THE PHIDIAS HYPERCAD SYSTEM: 
EXTENDING CAD WITH HYPERMEDIA

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ABSTRACT

PHIDIAS is software which integrates computer-aided design graphics with hypermedia to create a hypermedia CAD—or hyperCAD—system. PHIDIAS allows architects to develop building form while having immediate and nearly effortless access to a rich store of textual, numerical, and graphical information. This information access can make a wide variety of design literature and research findings available to architects in a way and at a time that they can easily use it. Thus, PHIDIAS is intended to help bridge the gap between architectural research and practice.

INTRODUCTION

This article gives an overview of the PHIDIAS software system, which is named after the Greek sculptor who was in charge of all artistic and architectural works in Athens at the time the Parthenon was built. PHIDIAS (PHI-based Design Intelligence Augmentation System) integrates computer-aided design graphics with hypermedia to create a hypermedia CAD—or hyperCAD—system. PHIDIAS is the first hypermedia system to support CAD graphics, and it allows a fundamentally new approach to supporting the design process with computers. In particular, PHIDIAS allows the architect to work on the development of building form while having immediate and nearly effortless access to a rich store of design information. This includes textual information, numerical data and libraries of graphic materials. The graphics can include catalogs of precedents, diagrams, architectural details, and a vast collection of "symbols" to use as building blocks for creating architectural form. A central reason for providing this computer-based information access is to make a wide variety of design literature and research findings available to architects in a way and at a time that they can easily use and evaluate it. Thus, PHIDIAS is intended to help bridge the gap between research and practice.

After the introduction, we give a brief overview and history of hypermedia, and then a discussion of the issue-based approach to design. After this presentation of background material, we describe the PHIDIAS system in some detail. The final section suggests possibilities for future work and conclusions about the work we have presented.
HYPERMEDIA: A DIFFERENT APPROACH TO INFORMATION MANAGEMENT

Basic Concepts of Hypermedia

Hypermedia is software that allows its users to explore and create non-linear databases of text, graphics, sound, or any other type of data. The term non-linear is used to distinguish the structure of a hypermedia database from the linear--i.e. sequential--structure of a normal document such as a novel, a word processor file, or a video tape. Hypermedia databases have a graph structure of nodes connected by labelled links. The nodes contain pieces of text, graphics, or other data, and the links represent relationships between the nodes. A single hypermedia database is called a hypertext document. A crucial capability of almost all hypermedia systems is that of navigation. Navigation through a hypertext document is most often the process of following links from displayed data to related data by pointing and clicking with a mouse. Many hypermedia systems augment this embedded icon style of navigation with query languages or browsers. A browser is a mouse-sensitive visual representation of the node-and-link structure of the hypertext document. Clicking with a mouse on a node in the browser results in display of the contents of that node.

Origins of Hypermedia

The basic concepts of hypermedia were first articulated by Vannevar Bush in an article entitled "As We May Think" (Bush 1945). In this article Bush proposed the development of what he called a memex. This was to be a machine which could be used to organize large amounts of text and pictures from various sources into a network of cross-referenced chunks of information. The nodes in the network would be connected by relationships representing associative links.

The first person to implement something like the memex on a computer was Douglas Engelbart. This software, known as NLS/AUGMENT, "was targeted particularly toward the core work of professionals engaged in 'tough knowledge work'--e.g. planning, analyzing and designing in complex problem domains" (Engelbart 1984). As part of this work Engelbart also invented the mouse and the word processor.

The terms hypertext and hypermedia were invented by Ted Nelson in describing his Xanadu project. Xanadu, which Nelson began in the 1960's, is an ongoing project with the goal of making all the world's literature available for search by computer. When completed Xanadu will allow its users to navigate through a vast network of related passages in books, articles and other literature.

AutoDesk, the makers of AutoCAD, have purchased controlling interest in Xanadu and plan to market it soon. When combined with AutoCAD, Xanadu will allow the linking of AutoCAD drawings with each other and with an enormous range of external types of information, such as spreadsheets and databases.
RECENTLY-DEVELOPED HYPERMEDIA SYSTEMS

The development of most current hypermedia systems began in the early to mid 1980's (Halasz 1988). Among these are Intermedia (Garrett, Smith, Meyrowitz 1986), Hyperties (Schneiderman 1987), NoteCards (Halasz, Moran, Trigg 1987), and Neptune (Deliale, Schwartz 1986). HyperCard is by far the most widely known of the current systems. While it is a fascinating and powerful piece of software, it does not have all the functionality of the more advanced systems and thus should not be taken as representative of hypermedia.

Horst Rittel developed an approach to the structuring of design information and processes which he called IBIS, for Issue-based Information System (Kunz, Rittel 1970). This has become the basis for a number of independently developed hypermedia systems, including gIBIS, MIKROPLIS, JANUS and PHIDIAS.

The gIBIS (graphical IBIS) system (Conklin, Begeman 1988) has a graphical interface including a browser and a variety of information updating and retrieval features. gIBIS runs on a local area network and allows multiple users to work simultaneously on the same issue-based hyperdocument.

MIKROPLIS (McCall 1989) is a text-only system for creating and browsing through IBIS hyperdocuments. It is the direct ancestor of the PHIDIAS system. In fact, PHIDIAS is actually a superset of the MIKROPLIS software. The former was built from the latter by adding a graphical user interface, a vector-graphics subsystem and several other enhancements.

The JANUS system (McCall, Morch, Fischer 1990) was the immediate predecessor of PHIDIAS. Although JANUS is implemented in an entirely different hardware and software environment, it resembles PHIDIAS in its combination of CAD with IBIS hypertext. JANUS accomplishes this by coupling separate CAD and hypertext systems using a knowledge-based approach. PHIDIAS, by contrast, makes CAD a part of a general hypermedia system and integrates graphics and alphanumeric data in a common framework.

ISSUE-BASED SUPPORT FOR DESIGN

PHIDIAS is the latest stage of a 13-year effort aimed at developing support for the PHI (McCall 1979, 1987) approach to IBIS. To understand PHIDIAS it is necessary to understand the overall goals of this effort. These goals originate in Horst Rittel's call in the early 1970's for an "argumentative approach" to design. This approach seeks to improve design by improving the designer's reasoning rather than automating it. Rittel advocated the development of computer systems which functioned as "natural intelligence amplifiers". Such systems should function, he said, like eyeglasses: helping you to see, rather than seeing for you.

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1 For a good survey of the systems coming out of this period, as well as the first generation systems, see Jeff Conklin's article "Hypertext: an Introduction and Survey" (Conklin 1987).
The IBIS Method

To implement the argumentative approach Rittel developed the IBIS (Issue-Based Information System) method for documenting design discussion. IBIS views design as centering around the deliberation of issues. Issues are design questions and deliberation is the process of arguing the pros and cons of proposed answers to the issues. During deliberation, issues are raised, answers proposed, and arguments are given for or against the various answers or other arguments. An issue is resolved by selecting answers on the basis of the argumentation. In IBIS, as originally proposed by Rittel, the separate issue discussions are linked together by a complex web—i.e., a "spaghetti structure"—of relationships.

The PHI Approach to IBIS

PHI (Procedural Hierarchy of Issues) (McCall 1979, 1987) extends IBIS by broadening the scope of the concept issue and by altering the inter-issue structure. In Rittel's IBIS, an issue is a design question which is deliberated; in PHI every design question is an issue, whether deliberated or not. PHI dispenses with the various inter-issue relationships of Rittel's IBIS and uses instead only relationships indicating dependencies between issues. The most important of these is the serve relationship, which indicates that the resolution of one issue influences the resolution of another. PHI concentrates on one particular type of serve relationship called the subissue-of relationship, defined as follows:

Issue A is a subissue of issue B if A serves B—i.e., the resolution of A influences the resolution of B—and B is raised before A.

In PHI, design is represented as a tree-like structure of nested issue-resolution processes. Each project has a single root issue. Issues are generated top-down by recursively decomposing issues into subissues.

THE PHIDIAS HYPERCAD SYSTEM: MERGING CAD AND HYPERMEDIA

Figure 1 shows the basic screen layout of the PHIDIAS system. The system has its own specially-designed graphical user interface supporting pull-down menus, tiled and overlaid windows, dialogue boxes, buttons, etc. As the figure shows, the basic layout is a split screen with graphics in one half and text in the other. The rationale for this layout comes from the theoretical foundations of the PHIDIAS project.

Theoretical Foundations

In addition to being based on Rittel's argumentative approach to design, PHIDIAS implements concepts proposed by Donald Schoen (Schoen 1983). Schoen sees the "language" which designers use to express their ideas as an intermixing of verbal and graphic expression. PHIDIAS therefore provides a framework for integrating vector graphics and text.
Schoen also sees design as reflection-in-action, a process involving continual alternation between graphic-based "action" and verbal/conceptual "reflection". To apply Schoen’s theory we further operationalized these concepts by dividing design into construction and argumentation. Construction is the kind of action involved in shaping the form of the solution—e.g., with a graphical CAD system. Argumentation is the kind of reflection dealt with in PHI. PHIDIAS supports action in the form of construction of vector-graphic objects, reflection in the form of PHI-based argumentation, and the rapid alternation between these which is required for reflection-in-action (McCall, Fischer, Morch 1990).

Support for Construction

Library of Building Blocks. PHIDIAS supports the construction of form using domain-specific construction kits (Fischer, McCall, Morch 1989) each consisting of building blocks for creating a particular type of designed object—e.g., a kitchen (Figure 1). Each building block corresponds to a node in the hyperdocument. Building blocks are assembled to construct complex objects—such as kitchens—which are in turn nodes in the hyperdocument. This assembly is done using a direct-manipulation-style graphics editor of the type which has become fairly standard in CAD: items are selected from the construction palette by mouse and dragged into the construction area, where they can be rotated, scaled and further translated.

PHIDIAS can be used to manage a large number of construction kits each with a large number of building blocks. New construction kits can be built using graphic objects constructed with the editor. In fact, there is no difference between the "symbols" used for construction and the objects
constructed using symbols. All are nodes in the hypermedia database. Since building blocks can be assembled into more complex building blocks, the system can in principle "bootstrap" itself to ever-higher levels of construction complexity.

Library of Precedents. The information management capabilities of PHIDIAS can be used to organize and retrieve both building blocks and constructed objects—since, in fact, they are represented in the same way within the hypertext document. This allows architects to store their previous projects within the system. These can be called up at a moment’s notice whenever needed. The system can also store a large number of design precedents, which can also be called up at any time.

There are two basic reasons for users to retrieve such complete designs while designing. One is to study them as a source of ideas for their current designs. The other is to "cannibalize" these complete designs, i.e., to incorporate parts of them into current designs. PHIDIAS has been specially designed to support the re-use and redesign of partial and whole design solutions from architectural precedents or from the designer's own previous projects.

Shape Grammars. One consequence of the PHIDIAS strategy is that it easily supports rule-based construction using shape grammars (Stiny 1980). As Stiny, Mitchell, Flemming and others have repeatedly demonstrated, this allows the generation of forms which appear to capture essential features of certain architectural styles. What is seldom mentioned is that they can also be used to generate realistic plant forms and topographic scenery as well as other fractal images, as in Figure 2. Shape grammars harness the power of exponential growth to allow the designer to create images having hundreds or thousands of polylines with only a few simple steps. Thus, for example, six simple mouse-based actions were sufficient to create the more than 1100 polylines in Figure 2.

Support for Argumentation

Argumentation with PHI. PHIDIAS has been especially designed to support the creation and exploration of PHI issue bases. In PHIDIAS, each and every issue, answer and argument is a node in the issue base. Displays of sections of the issue base are created by clustering textual items on the screen. This clustering is accomplished using the PHIDIAS Query Language (PHIQL) and the clusters are displayed in outline format. Its outline orientation makes the textual part of PHIDIAS looks superficially similar to an outline processor. But unlike outline processors, PHIDIAS uses labelled links and allows many thousands of items to be linked. Many types of clustered displays of the issue base are possible. The two most frequently used are a display of the quasi-hierarchical structure of issues (Figure 3a) and an issue with its answer and arguments (Figure 1).

Navigation is accomplished in PHIDIAS by pointing to an on-screen text and then indicating which outgoing links to use. With navigation the user is able to explore and create potentially vast issue bases. To create new nodes users need only point to the existing node they wish to link to the new node to, indicate the type of link to be used, then enter the text or graphics which constitutes the contents of the new node.
Figure 2. Fractal generated using shape grammar.

*Re-usable Issue Bases.* To facilitate use of PHI during design we have found it useful to create re-usable issue bases for particular problem domains—such as kitchen design. In general, it is far easier for a designer to modify a pre-existing issue base to fit a problem than to create an issue base from scratch. In addition, the pre-existing issue base can contain a wide variety of useful information of which the designer might otherwise be unaware.

For sufficiently complex problem domains, issue bases can be expected to be up to (the equivalent of) several thousand single-spaced types pages in length. Our current, experimental issue bases are still much smaller—the largest being just 500 single-spaced pages in length. We currently have a half dozen such issue bases in various sizes and stages of completion. These cover a number of design domains, including the design of dwellings, housing and small-scale commercial architecture.

*Virtual Structures.* A reasonably-sized issue base in PHIDIAS contains a great deal of useful information about a design domain. The problem is to make sure that the designer gets the right information at the right time, i.e., the information which serves the designer’s current purposes. This is accomplished in large part through the use of the above-mentioned serve relationships between issues in the PHI approach to IBIS. But this is not enough, for these relationships are, in a re-usable issue base, determined before the design task begins. In actuality, what is relevant to the design project changes with each decision the designer makes. Some way is therefore needed for the system to take into account the decisions the designer makes and their consequences for the changing relevance of information.
For example, imagine that the project is to design a kitchen using an issue base containing design information for kitchens in general (Figure 3a). There is an issue "What functional areas should be included in the kitchen?", and one of the candidate answers is "an eating area". If the designer makes the decision to reject this answer, then the issue, "What should the design of the eating area be?" should, in effect, disappear from the issue base (Figure 3b).

PHIDIAS uses a hypermedia-based computational mechanism known as virtual structures (Halasz 1988) to provide this automatic restructuring of the hyperdocument needed to deal with cases such as that in the above example. Virtual structures are queries, as opposed to text or graphics, placed at the nodes of the hypermedia database. Instead of displaying the contents of a virtual structure node, PHIDIAS retrieves information satisfying the query contained in the node. This allows the display of information to be contingent on the contents of the hyperdocument. In terms of the eating area example given above, the display of the issue "What should the design of the eating area be?" would be suppressed if the designer enters "reject" in response to the answer suggesting inclusion of an eating area as one of the functional areas of the kitchen (Figure 3b).

![Figure 3a. Unpruned issue base.](image_url)

![Figure 3b. Pruned issue base.](image_url)

Information Management

**PHIDIAS as a Generalized DBMS.** While designed to support IBIS, especially in its PHI variant, PHIDIAS is also a generalized database management system. It can thus be used for non-IBIS data in addition to or instead of IBIS. PHIDIAS has a highly English-like query language, called PHIQL (PHIDIAS Query Language), which allows information retrieval both by structure and by content. Structure-based retrieval exploits the semantic relationships—i.e., labels of links—
between nodes in the hyperdocument. Content-based retrieval includes both substring search and key-term search—keyword, author, date, etc.

PHIDIAS does not impose limits on the size of its data objects. The graphics can contain an arbitrary number of vector-graphic objects and polylines. The alphanumeric items can range in size from a single character to many pages in length. Clustered displays ranging from a single node to tens of thousands of nodes can be created by simple PHIQL queries. Maximum size and number of nodes is only limited by the amount of disk storage and/or maximum file size allowed by the operating system.

Graphical clusters. One important capability of CAD systems is that of displaying groups of graphic objects in layers, which are the analogs of the draftsman’s acetate overlays. Layers provide two major types of functionality for CAD. First, they permit a user to select subsets of the total drawing for display and manipulation. Second, they attach semantic meaning (a number or name) to images and/or groups of images. As originally conceived, however, layers are static, "flat" structures and are insufficiently flexible for use in support of design.

We believe that hypermedia’s intrinsic network structure provides a more powerful and natural means for creating clustered displays of vector graphic objects than layers provide. PHIDIAS implements hypermedia grouping of vector graphic objects through the facility of graphical clustering. This clustering goes beyond the functionality of layers in two ways. First, it explicitly represents positional and semantic relationships between graphic objects. For example, a sink can "belong to" a specific countertop, which itself "belongs to" a particular kitchen. Also, a stove top could "belong to" this countertop. Second, graphical clustering provides a natural and powerful method for displaying subsets of graphic objects in a large number and variety of ad hoc combinations. This is done through queries in PHIQL. For example, a display of the kitchen countertop and sink from Figure 1 can be produced by the query "find kitchen 101 with countertop with sink and cabinets and stove." However, the entire kitchen could be easily shown by simply modifying the query to read "find kitchen 101 with all elements".

Non-arguementative alphanumeric data. Considerable effort has been expended by a number of companies to couple CAD packages to database management systems. PHIDIAS already has such functionality in place due to the uniform structuring principle of hypermedia, in which each node is accessed in the same way regardless of its data type. This allows the inclusion of much alphanumeric data which is not issue-based—such as cost information, physical properties, constraint parameters, and so forth. PHIDIAS has much of the functionality found in commercial database management systems, including a query language and sorted displays. It can thus be used to manage a wide variety of databases. In fact, creation of databases with PHIDIAS is generally far easier than with most database systems.

Connecting Graphics and Text

Connecting Construction and Argumentation. PHI issue bases contain information relevant to construction. But our experience with users of previous PHI hypermedia systems has shown that this information is unlikely to be used unless special measures are taken to tie its retrieval to construction acts. In particular, it must be possible to immediately retrieve just that
argumentative information which is relevant to the current construction task. The system must know both the construction act the designer is currently engaged in and the precise section of the hyperdocument where textual information relevant to this task is to be found.

We have implemented this functionality in PHIDIAS by allowing mouse button clicks during construction to trigger, i.e., execute, retrieval of relevant issue-based information. Certain construction activities can be seen as implicit requests for information. When selecting a building block from the construction kit palette the designer should get information for deciding which item of a particular type to choose. For example, in PHIDIAS, when selecting from a palette of different refrigerators, a mouse click on the "fridge" button will provide the deliberative information on the issue "What type of refrigerator should be used?" (Figure 1). A mouse click on a particular refrigerator in the palette will give just the argumentation on that type of refrigerator. Once a refrigerator has been selected from the construction palette, a button click will then retrieve argumentative information on where to place it (Figure 4). The information for repositioning an object already in the construction area can also be retrieved by clicking on that object. In all cases, once information has been delivered, the PHI relationships provide means for navigation into deeper levels of the issue base.

![Figure 4. Issue-based information for location of refrigerator.](image)

*Annotating Graphics and Illustrating Text.* Hypermedia clustering permits textual information to be directly linked to graphic objects and vice versa. This allows text to be linked to vector graphic images as annotation. It also allows graphics—such as diagrams—to be linked to text as illustration. Thus, for example, a graphic image can illustrate a portion of an issue base. Conversely, an argumentative discussion can center around and refer to a "drawing." Many other uses for this linking of text and graphics are possible.
CONCLUSIONS AND FUTURE WORK

No CAD system for architectural design can be adequate without full 3-dimensional capabilities. The current version of PHIDIAS has 2-dimensional graphics only to allow us to concentrate on the problems of integrating text and graphics. We have been working for some time on the development of a 3-D graphics subsystem to add to PHIDIAS. In fact, the current version of PHIDIAS uses a 3-D data structure but only uses 2 of the 3 dimensions. We expect to have 3-D capabilities integrated into PHIDIAS within the next year.

In this article we have given a brief overview of PHIDIAS, the first hypermedia-based CAD--or hyperCAD--system. Hypermedia has important implications for CAD. It can provide an integrated information environment for all kinds of information of potential use in design. This includes graphical, textual and numerical information and all combinations of these. This has important implications for supporting creation of CAD graphics, and also for supporting the argumentative aspects of design thinking. It also provides ways of connecting these types of information to what designers do while they draw. In particular, it supports Schoen's concept of reflection-in-action and his associated concept of the language of design as an intertwining of graphic and verbal expression. This in turn provides a natural framework for bringing a large amount and variety of information to bear on the development of architectural form. PHIDIAS thus constitutes a vehicle for integrating many types of design research--not just CAD research--into design practice.

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REFERENCES


