indexed guided tours.

One starts step S3 by designing the navigation between entities, which is based on associative relationships. For example, the *teaches* relationship between faculty and courses is used to access all courses taught by a faculty member, and the *taught_by* relationship is used to access the information about all faculty members teaching a course. As shown in Figure 7a, we used conditional indexed guided tours in this case. The name of the relationship is used as a condition in these access structures to indicate which instances of the entities are to be interconnected. This ensures for example, that only the courses taught by faculty member *F* will appear when traversing the *teaches* link from *F*'s node.

Next, we design high level access structures by grouping items of interest. Figure 7b illustrates how to use groupings to provide hierarchical menu-like access to courses and faculty in the IS handbook. These menus are an alternative to the design presented in Figure 3. The grouping shown at the top of Figure 7b represents a menu with two choices: faculty and courses. Below this first menu and to its left is another grouping construct, that provides access to an alphabetical list of faculty (in the form of a guided tour) and to an index of faculty by rank.

By default, access structures enter an entity via its head slice. However, designers can specify a different entry point. This can be indicated, for example, by tagging the access structure with the name of the target slice. At the end of the navigational design stage, the ER+ diagram has been transformed into an RMDM diagram, like the one shown in Figure 3, that describes all access structures to be implemented in the system.

Navigational Design Guidelines

The design can proceed *bottom-up*, by focusing first on each entity and then on the more general access structures, or the inverse process can be adopted, resulting in a *top-down* approach. The approach discussed here has been mainly bottom-up because we followed a very structured design process. However, we anticipate that software developers will want to approach the design process in a bottom-up, or middle-out fashion. As Nanard and Nanard point out in their article, these requirements are an important consideration in the design of an RMM-based computerized environment for hypermedia design and development (see also [5]).

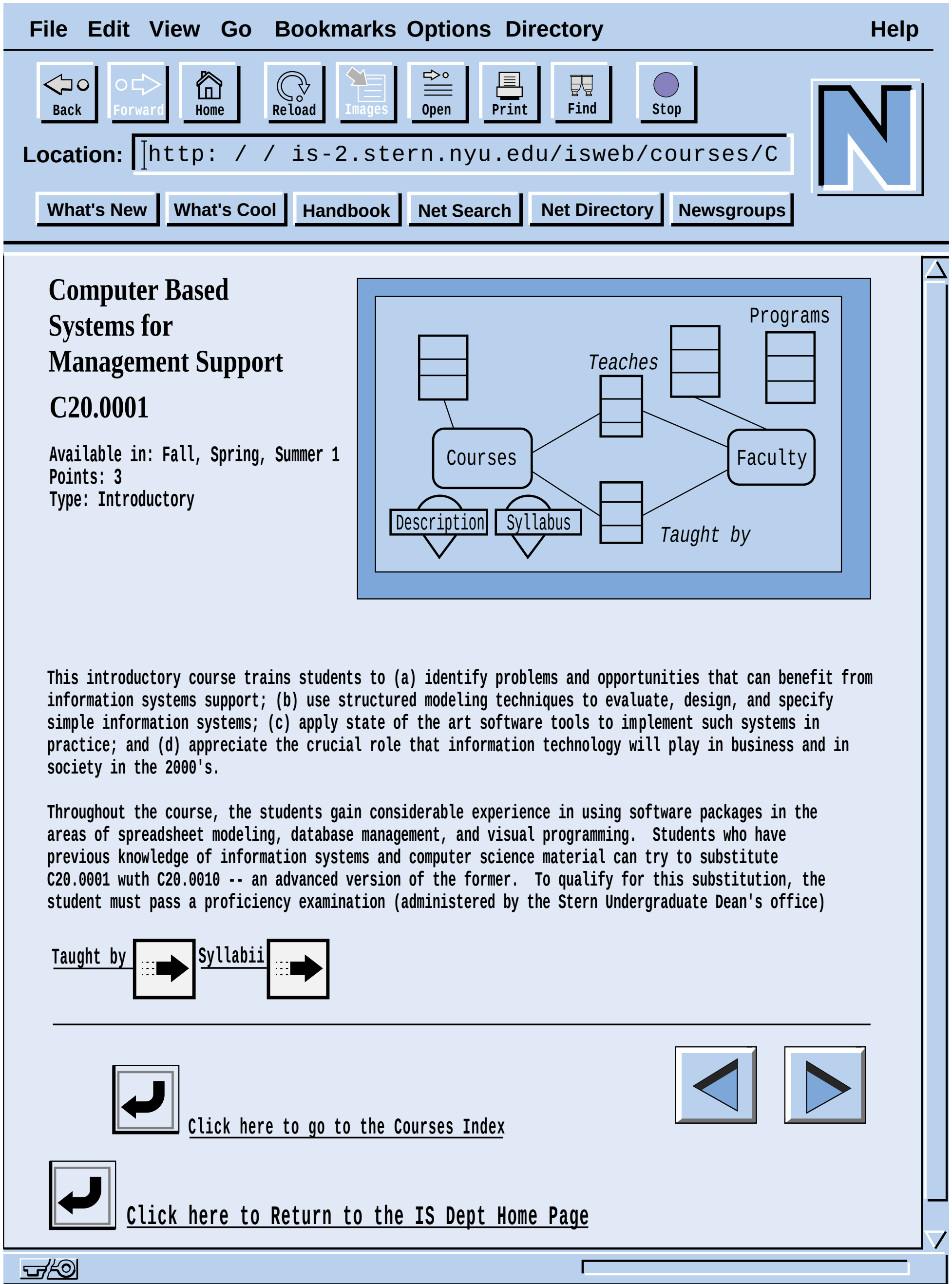


Figure 8. A course page from the WWW implementation of the IS handbook. The clickable map on the upper right corner is a by-product of the RMM methodology. It serves to orient users and is also an alternative means of navigation.

During step S3, designers have to identify (a) the information components and relationships that will be accessed, (b) the groupings that will be present, and (c) the access structures used in each case. Decisions regarding (a) and (b) must be based on system requirements obtained during the requirements analysis phase, reflecting the characteristics and logical structure of the application domain. Further refinements through user participation should be encouraged during the S3 design step. Regarding (c), we use a few simple guidelines. Groupings provide hierarchical points of entry; whenever possible, we try to reduce the depth of hierarchies to avoid user disorientation [17]. Alternatively, graphical cues can be used to provide an overview of where a reader is in the hypertext network. One-one relationships are implemented via bidirectional links.

For one-many relationships the choice is more complex: between a guided tour, an index, and an indexed guided tour. We prefer a guided tour to an index when the number of participating entity instances is relatively small (say, less than 10) and when there are no index keys that can be of help to users. For example, the research areas of a faculty member are organized as a guided tour because, for most students using the system, the names of the research areas are not very informative. On the other hand, when there is a large number of instances in the presence of a meaningful key, an index is better suited. Indexed guided tours are a hybrid, often used when there is a suitable index key and some local navigation is desired, as is the case with the courses taught by a professor, where the course number serves as a key.

User-Interface Design and Construction

Here we describe the remaining four steps of the RMM methodology. Because they do not deal directly with the design of access mechanisms, we provide only a brief discussion in this article.

Most current hypermedia building kits, such as Toolbook, HyperCard, Macromind Director, as well as tools used to create HTML documents, offer some degree of support for software development. For example, Toolbook and HyperCard provide graphical widgets for building code and libraries containing hypermedia programming constructs. However, these tools only facilitate the programming stage of software development, without addressing the broader design and development issues that have been outlined in this article. Step S4, *conversion protocol design,* uses a set of conversion rules to transform each element of the RMDM diagram into an object in the target platform. For example, a Toolbook list-box or an HTML form can be used to implement an index. Step S4 is currently performed manually by programmers. However, a group at New York University is developing an RMDM to HTML compiler.

Step S5, *user-interface design* involves the design of screen layouts for every object appearing in the RMDM diagram obtained in step S3. This includes button layouts, appearance of nodes and indices and location of navigational aids. Decisions about how link traversal, history, backtracking, and navigational mechanisms are to be implemented are made during step S6, *runtime behavior design.* Also during this stage, developers consider the volatility and the size of the domain to decide whether node contents and link endpoints are to be built during application development or dynamically computed on demand at runtime (see V. Balasubramanian et al in this issue). The RMM methodology, although geared toward the latter, also supports the former. Finally, step S7 consists of *construction and testing,* as in traditional software engineering projects. In hypermedia applications, special care must be taken to thoroughly test all navigational paths.

A sample application developed using RMM is shown in Figure 8, which depicts a screen from the WWW implementation of the IS handbook. The figure shows the head slice of an instance of the courses entity, containing information about the course C20.0001, the undergraduate introductory course in information systems. The map appearing at the top right of the page is obtained from the RMDM diagram. This drawing is a clickable map that can be used as an alternative means of navigation, in the spirit of Intermedia's Web views [25] and other graphic-based navigational approaches [19]. Such graphs can be constructed following spatial design principles, as discussed by Marshall and Shipman (in this issue), and are available as a by-product of the RMM methodological process. We are currently designing a suite of software tools to support the design and development of RMM-based applications [5], which we expect to use to further evaluate the RMM methodology.

Conclusion and Future Work

As demand for hypermedia products increases, there is a need to replace the current design and construction approaches, which are highly labor intensive and costly, with more efficient approaches that provide guidelines for project managers, produce standardized documentation, and give automated support for developers. Our objective in this article was to present a hypermedia design and construction methodology that addresses these issues. The proposed RMM methodology is most suited to applications that have a regular structure, especially where there is a frequent need to update the information to keep the system current. Many commercial applications, including product catalogs, electronic commerce gateways, design manuals, and interfaces to database management systems, fit this description. We believe the RMM methodology can serve as the basis for the design and development of robust hypermedia applications.

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