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# Customizing Multimedia with Multi-Trees

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## INTRODUCTION

The majority of multimedia applications rely on hypermedia technologies, such as HTML, XML, or PHP (cf. Lang, 2005, for a review on design issues of hypermedia systems). These technologies enable the presentation of any content such as entries in a digital encyclopedia or products on a company's homepage. In contrast to database queries, the hypermedia has to be navigated interactively. The navigation process frequently fails, and the user gets *lost in hyperspace*. This widespread phenomenon (Shneiderman & Plaisant, 2005) is caused mainly by an inadequate navigational design of the hypermedia. Making up an adequate navigational design becomes even more challenging if groups of users differ with respect to their knowledge of a topic's structure and if they have overlapping interests.

The navigational design comprises two components: the structure of the hypermedia and the layout of user interfaces. The latter aspect is the focus of usability studies (e.g., Falk & Sockel, 2005); whereas, the former is less frequently discussed in the literature and is given scant mention in lectures at universities or business schools. This article is mainly devoted to the former aspect, and:

- outlines the graph theoretic foundations for structuring hypermedia,
- introduces multi-trees for customizing hypermedia with respect to different user groups, and
- provides an overview of metrics to assess the navigational efforts of the user.

The approach presented herein differs from well-established human-computer interaction studies (e.g., Arroyo, Selker, & Wei, 2006), because it aims at quantifying the users' navigational efforts with respect to the structure of hypermedia systems rather than the interface design. This article presents a modeling approach, and all results are derived by a deductive analysis.

The remainder of this conceptual article is structured as follows: subsequently, the opportunities of struc-

turing hypermedia are outlined. Then components of users' navigation efforts are discussed, and metrics for the assessment of navigational burdens are presented. Afterward, advantages of multi-trees are highlighted using a numerical example. Starting from a discussion of the limitations of this approach, avenues of future research are pinpointed. The final section provides the conclusions of this study.

## STRUCTURING HYPERMEDIA

Hypermedia are networks comprising media objects (documents, pictures, films, etc.), pseudo-objects (pages for guiding the user), and links to interconnect media objects and pseudo-objects. In terms of graph theory, both media objects and pseudo-objects are nodes (or vertices) of a graph, which provide some content or navigational information for the user. The links are the edges of the graph, which enable navigation of hypermedia. Since the nodes are arbitrarily types of media (films, sounds documents, etc.), this simple organization scheme holds for many multimedia instances of our everyday life, of which the World Wide Web is clearly the most prominent.

For the design of adaptive hypermedia two types of nodes are distinguished (Brusilovsky, 2001; Muntean, 2005): navigational nodes and contents comprising nodes. If different types of media are knitted within one environment, the navigation within the media-objects has to be considered as well as the navigation between them. The subsequent considerations are restricted to the latter problem of reaching the individual media objects of interest, but do not address the complexity arising from the combination of different qualities of media objects.

An intuitive and straightforward organization would be a tree structure in which the entry node is the root and the media objects are the leaves. In this structure, all nodes that are not leaves are pseudo-objects. The Internet presents a variety of hierarchically structured organizations, such as companies and universities, al-

though virtual product catalogs could also be structured in this manner. Unfortunately, this principle allows for one, and only one, path from the entry node to each of the leaves. Moreover, hypermedia designers have to be self-disciplined, resisting any temptation to cross-link the leaves. Empirical evidence suggests that the professionalism of hypermedia designers does not hold the quality level of commercial software design (Barry & Lang, 2001). This leads to instances fraught with disadvantages with regard to (1) navigability and (2) maintenance costs.

Clearly, the tree is not the only graph structure, but one of several that might be adopted to create a hypermedia system. Subsequently, the following structures are considered:

1. **Sequence:** In this structure, the nodes can be accessed in a predefined succession. The user has no opportunity to navigate by himself or herself (e.g., a guided tour).
2. **Tree:** The nodes are hierarchically structured. Therefore, the user can navigate by choosing one from the various links emanating from his or her current position node. In order to support this navigation, the links are usually annotated with a few meaningful keywords, symbols or pictures, or “information chunks,” to provide the user with an impression of the contents in the nodes that might be reached following the particular link. Each node, with the exception of the leaves, has one or more descendant nodes, or “child nodes.” The number of child nodes equals the number of links originating from a parent node, referred to as out-degree in the graph theoretic literature. The in-degree is equal to one for all nodes of a tree, with the exception of the root node. Therefore, a maximum of one path from each node to a descendant node is possible in a tree structure. Each tree is a mapping of a particular hierarchy. Obviously, the sequence is a tree with an out-degree equal to one.
3. **Multi-Tree:** In contrast to the previously mentioned trees, the multi-tree structure allows for more than one father node in the graph. Consequently, a media object can be reached by traversing more than one distinct path of the graph. If, for instance, user groups (customers, suppliers, employees, investors, etc.) can be characterized by their interests, their read or write permissions,

or their knowledge of the structure, it is straightforward to define an access path for each user group. A multi-tree is made up of overlapping, identical branches of group-specific trees. Thus, redundancies are avoided and maintenance costs are kept at a minimum (Furnas & Zacks, 1994). Moreover, the navigational burdens of the user are reduced because they are restricted to a sub-graph. Understanding the structure of this sub-graph and developing a mental model is always easier than comprehending the complete graph (Otter & Johnson, 2000).

4. **Net:** A net is the most general form of graphs. All the topologies outlined previously are special cases of nets. If all nodes of a net are linked to one another, the user benefits from maximal flexibility, but is likely to suffer from information overload. The number of links, from which he or she has to make a choice, equals the overall number of nodes. Therefore, in a net of  $n$  nodes, the user has to process  $n-1$  information chunks in the absence of any support provided by a hierarchical structure. Usually, only some index nodes or site maps are linked to all, or almost all, the other nodes. However, even these pseudo-objects, for the most part, provide the user with a hierarchical, or at least alphabetical, order of the linked nodes. Of course, fully connected net structures are not adopted to interconnect multimedia objects, but net structures commonly arise by adding links in an unstructured manner during the creation, extension, or updating of hypermedia.

McGuffin and Schraefel (2004) provide an overview of further mathematical topologies for structuring hypermedia.

## NAVIGATION EFFORTS

For the assessment of already existing hypermedia, a variety of techniques, including cognitive walk-through, action analysis, or think-aloud, has been proposed (Holzinger, 2005). Commonly used metrics are (1) search time spent to assess a media object when starting from the entry node, (2) the number of key strokes needed in assessing the media object, (3) the retention time in the nodes, and (4) the number of recurrences to a particular node (Card, Moran, & Newell, 1983).

Navigational errors are utilized for quantifying the degree to which the user gets *lost in hyperspace*. Here, the number of rings (traversing back to the starting point), loops (rings embracing no smaller rings), and spikes (exploring a link and returning immediately) in the navigation path are considered.

These metrics provide evidence on the need for restructuring already existing hypermedia, but are of no use in the phase of establishing the basic design before implementation is made. In this situation, we need criteria to assess competing structures prior to the implementation. For this purpose, we have to consider the movement efforts of the users as well as their efforts of assessing all possible links before choosing which one to follow next.

Metrics for the movement efforts are (De Bra, 2000; Herder, 2002):

- **Distance** is given by the *diameter* of the graph. It is the maximum of all the shortest paths linking ordered pairs of nodes. Considering the diameter is a worst-case scenario.
- **Compactness** is given by the average length of the shortest paths between two nodes of the graph.
- **Complexity** is given by the ratio of edges to nodes of a graph.
- **Linearity** is given by the number of cycles and the lengths of the longest cycle.

Moreover, we have to account for the users' assessment efforts (Feldmann & Wagner, 2003):

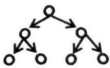
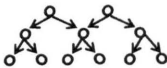

- **Out-degree** is given by the number of edges leaving a node.
- **Cumulative number** is the number of links that have been evaluated while traversing hypermedia.

Table 1 provides an overview of both users' movement and users' assessment efforts in the various graph topologies, with  $k$  denoting the number of nodes connected in the graph.  $\bar{a}$  is the out-degree and assumed to be constant, for simplification.

The overview in Table 1 considers general types of graphs, rather than particular instances. Thus, the movement efforts are expressed by means of an interval [minimal diameter, maximal diameter] as a function of the parameters  $\bar{a}$  and  $n$ .  $\lfloor x \rfloor$  is a mapping to the largest integer that is less than, or equal to, the argument  $a$ . With the exception of the net, the nodes with no predecessor nodes are the entry nodes. In the net, every node can be an entry node.

If the worst comes to the worst, the user has to traverse all the links of a sequence, but he or she is spared all assessment efforts. Although the tree and the sequence embrace an equal number of links, the navigational effort required differs significantly. In the tree,

Table 1. Comparison of graph topologies with respect to the navigational efforts (adapted from Feldmann & Wagner, 2003, p. 11)

Topology	Sequence	Tree	Multi-tree	Net
Characteristic	Succession	Hierarchy	Multiple hierarchies	Connectivity
Example	$0 \rightarrow 0 \rightarrow 0 \rightarrow 0 \rightarrow 0$			
(maximal) complexity	$\frac{n-1}{n}$	$\frac{n-1}{n}$	$\frac{n^2 - n \pmod{2}}{4n}$	$\frac{(n-1)}{2}$
Diameter $d$	$n - 1$	$\lceil \log_{\bar{a}}(n) \rceil; (n-1)$	$\left\lceil \log_{\bar{a}} \left( \frac{1}{b} (n+u) \right) \right\rceil; (n-1)$	$[1; n - 1]$
(maximal) number of links to be assessed	0	$d\bar{a}$	$d\bar{a}$	$n - 1$

Legend:  $\circ$  nodes;  $n$  number of nodes;  $\rightarrow$  directed link;  
 — undirected link;  $b$  number of entry nodes;  $\bar{a}$  out-degree;  
 $u$  number of shared nodes in a multi-tree.

alternatives have to be evaluated, but the search path can be abridged substantially. A perfectly balanced tree with a constant out-degree,  $\bar{a}$ , minimizes the diameter. Obviously, the sequence with its out-degree equal to 1 maximizes the diameter. The multi-tree might have  $b > 1$  entry nodes because it is made up of overlaying trees. A node is said to be overlaid if it can be reached via more than one path in the graph.

Comparing the sequence as one extreme with the net as the other extreme, Feldmann and Wagner (2003) pinpoint a contradiction of the two components of navigational efforts. The more flexible the navigation in the graph becomes, the lower are the movement efforts and the higher are the assessment efforts.

## MULTI-TREES

Multi-trees overcome the contradiction of the navigational efforts outlined previously by meeting two principles.

### Hierarchical Order

The length of the path to reach a node is reduced by increasing the out-degree,  $\bar{a}$ . Consequently, the depth of a tree or a multi-tree decreases. Starting from a net structure with full connectivity, the assessment can be reduced by hierarchical ordering. The alleviation of assessment efforts is given by  $e = k - \lfloor \log_a(n) \rfloor \bar{a} - 1$ . Thus, we can appraise changes of the structure *a priori* of the implementation. Feldmann and Wagner (2003) consider, for instance,  $n = 500$  objects. A binary tree, ( $\bar{a} = 2$ ), has a depth of  $t = 8$ . The user has to choose eight times between two alternatives and, therefore, six assessments are necessary. The alleviation of assessment efforts is  $e = 483$ . A net with full connectivity embracing 500 nodes has  $n(n-1)/2 = 124,750$  edges and maximizes the complexity to 249.5. A multi-tree with 500 nodes has a maximal complexity equal to 125 because of its hierarchical order.

### Hiding Irrelevant Nodes

In a tree, a user has access to all the nodes, regardless of his or her particular interests. If the constant out-degree is  $\bar{a} = 2$ , and two entry nodes are available (as sketched in the example in Table 1), and the overlapping is on the

second hierarchy level, the multi-tree consists of three branches. Nodes of the left branch are accessible from the left entry node only; nodes of the right branch are accessible from the right entry node only, but nodes of the middle branch are accessible from both entry nodes. Extending this structure to Feldmann and Wagner's numerical example leads to 166 nodes in each of the branches. Because one of the three branches is hidden from the users, the complexity reduces to 0.664, but the diameter still equals 8.

An additional advantage is the ability to cope with the diamonds in the graph structure (Furnas & Zacks, 1994). A diamond is a feature of a directed graph with at least two distinct paths from a node to a succeeding node. Such structures are frequently desired. For instance, one might allow the user to browse the Web site of an organization with respect to its divisions and subdivisions to find the contact details of a given person. However, browsing with respect to sides and locations might be a promising strategy as well, if the user knows the city in which the person is working. This can be enabled by structuring with multi-trees, but not with alternative structures such as hyperbolic trees (Herman, Melancon, & Marshall, 2000).

## FUTURE DEVELOPMENTS

The most pressing challenge of further research activities is the shift from the deductive analysis of general structures to empirical investigations of instances by means of human-computer interaction experiments. These experiments have to cope with different abilities of the respondents and the interaction of impacts of structures with impacts of interface designs (McEneaney, 2001; Muntean, 2005). The selection of suited instances has to be systematized, and benchmarks need to be established.

Moreover, this study assumes all nodes to be of the same quality. Different types of hypermedia objects are likely to bring a higher degree of complexity to the navigation problem.

Additionally, the progress of related disciplines, particularly in the field of adaptive hypermedia designs in conjunction with pattern recognition algorithms, might enable us to alter the structure of individual branches of trees or multi-trees automatically, when the user groups' preferences or interests change.

A prototypic software to create and browse multi-tree-structured hypermedia is the DYMU-Tree by Feldmann and Wagner (2003). The more sophisticated TreeJuxtaposer by Munzner, Guimbretière, Tasiran, Zhang, and Zhou (2003) extends the multi-tree principle to a distortion-based visualization of graphs. Up to now, the implementation of the multi-tree-based navigation is restricted to prototypic applications. The integration of the multi-tree concept in authoring tools will offer both a competitive advantage for the vendors of the tool and an opportunity for testing the theoretical concept in practice.

## CONCLUSIONS

Multi-trees have been shown to be appropriate for structuring hypermedia because they overcome the contradiction between the assessment burdens and the movement burdens. In general, the complexity of a graph can be reduced using multi-trees. Moreover, multi-trees allow for adjusting hypermedia to the needs and preferences of distinct user groups and, therefore, correspond to the demand for personalization and customization of hypermedia design. The major advantage of the approach presented herein is the opportunity for an assessment of navigational burdens, prior to implementation.

More generally, the perspective of navigational design is broadened from interface layout, as discussed in the classical human-computer interaction studies, to a perspective comprising the structure and the needs of different user groups.

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## KEY TERMS

**Hypermedia:** Hypertexts enriched with multimedia objects (such as audio, video, flash plug-in, etc.) to create a generally non-linear medium of information.

**Information Chunks:** Chunking provides the readers with comprehensive presentation of the topic or contents of a node.

**Mental Model:** Representations of real or imaginary structure in the human mind enabling orientation as well as goal orientated actions and movements.

**Multi-Tree:** Overlapping trees that allow for more than one path connecting two nodes.

**Navigation Process:** Exploring a hypermedia interactively to find information, product or service offers, or just for entertainment.

**Tree:** Graph in which any two nodes are connected by exactly one path.