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A conceptual model for a software interface between designers and computers

Sadler, William Edward, Jr., Ph.D.
The Ohio State University, 1991
A CONCEPTUAL MODEL FOR A SOFTWARE INTERFACE BETWEEN
DESIGNERS AND COMPUTERS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Doctor of
Philosophy In the Graduate School of The Ohio State University

By

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****

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Chapter I

Introduction

A. Overview

Computer graphic representation and visualization of three-dimensional form have made significant advances in recent years. The advances allow for new methods and increased speed for rendering object geometry and associated attributes. Despite the potential of these powerful computing systems, an interface for the designer is still being resolved. The creation of such an interface is no trivial task.

Several reasons account for the slow development of a usable interface. Design processes are only partially formalized and are poorly understood. Science is only beginning to reveal knowledge about cognitive activities that relate to the creation of objects. Object generation can be viewed as a mixture of rational and emotional activity. External references and processes such as historical knowledge, understanding social needs, spatial constraints, and manufacturing limitations impact the internal cognitive action. Some design methodologists suggest that step-by-step, clearly articulated routines or strategies add to the quality of the creative activity. Others suggest that lateral networks contribute to a more satisfying visual result by focusing on problem resolution strategies. It is reasoned that these lateral networks of connected design activities and information enable designers to achieve results
by relating various aspects of the problem simultaneously. Gathering and managing knowledge about a visual design problem, an understanding of the medium in which an object will be realized, and a clear perspective about the context in which the object will be interpreted, provide a significant framework for designer-computer interface development.

Computers can augment the human design skills of managing knowledge. Skills of direction and organization might well supplant those hand skills that have been viewed as essential in sketching and drawing, especially the careful translation of three dimensional objects onto a two dimensional surface, such as a drawing.

The human ability to develop tools to augment natural capability and native skill level is well documented. A cadre of issues needs to be addressed as computational tools begin to play a significant role in assisting the designer. The rapid entry of complex object geometry must be facilitated with better computer data generation techniques.

A structure which provides for a close, knowledgeable interaction between the designer and the computer is described as a conceptual model in this study. The conceptual model is a plan designed to be useful in future systems implementation. The conceptual model is synthesized from a study of patterns of design activities. Association is made between those design activities and the computer interface and computer graphic capabilities. Additional problems relative to computing and designing are described to provide a better understanding of this area. This increased understanding could lead to additional future resolution.
First, the study addresses the concerns for the individual designer. It examines the relationship of computing to approaches used in design activities. Also addressed is how the computer would be used by the designer. A number of user-centered mental models or working patterns are discussed.

This study continues by examining the value of tools used in computing and by considering possible relationships at the interface with the cognitive styles of designers and the type of problems being resolved. The conceptual model is further developed by presenting the knowledge designers and other visual workers need to better understand the software requirements of a designer-computer interface.

In the conceptual model, new software tools which have been developed in computer science will significantly improve both the interface and the flexibility and scope of computer systems. The type of display feedback that seems appropriate in helping the designer realize more satisfying objects is addressed by providing an electronic simulation, solution focused "sand box" or "test bed" for creating three dimensional form.

The study examines current trends in interface design, such as the structuring of tools and visual feedback. Some interface tools are mimetic of traditional methods used by designers. The term "metaphors" is being used in commercial software programs to describe the likenesses of real world conditions or situations with software capabilities. These metaphors include painting, sketching, additive sculpting, subtractive sculpting, and turning material on a lathe. Designers try to use these software and hardware tools with varying degrees of success.
When or where the computer should be used as an effective medium for spurring the development and communication of ideas leading to objects or artifacts is still a question. Ultimately the answer will be determined by functional tests, economics, users, and management. As a step towards understanding these factors, this model is meant to describe and facilitate the development of an appropriate software interface for design.

B. Definitions and Descriptions

The cognitive and physical action required to form or shape the physical characteristics of a developing artifact is called form-giving.

The object is a form or shape. The goal of much design activity is to develop a useful object. The result of the design activity is a physical world "real" object or artifact. The object can be simulated as an image. This image may also be a symbol representing various interim resolutions as the designer develops the final artifact. The simulation is represented as a code that can be processed by the computer. The simulation of the artifact is given structure as a geometric representation and specified by an ordered Cartesian coordinates or other mathematical system. The geometry is then represented by a data structure that can be transformed and manipulated. An example of such a transformation would be a need to compress the data to streamline processes and facilitate storage. The object data is stored in its simplest complete geometrical form. The "virtual" object exists only in the computed form and is realized as an image through computer graphics techniques. This virtual object can be compared with the "real" object or artifact it simulates.

The object may have meaning as a symbol by its appearance. The designer may use this symbolism to transmit the intended object qualities to the
user or observer. The intent of the designer may be conveyed through the characteristics exhibited in the artifact. For instance, a red button on the front of a power saw is designed to mean "emergency off switch". The artifact then has semantic elements that may be revealed through criticism. It may be the intent of the designer to use these semantics to help the user or observer understand how the object is meant to be used. The symbolism that is used is very dependent on the relationship between the object and the culture or local sub-culture, or even the individual using or viewing the object. Only a pattern of understanding may occur and not a general consensus. A variety of aesthetic resolutions will be desirable to satisfy a variety of tastes.

The context is the space surrounding the object, the time frame in which the object is viewed or used, and other objects in that space that may affect the object. This space and those surrounding objects may represent a physical change in understanding the object's intended use or meaning. The context may evoke a change in intended behavioral or emotional responses as the symbolism of the object is interpreted by the user or viewer.

The attributes are physical characteristics or descriptions that describe the object, such as geometry, color, texture, opacity and reflectance, as well as interpreted characteristics that might be assigned intentionally by the designer or other individual observer of the object.

The tool is understood to be an object, procedure, or operator that aids in the performance of an action, such as the creation or manipulation of another object. Some attributes of the resulting object might be echoed in or be affected by the tool.
The user is the designer working in the system environment. The user is a term that connotes a passive state, where an individual participates in computing as a harvester, a user of software and hardware resulting in work accomplished in a domain often unrelated to computing. The user in this study is moved into a realm of being informed and contributing to the computing environment. The use of the term user begins to connote a designer who is also a "planner" or "programmer". This designer may use meta-language such as graphic symbols and the image of the object at various levels of abstraction, or a more conventional programming language to cause change in the current state of the software system. The user may also be a participant by specifying portions of the system through collaborative work with professional programmers, software developers, and computer scientists. This working network and designer specification allows for a variety of configurations and conditions as an object and its context is being simulated.

The software interface is the portion of the computing system environment which provides a useful platform for the user to exchange information with the machine. The designer instructs the machine what to do. Typically, it is expected that the computer carries out the instruction through application software or software that is task specific. The computer has to have been programmed to do what the designer requests. There may be cases, however, where artificial intelligence uses heuristics or applied rules and "learning" to help program the machine or redo programming that may cause unpredictable but reasonable results.

The designer expects a result from the computer. A return of information that is needed, a computer graphic image, or even a questioning
strategy as feedback can encourage the designer to proceed with another communication. The result flows through the software interface to be formatted and returned as communication to the designer. Information that the computer has been programmed to calculate or retrieve is dependent upon design action or situation.

Special interface design programs known as user interface management systems (UIMS), tool kits, and window managers (Tock, 1990) provide the software interface designer with building blocks to use in creating input and output formats for application programs. For example, Hypercard, a Macintosh application, could be considered an "advanced user oriented" interface toolkit.

The interface often accommodates shared work between the computing system and the user and members of the user's design team or sphere of influence. It is here that an exchange of information and "ideas" occurs. The expression of the designer and the constructs of the system meet for input and output. Graphic object representation and manipulation are returned as feedback to the user. Enhancement to the system or better understanding by the user improves the function of the interface.

The medium is the substance that carries the message or the means of representing information. In design, the medium of choice has traditionally been pencil and paper. The designer sketches, makes written notes, or drafts an "idea" on the paper. The "idea" is transcribed, refined, and given "concreteness". Using a medium such as clay, cardboard, or plastic, the "ideas" are made into scale models and prototypes. These prototypes and scale models are often made to represent final objects before production.
graphics are becoming the medium of choice for some designers during portions of the communications process. Objects and contexts can be expressed in a meaningful way to the people wanting to know about the "idea", such as a client wishing to fund the "idea" or someone wishing to make or use the object.

Mental models are described by Norman and Draper (1986) as the ways in which a system is understood to work by the user. A mental model is often based on a series of metaphors that are common to the domain of the user. This model may be close to the actual functional description of the system or as an external myth representing the way a system functions totally separate from the actual working structure. The external myth consists of metaphors or likenesses of observed or reported current practices and activities. An example of this myth is "a computer paint system complete with brushes" while what is functionally happening is a sampling of the position of an input device and illuminating corresponding picture elements on the display screen.

This definition may be enhanced by a special definition of metaphor. Metaphor is used in an unusual and symbolic way. One use of metaphor is the relationship between the way the user typically addresses work (the mental model), what the user thinks the computer is doing, or the similarity to an actual working process practiced in the users' world through traditional means (the external myth) but not by presenting the physics or electronics of the computer. An example of this meaning of the term metaphor is, the illumination of picture elements on the screen of the computer is "like painting". The second use of metaphor is the symbolic interpretation of artifacts through criticism or product semantics. An example of this meaning is, the desk lamp is "like an arm holding a torch".
Language represents a structure by which a user communicates with the machine. Communication can occur through a tightly controlled syntactic code of "conventional signs". A standard syntax can be exemplified by formal symbols such as Arabic characters, standard international travel symbols, conceptual graphs, predicate calculus, or other mathematical notation.

Communication can occur without the use of a tightly structured language, but with a set of natural signs, such as "photo-realistic" computer pictures. Natural signs rely on comparisons to convey a message and may be exemplified by pictures, photographs, or other imagery that is "like" or seems to represent a meaning.

For a complete understanding to occur, both types of language are important parts of the interface display. This exchange of information occurs visually between the user and the computer based on verbal information and imagery. Various forms of presentation, representation, or symbolic code are helpful in transmitting information. Because of the primary importance of language to the development of the model, an extensive discussion of its various forms follows.

Language appropriate to problem solving not only means the use of written or spoken language, such as English, but a visual language that may represent objects, spaces, and contexts. Gombrich (1962) brings attention to "natural signs" in painting and "conventional signs" used in spoken words. He suggests that it "has become increasingly clear since the late nineteenth century that primitive art and a child use a language of symbols rather than natural signs" (p. 76). It may be argued that a child does not look at trees but is satisfied with a "conceptual" schema of a tree based on conceptual images from
previous knowledge rather than from seeing.

Gombrich continues by stressing:

what matters to us is that the correct portrait, like a useful map, is an end product on a long road through schema and correction. It is not a faithful record of a visual experience but a faithful construction of a relational model....The form of a representation cannot be divorced from its purpose and the requirements of the society in which the given visual language gains currency (p.78).

The development of understanding of formal and interpreted symbols and images and an adherence to this formalism is essential while working toward the designer's immediate goals. One major reason for approaching the problem of representation from a graphic viewpoint is that the image carries more visually concrete information. Gombrich (1962) explains how illusion can give false meaning. It is important that visual virtual models convey correct information. This may mean reducing the information to a level of abstraction where only the relevant meaning is portrayed. Reality may be distorted to improve understanding. The absence or enhancement of color, texture, or surface may permit the designer to more clearly understand particular qualities of the current design variation and those characteristic variables which are manipulated in the simulation. A static graphic image of an object can be enhanced through animation. Moving around or through the virtual object presents views of complex objects that are difficult to imagine. This additional information can be viewed by the critic or client as the object is being developed.

Several of Gombrich's examples of illusion could be countered if the
objects were represented through a three dimensional database. Even so, because the screen represents two dimensional images as a matter of course, two dimensional language conventions are needed to give impact in single instances, such as, projected perspective, atmospheric perspective, and overlapping shape. To reduce illusion, a moving animated object acts as a visual simulation or a more "natural" (in modern Western culture) visual communication of form representation.

An example of language as graphic visual representation might be the viewing, through computer graphics, of a virtual object that is projected using three point perspective and "wire frame" line drawing conventions. The problem of illusion might be reduced by the viewer's understanding of the method used in these conventions, such as picture plane projection or the attributes associated with the database represented. If an understanding of the algorithm and the parameters of viewing the object are understood, then a more conclusive understanding of the simulated object would seem to follow.

A discussion of an object changing shape or shape interpolation exemplifies how understanding is improved by combining visual language and technical methods. The interpolation of two surfaces occurs when a starting surface and a similar, but contorted, ending surface are specified. As the interpolation begins, comparisons are made between the Cartesian data of the two surfaces. The averaging of these two surfaces in various degrees reveals surfaces which differ from the original surfaces, but still have characteristics of the two original surfaces. These "in-between" forms may be referred to as numerical percentages of each.
It can be reasoned that seeing a computer graphic representation of the "in-between" geometry will cause a clearer understanding of the interim objects. Seeing a graphic image of the beginning and ending objects and only a numerical designation of an "in-between" object causes speculation as to the appearance of the "in-between" object. The visual feedback of an image of the "in-between" geometry enhances understanding of the process as well as the geometry. If the objects are extremely complex, then the numerical designation may only be confusing to the computer user. Of course, the type of interpolation and the resulting numerical description may remain the best method for technically storing the object. This matters little and is often transparent to the designer at the interface.

Different qualities might be added to the interim object by additional manipulation using visual language. One such syntactic element is the use of a sketched curve. Using an input device such as a digitizer tablet, a curve is sketched on the screen. The curve is a function designed to represent a change in the scale of the object over time. The appropriate sampling of the curve's data would be seen in the object. This concept is drawn in Figure One. (See Figure 1)
Another example is using the data from sampling the sketched curve as a function that affects the rate of change of the interpolation of the object. The magnitude of portions of the "in-between" geometry can be controlled or constricted using the parameters set by the curve.

This scaling could be done simultaneously adding constraints during the shape change interpolation. The results can be displayed as a series of
graphic images or as an animation of the change. These curves, other objects, or organized data can be used as parameters that act as mathematical influences on the original object and can be considered "tools" affecting or controlling changes in the developing object.

Language also refers to the way that designed objects are described. Written and spoken language may be used to express an idea and could, in the most inclusive sense, be considered as an aesthetic work, as in the case of poetry. This verbal expression may then form the basis for visual illustration.

Since abstract symbols can be used to compose a language (Gombrich, 1962), inspiration for form giving may come from a series of symbols, transformations, and human creativity (J. Reese, 1986). In object semantics, the meaning, or what behavior or emotion the designer intends the object to evoke, is reflected in the form of the object itself, in some cases, quite literally. For example, a telephone answering machine becomes a combination of the human ear shape and a notebook shape. The object becomes a three dimensional symbol of its own meaning. (D. Gresham, personal communication, 1988).

In the process of reviewing any representation, there is a need to deal with many abstract concepts that might be best described in a symbolic way, such as written and spoken language, visual abstract symbols (such as graphs or line images) and 'photo-realistic' imagery. The image notation of the "cubists", in expressing multiple views of geometry in a single view as a two-dimensional painting, may suggest yet other approaches to image representation.
Multiple repetitions or a "storyboard keyframe" in a single two-dimensional image could help in the understanding of an object's form. This may especially be the case if a common syntax could be developed by the designer or, in special cases, even by the uninitiated audience. An example of this developing culture is the Apple Macintosh "point and click" interface strategy. If images of a dynamic object, transforming over time, are compacted into a visual matrix as a series of static images, the object can provide a visual test for fidelity. Of course, it is important that enough screen resolution is available for viewing. Furthermore, animation of an object rotating, provides continuous feedback as changes are made. Multiple windows on a single display screen allow for simultaneous views of the object.

Other methods of visual representation might prove useful. In the past, primitive painters worked by placing flat looking objects in flat looking vistas while painters from medieval times used a hierarchy of relative size to establish object importance. These paintings were done with no regard for (or understanding of) perspective. In contrast, Eichenberger's multiple vanishing point, wide-angle perspective system (1970) takes advantage of complex projections to form a system. The still photographer who takes multiple pictures in three hundred and sixty degrees and then mounts the panorama in a flat strip can represent an interesting image which conveys information to the viewer about the entire spatial context in which the object exists. Such image arrangements can be viewed as samples of a visual syntax which is achieved through visual feedback from computer graphics.

Another dramatic visual demonstration occurs when viewing the Omnimax film system which surrounds the audience with moving images on a
curved screen. The film image is recorded with a very wide angle lens, capturing a great deal of information. The image is preserved as distorted visual code. The eye-mind is capable of deciphering the image with the help of a special projector. This curved spatial representation provides more information, containing visual clues to promote an understanding of the object. This was demonstrated at ACM-SIGGRAPH '84 (1984), in the Ominimax Theater in St Paul, Minnesota, where computer graphic works were projected on the surrounding screen. The scale of imagery and the surrounding effect created the illusion of a closer visit to virtual objects and imagined computer places through both sight and sound.

Another example of diverse visual language is three dimensional imagery. Two polarized computer generated images simulating the parallax of the eyes of the observer are prepared. If the observer wears polarized eye glasses to isolate a single image from each eye, the effect is an interpretation of volume or of three dimensional space. The parallax can be simulated using two computer generated images with slightly different viewing parameters. When this technique is multiplied and recorded on motion picture film, the result is a computer generated three dimensional movie. Using these methods, Toshiba presented such a film with three-dimensional projection at ACM-SIGGRAPH '85 (1985). Where these simulation techniques are used, management of a greater number of variables controlled by the computer result in different spatial references than traditional graphic depth cues. The scale of the objects are not just compared to the background, but are understood to be a part of the three dimensional environment of the viewer's space. If the projected image was viewed as a traditional two-dimensional film, where the
screen was the surface for viewing, the characters appeared to be much larger than when they were projected in three dimensions.

The traditional graphic visual clues of linear perspective, atmospheric perspective, and overlapping shape provided for a different interpretation of the scene than when the objects were viewed in simulated three dimensions. The result was a change in the reference. In three dimensions, less importance was placed in the interpretation of the classic two dimensional cues for showing depth, and more emphasis was placed on the interpretation of the stereo visual affect. In three dimensions, the objects appeared very close to the viewer and seemed to be just beyond arms reach. The objects or characters, when viewed without the glasses in two dimensions, seemed much larger in scale, forming very large characters because of the relative scale with the background. The scale of the objects was clearly provided, in part, through the paralax of the eyes. Thus, it seems that a more "natural" understanding of the imagery occurs when viewing the three dimensional projection.

This example points out the complexity of interpretation of visual language. The classical approaches to three dimensional representation on a two dimensional graphic surface through visual clues were simplified by the introduction of eye paralax of the stereo pairs. It suggests that a formal vocabulary of visual clues, such as an understanding of projected perspective, may be supplanted by more spatial display formats. If two dimensional graphic conventions are used to simulate three dimensional objects, then the conventions need to be understood by the observer to ensure a measure of continuity. This need for understanding parallels some aspects of written language. If information is to be viewed in a graphic form, then the visual
language needs to be addressed at the lexical, syntactic, semantic, and conceptual level.

The computer's representation of the three dimensional computer graphic uses a traceable set of conditions to establish the image from the database. These parameters, in a typical computer rendering, can be tested to ensure the image is more correct. These parameters, although limiting in terms of the way a three-dimensional model is presented to the designer, provide a syntax for model-to-image structure. Visual notation, potentially playing a major role in the future of visual form-giving, is specified as a future research topic.

It is reported that the three dimensional imagery of "artificial reality" can seem so "real" that people feel they are a part of another world. This realism might permit the direct reading of an environment by the designer. John Lasseter, who has won an Academy Award for "The Tin Toy", a computer animation, states in a New York Times report, "We can do certain things with computer animation that can't be done any other way. We can create characters that are truly three-dimensional" (Fisher, 1989).

The medium also possesses the possibility that the user or audience could be fooled by a well articulated resolution that has no possibility of a real world counterpart. This ability to trick the mind would seem useful in many instances in testing behavioral reaction to simulation. In some special cases, it would seem that language has given way to understanding through illusion. A "datasuit" covered with sensors along with special projector glasses worn on the head may be used to encircle the virtual world adventurer in computer generated three dimensional space and time.
Each (moving image) represents a three-dimensional microcosm, stored within the memory of the computer, that human operators can turn, twist and reshape all they want. When special goggles, bodysuits, and gloves are used to display and manipulate the images, those microcosms can become so real that viewers feel they have stepped through a kind of electronic looking glass into a completely artificial, computer generated world (Elmer-Dewitt, 1989, p. 65).

Visualization with computer graphics is used as a means to present scientific data. At one time, the definition of the term visualization may have only meant the mental image that is formed through some mysterious functioning of the mind, projected in a rather illusive way into consciousness. The definition supported by the visualization of scientific data, however, is related to communicating ideas in design.

Visualization is a method of computing. It transforms the symbolic (numbers) into the geometric (objects that can viewed using computer graphics) enabling researchers to see the unseen. Visualization embraces both image understanding and image synthesis; that is, it is a tool both for interpreting image data fed into a computer, and for the generating of images from complex multi-dimensional data sets (McCormick, et. al., 1987, p.3).

In some cases, difference in the use of simulation and visualization in scientific investigation and the practice of design are differentiated by the generation and interpretation of data. In a scientific investigation, the data is the result of mathematical comparisons or models. However, in the case of the designer, the data may sometimes be a result of the designer generating complex information. This information is the result of the designer's control over a number of modeling or prototyping methods and tools. The design methods and processes employed express new, created realities. The data that the designer may wish to reveal may be for the purpose of aesthetic development
and useable objects. It seems desirable that in many cases the numerical representation of the object is invisible and only the image of the object be seen by the designer during the generation of the geometry. Soon, many designers may view the design of these processes as symbiotic with the design of the resulting object.

The conversion of ideas about form-giving and the making of objects through numerical representations is a key problem area for designers. The tools that generate the geometric numerical data are difficult to use and many are not very robust. One approach to resolve such problems is to represent objects graphically as designing occurs. Adjusting numerical configurations at the base level of computer interaction is impractical. In many cases, the designer needs a higher level path for making those representations through numerical designations. Many interfaces provide this path by presenting an "external myth" formed around a "mental model". For example, a paint system represents an external myth of painting to the user while the mental model is the user painting.

A common example of a desirable relationship between designer and machine is expressed by Mumford's (1963) description of the hammer which becomes transparent to the carpenter as he or she pounds nails into wood. The effectiveness of a tool is increased by this relationship where the tool becomes a natural extension of the user's style.

Designers will need to describe tools, procedural actions, and behavioral simulations. The level at which a computer tool configuration process occurs, however, would usually be at the highest language level. (See Figure 2) This takes place in the form of visual meta-language which links
operations by pointing and clicking at icons in a sequence.

<table>
<thead>
<tr>
<th>Level</th>
<th>Language Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-level</td>
<td>procedural meta-language</td>
<td>Sim city</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(object oriented</td>
</tr>
<tr>
<td></td>
<td></td>
<td>manipulation)</td>
</tr>
<tr>
<td>Mid-level</td>
<td>programming language</td>
<td>C</td>
</tr>
<tr>
<td>Low-level</td>
<td>machine language</td>
<td>register shifts</td>
</tr>
<tr>
<td>Base level</td>
<td>activity</td>
<td>(binary math)</td>
</tr>
</tbody>
</table>

Figure 2- Pathways to base level activity

Basically, it is important for designers to understand fundamental concepts about the way the machine works yet manipulate and generate at the highest possible level. Designers may control or develop base level processes using high level language or communicate their specifications to professional programmers. However, the additional knowledge of underlying numerical manipulations seems important in order for the designer to have a basic understanding of limitations and an ability to communicate within the designer-programmer team.

Psychologists study existing and proposed changes to the interface as a decomposition of interface elements in an evolutionary fashion. An example of this is the psychological testing of the best way to represent information in menus, a metaphor employed by many current interfaces where commands are
made by selecting an item from a list or chart (Callahan, Hopkins, Schneiderman, and Weiser, 1988).

In many cases, information processing requires a more subjective relational response or input by the user. As an example, the menu metaphor would be viewed as being valid for types of interactions where a selection of information is required. However, the interface cannot be limited to predefined selections. Many types of decisions require relative positioning of information that might be better accomplished by a series of sliding scales. Thus, ranges of qualities, values, and relative actions must be represented. Complex scenarios can only be accomplished on more flexible computational interface components. For the designer, this can be accomplished using elements of the spatial interface display specified in the conceptual model. The spatial display may encourage the designer to use computer graphics as a media for fantasy, play, gaming, and simulation.

C. Art and Design

The following analysis assumes a view that there are relationships between art and design. This relationship establishes a justification for visual language in design. Design in this study is referred to in two ways. The first is a global view which is extended, implicit, and inclusive where design is an action of planning. The second is a more limited view and is an explicit, exclusive position where certain activities are proposed and a direct charge or specific action, object or context is specified. Entry is made into the working realm of the problematic portion of this study, when a specific action results in the generation of objects of visual art. The relationship of these objects and spaces with other objects in a context is also a part of the exclusive design
activity. These objects, along with spaces and contexts, then need to be interpreted by human beings.

The exclusive way of looking at design cannot be viewed in isolation. It must be analyzed in the greater context of the inclusive view. Since both views need to be expressed to facilitate clarity, the inclusive view of design is referred to as planning, while the term design or form-giving is reserved for the exclusive view. However, one must keep in mind there may be some overlap between the two terms where either may be appropriate.

The making of art may be an expressive, materials-sensitive, spontaneous activity which is not necessarily related to a clear plan. It can, however, be viewed as an activity that represents an act of planning. The planning process may be extremely interactive and spontaneous and not separated from the act of generation or the making of the art. This view is exemplified in painting when the artist selects portions of a work in progress to be the model for the rest of the work (Ecker, 1966). The context is important to the meaning of the art object; likewise, the design specification of the context is important to the design. An example of the importance of context is the display of Duchamp's urinal in an art gallery, raising this obscure object to a place of prominence. From this perspective of context, art and design can be considered similar.

Design may also be considered a subset of artistic activity where art is designed and then made, while designs may never be actually realized as artifacts. Computer modeling of objects seems to bring any division closer. It is reasoned that computer graphic simulation and modeling is a form of design realization, and may result in the making of art.
Some may maintain that there are clear differences between the activities of design and art. It may be argued that art has freedom from imposed constraints, while design has to answer a need or have a purpose. Although the former position is included as an approach used by some in design (see Chapter 4), basically, it is not addressed as a substantive portion of this study. This is an extremely complex and difficult distinction.

Polar views are presented about the way computers will be used in design activity. An underlying assumption of both of these views is that computing is good for designing. One position is that human weakness in the design process will be augmented by the rapid processing of complex data bases and information sets developed by the human designer. This knowledge base is processed by the computer under the designer's control. The designer or design team thus bears the responsibility for resolving the problem including the depth and breadth of the design. This responsibility includes the development of "satisfying resolutions" (Rittel, 1988). This view most closely resembles the decision making process in art where the problem may be of the artist's own choosing and therefore, the solution may be judged based on the artist's own description of the problem. Thus, the character of the piece and interpretation of the critic may all play a role in clarifying what the work is about. On the other hand, Minsky's (1989) work explores an artificial means to solve problems. It can be reasoned that design activity may eventually be understood to the point that a system or systems can be developed to mimic or, if carried to the most radical end, replace, the human decision-maker in the design process. Parameters for decision-making and control data taken directly
from the community using the object might be traced. Input might come from a survey or the best guess of experts, in order to establish seed values for these parameters. The system then calculates or 'dreams up' a solution based on connective artificial intelligence learning and modeling. In this scenario, the responsibility rests with the system designers and may include a great number of concept developers.

Although research supports each position, a more flexible view that includes elements from both positions seems the most practical for the near future. Development of a hybrid, or the blending of the two in the most appropriate way, is a current challenge confronting applied interface design.

In either case, aesthetic resolution must be an important part of these processes. Without aesthetic resolution, information often represents the lowest limit or lowest common denominator. In the case of a designed object, it may barely function and not be satisfying. As another example, an assembly of words forming a factual report may need much additional work to become poetry. Likewise, the "poetry" of an object needs to be designed, enabled in part by the tools of the hand and mind. Such transformation processes would seem to necessitate human mediation in the near term.
Chapter II

Methods

"Methodology is the study, the description, the explanation, and the justification of methods" (Kaplan, 1964, p.20). Kaplan goes on to express that methodology, when used by philosophers, is often indistinguishable from epistemology, the theory of knowledge or the philosophy of science. This section examines a variety of methods that relate to this dissertation in various contexts.

A. Methods for Generative Problem Solving

Methods for this study are analogous to a strategy specified by Arnheim (1969) which brings together an association of disciplines, one in which several essentially separate and independent disciplines are studied to develop an understanding of a problem; for example, cognitive process and concept formulation. "What is called for in such a situation is not only experimental and practical research on particular aspects, but first of all, an overall strategy, a survey of the total field to be investigated" (Arnheim, 1969, p. 2). Philosophy has long been concerned with these problems, and the history of science offers rich case material (Arnheim, 1969).

It was reasoned that a better understanding of a designer's thinking and working style and a description of the tools classically associated in the practice of designing, would help in developing the specifications for a
designer's interface. From this analysis, a conceptual model is developed to act as a guide for the designer interface. This study, then, is viewed as planning, using rational means to describe processes, classification, and relationships that the designer will find useful.

The methods to enable this study are centered in logic. Logic-in-use describes the use of logic that is informally structured and flows through the text. Logic-in-use is employed while describing and analyzing pertinent literature, as well as the synthesis of interface specification. "Not only language and culture affect the logic-in-use, but also the state of knowledge, the stage of inquiry, and the special conditions of a given problem" (Kaplan, 1964, p. 8).

Deduction and induction are often described as useful formal logic in scientific investigation. Deduction is considered to be explanatory and is often used in proving theory. This form is exemplified by the following expressions:

All of set A is a member of set C.
Set B is a member of set A.
Therefore: Set B is a member of set C.

Induction is a form of logic where a prediction is made based on a given observation or a major premise that is qualified, seemingly consistent but not absolute. It is a less conclusive form of logic because does not reveal fact. If the major premise is well observed and measured, these predictions are still very reliable. However if the major premise is inaccurate, various problems might cloud the accuracy of the predictions. This form of logic can be exemplified by the following expression:

C has been observed occurring with regularity over a period of time.
Therefore: C will occur again.
Since the nature of the problem addressed in this dissertation is generative, much of the logic-in-use will be abduction or retroduction. A case for generative reasoning can be structured around the analysis of abduction described by Pierce in Buchler (1955). It is reasoned that if a new rational idea is to exist, the creation of that idea must be able to be couched in logic.

Pierce revealed a form of reasoning that explains the way that hypotheses are formed prior to the processes of deduction or induction. "The first stating of a hypothesis and the entertaining of it, whether as a simple interrogation with any degree of confidence, is an inferential step which I propose to call abduction. The form of the inference is exemplified by:

The surprising fact C is observed;
But if A were true, C would be a matter of course.
Hence, there is reason to suspect that A is true"
(Buchler, 1955, p.151).

Pierce goes on to explain that generative guesswork based on objective, qualitative characteristics may be used to make determinations about the validity of a hypothesis. He calls this form of logic abductory induction.

It is an induction because it is a test of a hypothesis by means of a prediction which has been verified. But it is only an abductory induction because it was a sampling of characteristics ... to see what proportion of them ... were possessed (by an object). Abductive induction occurs when characteristics cannot be counted or even weighed.... It also partakes of the nature of abduction in involving an original suggestion; while typical induction has no originality in it, but only tests a suggestion already made (Buchler, 1955, p.151).

The key to this passage is the formalization of generative conjecture in
the process of logic leading to a proof. It can be reasoned that abduction is analogous with the generative form of the activity described by Hillier, Musgrove, and O'Sullivan (1972) as conjecture-analysis and by Tovey (1984, 1986) as conjecture-analysis-synthesis. Pierce does not necessarily consider the linear path that these forms present.

A method for approaching the structuring of the problematic portion of this research stems from a systems design theory of Rubenstein and Hersh (1984) for interface development. This theory specifies task analysis in systems design as the first step toward an interface specification. The literature review has also followed this structure. The overall approach proposed by Norman and Draper (1986) as "user centered systems design" is generally followed. A better understanding of the complexity of the design task is derived from a study of design methodology.

The second stage in interface specification includes the development of an "external myth and conceptual model" (Rubenstein and Hersh, 1984). The external myth is the organization of the interface into a structure that the user can identify and use easily. It models a process familiar to traditional approaches, in this case, design visualization. The conceptual model is a plan designed to be useful in future systems implementation.

An external myth is established by examining literature about "design work". It is hypothesized that the "external myth" must include pathways to programming. Traditional metaphor relationships with design media techniques such as sculpting, extrusion, and painting should be used as a part of the "external myth" to encourage the non-computing designer to participate in system use. As the designer becomes more familiar with computing, these
traditional myths can and should be reduced if they are not necessary to support a new paradigm. Instead, the external myth should support the activities of the new tools and procedures where the computer is most useful and should not replicate tradition for the sake of tradition. An external myth of surface interface with windows and menus is useful because of its current success in introducing the system to novice users. This external myth is a derivative of the Xerox Star/Apple Macintosh, which has a metaphor of office operation, such as a desktop, files, and cut and paste operations. Significant additions have been developed for the designer to encourage participation in the specification of more powerful computing tools and the monitoring of complicated but ordered displays.

The external myth has often excluded the user from direct access to the logic of the software and hardware. For the "external myth" to become effective in design, the need exists to represent the manipulation of physical systems and the simulation of social and behavioral networks. This study emphasizes the development of natural language through images and icons, or a visual language, and then relates that language directly to useful tools and procedures. The visual language specified takes advantage of the three-dimensional and animation capability of computer graphics software. The mental model and external myth developed in this study for the interface is using the three-dimensional volume of space and the fourth dimension of time.

Ideas were extracted from behavioral patterns or approaches to design for the purpose of relating objects, contexts, and spaces being conceived, visualized, and interpreted over the interface by the designer. This approach helps conceive an interface strategy based on a "mental model" of the
designer's cognitive style and is realized in part as an "external myth".

This study creates a conceptual model which incorporates patterns of approaches to design, design activities, and the cognitive style of the designer. The conceptual model is developed by abduction. Since the abduction results in a more meaningful understanding of the association between design and computing, this conceptual model represents a strong reference to patterns and interactions dealt with in design. Scrivins states that "understanding is roughly the perception of relationship." (cited in Kaplan, 1964, p. 336) A pattern model is a system of relations. The pattern model, as compared to the deductive model, is used to explain. In the pattern model relationships are fundamental, as well as giving some notion of closure, wholeness, unity, or integration. The deductive model, however, has the advantage of greater exactness.

Kaplan, referring to pattern models, states that, "In my opinion, the effort to arrive at a more general and rigorous treatment of cognitive patterns is a most worthwhile endeavor; my impression is that considerable progress is now being made in psychology, mathematics, linguistics, and perhaps logic and philosophy as well." He continues by expressing that "predictions play a part in the pattern model as a way of specifying what is needed to fill the pattern." (1964, p. 333)

"Descriptions often play an explanatory role: they allow us to see relations which had previously escaped notice." (Kaplan, 1964, p. 336) A description may enable us to supply a whole framework which we already understand, but we were unaware of the relevance. The explanation does its job by providing us with what is called a cognitive map. This map which
explains how things around us are laid out. Every explanatory pattern is a fragmentary map of a limited territory; we aim to fill in details, and to fit together fragments. As this aim is pursued the maps are subject to continuous testing, for according to Kaplan, sound explanation is one that grows on us as our knowledge grows (1964).

The conceptual model contains relationships of semantics as icon, symbolic, and geometric information for classifications. The method of classification of the objects, contexts, and actions is from Spradly (1979). He discusses "domain analysis", suggesting that domains or categories may be names for things, terms (elements or taxons) and semantic relationships.

Spradly's form includes:

- strict inclusion: X is a kind of Y
- spatial: X is a part of, or holds a place in Y
- cause and effect: X is a result of Y, X is a cause Y
- rationale: X is the reason for doing Y
- location, action: X is a place for doing Y
- function: X is used for Y
- means end: X is a way to do Y
- sequence: X is a step in Y
- attribution: X is an attribute of Y

Many of these relationships can be treated in matters of degree.

User-centered system design is the focus of the method employed for the system specification (Norman and Draper, 1986). This emphasizes the development of an external myth which can be equated with a description of the approaches practiced by the designer. For the myth to function well, it must not
cause the user to halt in a process or activity because it represents an incomplete
description of the desired action. The myth may simply prevent the next logical
stage of the project, not because computing is not possible, but because the
protocols lack the ability to enter the problem area.

In the user-centered approach, characteristics of the user group are
addressed in a system's specification. Thus, the user-centered systems design
is helpful in providing knowledge gathering methods to help formulate the
mental models used by the designer working with the computer system.

It can be reasoned that visualization helps result in a better
understanding of the processes, objects, contexts, and spaces associated with
analysis of the complex tasks performed by the designer. The external myth of
the interface specification is based on a synthesis of those patterns of
approaches to design, cognitive style and design activity. However, the myth
must be kept in perspective. Avenues need to be established to extend or
discard the myth if the situation warrants.

A shift in working style may affect the design of the interface.
Changes might begin to affect the skills required to perform tasks. This
presents a situation that is unlike methods of "user-centered systems design,"
where specifications fit traditional design practice. In this case, additional
system modification is based on knowledge that the user gains as form-giving
occurs. The proposed idea of "designer as participant" is a position that is
initially user centered, where a flexible tool set is provided to the designer. The
important strategy, however, is for the designer to eventually use the system to
develop an ability to construct additional desired tools, or specify variations on
existing tools through higher level programming in collaboration with other
designers and software developers with special skills. An example of this higher level programming is the organization and manipulation of icons. Using animation, the icons may actually graphically trace the action of the procedures (Brown, 1988).

**B. Research Scope and Exclusions**

This study proceeded as a parallel effort, where research in one domain requires comparative research in another area. Such a structure traces the results of design activity through a network of information, again from general to more specific. The study progresses from the overview of the mind, through a description of philosophical points of view. Viewpoints about scientific inquiry, the association of art and design, and theories about the act of designing are included. Directed toward those audiences most affected by the outcome, namely designers, this research study continues by focusing on developing a description of approaches practiced within designing activity.

Literature is reviewed in several areas. A review of literature pertaining to computer and human interaction (1982-1990) is a major portion of this study. Expert synopsis is used as the method for the review of early interface literature. The study of human-computer interaction is relatively new. A special interest group of The Association of Computing Machinery (ACM) was established in 1982 for research and publication in Computer and Human Interaction (SIGCHI).

A comprehensive literature study concerning the association of art, computing, and design is done as well. This literature associates the key words of art, design, and computing from the Educational Resources Information Circulation (ERIC) subject reference search.
Dissertation abstracts were searched using the key words computer user interface.

Portions of computer aided design (CAD), which relate to computer assisted drafting, or the development and the archiving of drafted images are reviewed by studying commentary or reference material that summarizes the current state of research. Physical interactions or demonstration with some of the existing software is also undertaken, to provide a basis for functional testing.

In addition, the literature concerning associations of design visualization and object generation is reviewed. Recent literature concerning design methodology and process is presented in Chapter III and IV. Study of first generation design methodology is limited to references determined by domain experts. Literature on computer graphics in the area of form-giving, object generation, and animation is also included.

C. Statement of the Problem

The problem under study is the development of a conceptual model which accounts for the required dynamics of a designer-centered computer interface.

D. Explanation of Criteria

It would seem natural to consider the generation of real world objects by the designer, using the computer interface, as a test of the fidelity and utility of the model.

The model should be tested for utility by comparing the level of complexity of virtual objects created from certain classes where complexity is
historically a matter of routine. This testing of the model should be done as a planned activity, deductively and experimentally determining the value of the components of the related structure.

Since the model is a specification of relationships, utility of the model can also be tested by comparing the model's efficiency and proficiency in assisting the designer in creating objects of certain classes. However, the full implementation of the model cannot be accomplished in this study. The model is developed logically, however, this does not substitute for "weakness that could not be seen and developed in the process of real trial with real users" (Gould and Boies, 1987, p. 5). The vast scope and manpower of implementation, even for rapid creation of prototype segments, is not a practical matter for this study, but is for future research. Observations of existing systems, however, have provided insight into the potential success of future implementation. Successful components of existing systems that work have been extracted to help develop the model.

Popper (1976) develops an interesting theoretical structure about realities. Although this is theoretical in concept, this structure is useful in explaining relationships between virtual worlds, physical worlds, and design activities. He structures three worlds: 'world one' consists of objects that are found in nature and those added to nature in a physical form; 'world two' is the world of thought processes; and 'world three' is in the form of statements resulting from thinking processes.

If we call the world of things, of physical objects, the first world, and the world of subjective experiences the second world, we may call the world of statements in themselves world three....... When I think of a picture I know well, there may be a
certain effort to recall it and 'put it before my mind's eye'. I can distinguish between (a) a real picture, (b) the process of imagining, which involves effort and (c) the more or less successful result. Clearly the imagined picture (c) belongs exactly like (b) the process of imagining, to world 2 rather than to world 3. Yet I may say things about it which are quite analogous to the logical relations between statements (Popper, 1976, p. 141).

In most cases in this study the objects described are virtual objects. They may be considered icons, or symbols representing ultimate objects of real world constructions. It may be useful to consider how well the construction and manipulation of the conceptual model and the virtual objects or icons created lead to challenges for the mind, and not necessarily the craft of the real world artifact. What may not be needed is a one-to-one, 'design to the real world' object, but a means to handle complexity, to sort, and to transform virtual objects, leading the intellectual development of design toward more satisfying aesthetic resolution sets.

The activity of generating form with the computer will only represent a portion of the final real world implementation. The model proposes the hypothesis that graphic images, animation, virtual projection or an object with physical substance have some commonality. The computer generative activity is only a portion of the utility of the interface. Virtual objects are viewed as symbols which closely approximate objects formed through mental activity. These objects eventually can become part of the physical world by "making" or by "imaging". Icons have no physical substance but have visual and intellectual substance. This means that a relationship is developed between the imagined image and the computer graphic image. This relationship should move the imagined image, the computer graphic digital image, and the finished artifact
closer to the same interpretation. It should be noted that a "real world" object, such as a prototype, is often the best presentation of the artifact. Consequently, virtual three-dimensional display of a simulation would give a good representation in a prescribed context.
Chapter III

Literature Review

The literature review begins with the broad, implicit, inclusive view of design and then proceeds to the more limited, exclusive view. The inclusive view is considered to be planning and problem solving. While the exclusive view deals with aesthetic visual presentations of objects, spaces, and contexts.

A. Planning and Design

The broad, inclusive view is discussed by Rittel (1988). He states that design is a rational activity, and that all people design some of the time. This inclusive view of design is cognitive activity where planning is involved. Examination of this view will lead to a better understanding of cognitive action used in planning resolutions to problems.

The lack of consensus about how the mind works gives insight into the difficulty of categorizing the design activity as it is "practiced by everyone, part of the time". Although contemporary views are based on the scientific analysis of how the brain works to permit the formulation of theories, some of these researchers views are oriented toward a biological-instinctive explanation of how the brain works to formulate ideas (Gould and Marler, 1987), while others use electronic models to explain how the brain processes information (McClelland, Rumelhart, and the PDP Research Group, 1986). Still other theorists focus on chemical analysis of brain functions (Bergland, 1985) or base
their hypotheses on behavioral patterns (Kaplan, 1964). Thus, although all attempt to shed light on the thinking process and associated activities of the mind, there is a lack of agreement. These disagreements over how the mind works relate directly to design. For instance, design may be viewed as a pondering and planning of events, a relationship of references, or as a circumscribed map of action that can be calculated.

Levy (1985) approaches design as rational and partially based in both science and artistic activity. Burke (1986) advances the idea that the connection, interaction, and interrelationship of events leads to new achievements in science.

A common view of science is that scientists gain ideas in an orderly and sequential manner. For instance, new theorems are constructed on proven laws. Hypotheses are tested for "truth" over and over again until new knowledge is gained.

In contrast to this "method", Kuhn presents knowledge as a series of methods for achieving work. These methods of standard operation are referred to as paradigms. He states that science is advanced by a paradigm shift where a given series of truths are, in some cases, rather suddenly discarded because of new underlying evidence that simply shows that the old way no longer works (Ollroyd, 1986). Furthermore, Feyerabend "believes the privileged position of science should be abandoned" and there should be "free choice as to the knowledge system one espouses" (Ollroyd, 1986, p. 338).

Popper (1976) suggests that proving a theory positively is not the best approach to science. He reasons that every effort should be made to disprove a seemingly insignificant event. He promotes the isolation of a single
specific incident or hypothesis which limits the problems of testing complexity as opposed to leading to the possible consideration that all elements are true because the major outcome is proven correct. If the isolated element is disproven, then it can be removed from the realm of truth with certainty.

B. Form-giving

The specification of design tools resulting in the direct or indirect manipulation of computer modeled objects, spaces, attributes, and contexts will be a major part of the activity of design. Direct manipulation refers to the interactive transformation of graphic icons or symbols by the user to cause or represent action to the computer (Smith, Irby, Verplank, and Harslem, 1982).

As computing enters the interactive portion of the design process, weaving into the conceptualization phases of object form-giving, design paradigm shifts seem inevitable. These paradigm shifts will perhaps parallel the shifts that can be witnessed when comparing the compromise and enrichment of publishing before and after the entry of desk top computing and sophisticated word processing software. Another analogy is the advent of machinery and associated tools that caused changes in design during the Industrial Revolution of the late eighteen hundreds.

Understanding of the designer's own cognitive style may give insights into the best interaction technique for beginning design processes. For example, the Apple Macintosh interface with its standard protocols helps the user to remember simple processes and leads to learning about the system through browsing and action activities. It seems that keyboard skills are often grudgingly learned when a mouse is available, but once the keystrokes are internalized the keyboard eventually provides for faster control of many
activities than does pointing and clicking.

By providing a visually action oriented game as an interface environment, the individual is encouraged to interact at the highest possible level in a very natural progression of learning. If an interface can be developed that permits this variety, yet quickly moves the designer into a more productive mode, then the situation for design will be vastly improved.

New paradigms are emerging for object representation and manipulation structured around graphic symbolic portrayals of mental images transferred to the computer's virtual space. These new paradigms for object representation can be compared to the more traditional transference of images to a physical form, such as pencil and ink sketches (Hanks, 1980); (McKim, 1980), realistically rendered computer pictures, prototype model artifacts or actual "real objects".

Visual elements of the design solution are articulated by a number of literature sources and can generally be described as harmony, unity, value, line, shape, color, proportion, composition, and texture (Brooks, 1988; Dondis, 1973; Gombrich, 1962). Many of the formal criteria for the criticism of designed objects are based on the qualities and relationships of these elements. These visual elements become a part of the objective sets of overall criteria that are described by the individual designer in forming "satisfying" solutions.

Satisfying solutions are objects or actions that achieve many of the actual needs and perceived needs of individuals associated with the problem under an imposed time constraint (Rittel, 1988). These solutions may stem from emotion filled, subjective fact-finding, representing a process of artistic activity rather than an exacting science. Designers might work from the holistic
to the specific to arrive at a concept and only later develop the details. Conversely, they may work from a specific detail of an existing solution greatly affecting the associated whole. These direction changes may occur often within the course of design resolution in a random way as the need to do so is perceived. Consequently, the computer interface must work up a structure from specific detail toward the concept. It must also allow for the decomposition of the concept and the recomposition of the altered units to reform the whole object for critical analysis.

Satisfying solutions include informed decision making as a part of object evolution from a knowledge base. Rules of thumb as well as references aid the designer in establishing an object's meaning. Even when a designed project is resolved, criticism seems difficult. The "emotional" values seem to be the most "ill defined" and left to the powers of observation and interpretation. Abstract comparisons and analogies often prove to be most useful as explanations.

For the designer to become fully involved in the structuring of the computer working environment, tacit design knowledge must continue to be further revealed (Schon, 1988). An understanding of methods for working with complex "ill-defined" problems is also necessary in order to take advantage of the computational power. The designer will be making use of, and contribute to, the computer work environment for portions of the design activity. Haeberli (1988) states that expressive systems and ready made systems will always benefit some and leave others unsatisfied. Playing the role of active arbitrator, the designer will lend judgment at appropriate times throughout the process of computer system development.
To enable the designer to structure idiosyncratic systems, an extended knowledge of mathematics or an overview of mathematical processes is desirable. The designer's mathematical knowledge helps prevent systems limitations. This understanding of mathematics will help in the development of tools that complement working style. Progress has been made toward expert systems where the task is well understood. For now, the wicked nature of design problems make it unlikely that intelligent systems can be applied to a variety of tasks without human intervention.

C. Design Methods and Theories

There is a diversity of theories about what design is and how it should be practiced. The variety of cognitive styles and methods of practice among designers partly accounts for this lack of concensus. Also contributing are the special requirements of each of the multitude of problems that are addressed by a select cross section of designers. Some theories appear to be more or less applicable to certain types of problems. For example, one inclusive planning theory supports the idea that once the wicked problem is defined and understood, it becomes tame and more easily resolved (Rittel, 1988).

Design theories also seem to take on particular characteristics in different domains. Some designers, with an intuitive style, seem to rely primarily on interactive visual object development. Since more powerful machines are becoming available with interface protocols that are easier to learn, members of this group are utilizing the computer in a more productive manner with less frustration.

Several process models of design methods have been proposed. The ability to break down design activity into smaller components has been in place
and can be used to better understand actions and networks used for problem resolution. For instance, Harary (1974), a mathematician, has broken down much design activity into graph theory.

While Harary relies on graph theory to trace problem resolution, Alexander's (1964) major premise is one of analysis-synthesis. In this first generation process methodology (Cross, 1985), the designer divides the design problem into a hierarchy of elements and subsets. After an analysis of problem requirements has occurred, a program can be developed to solve the problem. A tree diagram can be used to represent the synthesis or realization of the program.

Like Alexander, Archer (1963, 1964) views design as a step-by-step process however, a communication network is added to the model. Communication is carried out between various personnel affected by the design. The major difference between the two models is that Archer introduces the idea that the designer's values and the incidence of original ideas should occur during the design process. Jones (1963) structured the design process around the designer's model of the problem. He suggested a variety of techniques for formal analysis and synthesis.

Cross' (1985) studies in design methodology suggested areas of research about how computers can better assist design efforts. Hillier, Musgrove, and O'Sullivan (1972), studying working architects, observed that the linear process oriented paradigms of the first generation methodologists were not being followed in practice. The analysis-synthesis model of gathering information and then analyzing the results was actually being done through a process of conjecture-analysis. An idea for a solution was matched against the
situation and if the solution seemed to be satisfying, it was implemented. Others later agreed and expressed a hybrid method that included intuitive and intellectual mental processing. In these models, the designer takes advantage of conjecture-analysis, but works to a greater end. This is the synthesis of resolution (Tovey, 1984, 1986).

Rittel (1988) is a proponent of the ability of the computer to record and compare information that is gathered and structured to enable the designer to better understand the ill-defined or "wicked" problems associated with design. Solutions for wicked problems are products of a variety of dynamic elements. Rittel claims that events that occur in defining the problem are as much a problem as the problem itself. He is opposed to trial and error resolution. Due to the dynamic nature of wicked problems, the very nature of the problem changes as the trial is occurring. Trial and error also implies that a better solution might be found. The idea of an optimum solution is nonexistent in his thinking; wicked problems can continue to be worked on after a satisfying solution is designed. Rittel ascribes to design as a plan.

Bazjanac (1974) extends Rittel's theory to one of a learning model, the idea that the progressive stages to a design solution are gathering information by learning and redefinition. This knowledge gathering process is repetitive, redefining of the problem and solution, until the incremental knowledge gained is insignificant or the understanding of the problem does not change with the additional information available.

Schon (1988) goes on to develop a theory that accounts for the knowledge that designers use when working toward solutions. Schon argues that designers mentally enter and work in virtual "worlds" that are constructs
of the mind, referencing several "types" of knowledge through a variety of implied "rules". These types are: functional types or physical functional attributes or limitations such as the height of a doorway; references or an understanding or image of a particular object and its attributes, such as a particular chair; spatial gestalt or the perception or the whole interpretation of the current condition, including the plan, the existing format, and the meaning of the problem; and experiential archetypes, or the individual's image or conjectured mental picture of the object, based on the understanding of all cumulative knowledge. In this study, several approaches to design are synthesized (see Chapter Four) based on the types, rules and worlds of Schon.

Product semantics is also an important consideration. The claim of this hypothesis is that the artifact has meaning and that this meaning can be designed. Much design work is not documented in literature, but can be formulated through criticism of an object. Gresham's (personal communication, 1989) work is theoretical and symbolically demonstrates a rather literal iconistic view of the "object representing function". A video camera is formed to not only fit around the face, but mimic portions of the face. The microphone echoes the form of the ear, and the lens appears to be an extension of the eye.

D. The Context of Human Computer Interaction

Baecker and Buxton (1987) separate interface concepts into such categories as the psychology of computer programming, models for computer use, cognition and computer use, and the three channels of interaction. The three channels of interaction include the visual channel or the qualities of feedback the user can expect from the screen. The haptic channel is the second
channel of interaction and involves mostly input from the hand although there is some implication for touch as feedback. The audio channel deals with speech as input and sound as feedback, including synthesized speech.

Visual perception of images on the screen requires the user to understand what is intended to be understood by seeing. Perception is an active process and not merely a passive response to visual presentation. The active nature of this perception suggests that as the designer is involved in a session, conjecture or hypothesis building takes place. Two approaches can result. The first is a bottom up, or data driven computation, and the second is a top down or conceptually driven computation. In either case, the need for perceptual consistencies may play a role in understanding the meaning of the images.

Human factors literature includes the anatomical and physiological properties of the eye, the neural pathway to the brain, the dimension of vision, and the perception of brightness, contrast, flicker, motion and color (Baecker and Buxton, 1987; Kantowitz and Sorkin, 1983; Sanders and McCormick, 1987) focus on specialized kinds of displays. These researchers consider, among other topics: the appropriate alpha numeric displays, visual codes and symbols, quantitative and qualitative displays of data, signals and warnings and representational displays and guidelines for the human's ability to discriminate display coding using various stimulus dimensions. Multiple stimuli can be combined and effectively used together.

The design of effective graphic communication is the domain of graphic design Baecker and Buxton (1989). Bowman (1968) provides an introduction to effective graphic communication. Visual vocabulary of elements include point, line, shape, value, and texture. A grammar is provided for
spatial organization. A structure is given for volumetric perspective. Furthermore, a syntax is developed for presenting the image using relationships, differentiation, and emphasis and an extensive design library is provided to show natural appearance, physical structure, and organization of parts in relationship to the whole.

Haeberli (1988) directs attention to Smith (1986) as a leader in the relatively new field of visual programming. The method of direct manipulation of programming elements provides a visual language for individuals that prefer a direct, visual approach and feedback with the computer.

Frederick Brooks (1988) and his students, working at the University of North Carolina, Chapel Hill, demonstrate the ability to make systems with three dimensional mental models operational. In experimental systems, three dimensional actuation devices are used, such as manipulator handles with multiple degrees of freedom. These devices, constructed of tubes that point in the direction of the three axes of Cartesian space, give the user visual, "real world" feedback as objects move about on the screen.

In addition, at the Media Lab at Massachusetts Institute of Technology (Brand, 1987) reports on experiments in voice actuation, large screen projection, and object manipulation. This work is a milestone for continuing research.
Chapter IV

**Description of Approaches to Design**

A. Approach Where the Design of Objects is Directed Toward Satisfaction of Society

**Approach of Satisfaction of the Object User**  This approach to design relates objects to individuals or groups of individuals that will use, interact, or have emotional contact with an object. This approach usually involves an understanding of the person(s) that the object will affect. Psychological relationships, ergonomics, ethnographic factors, and other human factors are taken into account when forming the object. *Professionals concur that public safety and human factors should be given a high design priority.*

**Approach of Satisfaction of People Affected by the Problem**

In this approach, the designer gathers as much information as possible about the political structure and social conditions surrounding a problem. A problem exists where the goal state is different than the current state (Rittel,1988). The quality of any solution is measured by how well the social structure is satisfied within certain constraints, especially time limits. If a new entropy exists, then the problem is satisfied.

**Approach Where Design Satisfies Historical Tradition**  Design can also be related to a study or trace of historical references with the awareness
of their refinements and current interpretations. Since it is impossible to consume all of the original historical documentation, even if available, one needs to rely on the experts in the field to maintain a historical, operational database.

Although this "historical truth" is subjective and contains cultural biases, the addition of the exploration of this knowledge base can increase our understanding of historically related, satisfying solutions. This knowledge seems to help the mind process and integrate "new" resolutions. Works from the Bauhaus (Whitford, 1984) and Ulm school are examples of design influences that continue to serve as references for style, structure, and comparative analysis during criticism. Although usually considered beneficial, one must be careful that the historical influence does not overshadow and unnecessarily predispose the problem's resolution set to a smaller domain. Despite some cautions, in most cases, historical knowledge improves design discourse.

**Approach Where Design is Driven by Technology** In this case, the technology itself is the impetus for the creative energy that generates the project. The artifact is designed to take advantage of a technology that is emerging, for example, holograms and computer graphics. This technological approach may be based on either a trend or long term dedication to a particular medium. New technology may also simply resolve old perplexing problems. The success of the technological approach hinges on a combination of ideas and appropriate applications.

**Approach Where Design is Limited by Authority** This complex approach is practiced in many design projects where windows are provided by
controlling authorities. These authorities provide windows through which the
design process, object, and context must fit. Corporate concerns, such as time
and profit, are sometimes blatantly obvious or can be indirectly expressed. The
designer may reject the imposed limitations even though the design task may be
simplified by the restrictions. However, these external concerns should not
eliminate the need for awareness of other limitations. For instance, the
computer system chosen may install additional limitations in creative processes.
Therefore, designers need to contemplate and react to all these constraints that
have the potential of undermining design activity. At the same time, they need
to formulate and continually evaluate their ethical positions.

B. Approaches Where the Design Processes are Structured

Cross (1986) defines a series of methods for design processes. The
following is an analysis of these "process structured" approaches to design
work. The specification of these approaches is the synthesis of Schon’s (1988)
view of design knowledge, Cross’ review of methods, and personal
observation and design experience. Designers may ascribe to elements of
various approaches or follow the characteristics of one approach rather
exclusively.

**Approaches of Linear Design Process** Process oriented design is
characterized by the linear methods of analysis-synthesis of first generation
design methodologists; such as Alexander (1964), Jones (1963), and Archer
linear process of programming, data collection, synthesis, and communication.
This model is useful in the reconciling of a wide range of factors such as
function, manufacture, and marketing. These methodologies help record design
activity but do not successfully model design process.

Second generation process methodologies include Hillier, Musgrove, and O'Sullivan's (1972) conjecture-analysis, Tovey's (1984, 1986) conjecture-analysis-synthesis, and Rittel's (1988) issue based information system (IBIS). These approaches are better suited to "wicked" or ill defined design problems often confronted in inclusive design activities.

Process oriented design is identified by studying the ill-defined problem from a ritual of process. Many of the processes of design of three dimensional form tend to be linear. Ballay (personal communication, 1986) describes the design process as a metaphor of a line with spaces, where the lines represent conceptual action and the spaces represent tedious activities.

**Approach of Lateral Design or Parallel Processes** The design process can be viewed as a network relating links to nodes. In this process, a difficulty exists tracing the sequence of events leading toward the resolution. Such a difficulty is one of the establishing attributes of the wicked problem. Many designers seem to have no clear pattern toward the solution set. This problem seems to be a function of the mind as it works through interrelated ideas (Cross, 1986; Koberg and Bagnall, 1972). In fact, sometimes no beginning or ending is even clear, let alone the means or processes to achieve the design.

Being able to represent the complex structures of design problems is useful but complicated by the changing nature of the wicked problems. Nodes and their connections can be linked to help represent the problem at a point in time.

C. **Approaches Using Object and Context References**

**Approach of Sensory Awareness and Synthesis** From the
complexity of skin texture to the unit simplicity of the egg, natural surroundings and objects have been studied, sketched, and used as inspiration for art and design. Through sensory study, some designers trace relationships in the natural order and use them in their design. The subtlety of color in a recently fallen leaf, the patterns on tropical fish, the geometric patterns of a building facade, or the structure of bones in a skeleton could all be references that might evolve into designed objects.

The arms that are used on many industrial robots and television camera "eyes" that exist in unmanned surveillance vehicles are testament to the close relationships between manufactured objects and references. The ideal in this approach may be to first use a stimulus from nature as an inspiration and then reference the stimulus as a part of the vocabulary of form when synthesizing the design.

**Approach of Emulation of Natural Forces** Portions of nature can be viewed as a reference for the structuring of three dimensional objects. The resulting shapes and spaces are based on a combination of internal forces and external forces. Objects that grow and change over time use a preset "map" set in the genetic material as the internal force to determine their basic structure. External forces, such as environmental conditions, also influence the shape and structure over time. Both internal and external factors contribute to the state of the form at any given moment.

In computer simulations, these internal and external forces can be programmed to influence the geometry and attributes of objects. For instance, designed objects can be warped, stunted, twisted, and stretched according to an algorithm modeling environmental condition. If the designers are aware of this
capability, they may use prescribed actions to affect the object that is being designed. The designers may specify procedures to software specialists or gain the mathematical skills required to develop procedures for this technique (See Chapter 6 - mathematical tool section).

Thompson (1968) has described the structure and catalog of grown objects in *On Growth and Form*. Given the mathematical tools of the computer, Thompson's material could be a valuable direction for continuing research. While the specification of the algorithms is the beginning in molding objects using environmental factors, next might be the molding of functional abstractions that can be used generally to cause a visual metaphor affecting the data base resulting in a change of character of a designed object.

The geometry of form was long ago addressed by the Greeks and continues to be studied through such contemporary structures as the geodesics of Fuller (Edmundson, 1987) and the fractals of Mandlebrot (1987).

**D. Approaches Based on the Satisfaction of the Designer**

**Approach of Abstract References and Presentations** A less clinical consideration to the design is at the center of this approach. The basic premise is that there is an unclear relationship between the design and the process; thus, the nature of this design approach is more abstract. The design of objects is a result of untold numbers of factors, including personal preference. The designer and the object are identified as having an almost parent/child relationship during the design activity. The synthesis of design processes is clear in the form of active or passive concentration on the design activity. Perhaps this is the approach that most promotes and takes advantage of the "ego" of the designer. "Monuments" to designers are sometimes created
where this approach is practiced.

Although the designed object can be broken down into formal attributes, the designer using this approach, would not attempt to determine how the design was realized. To segregate the object into a developmental process by the designer or critic would be viewed as a conjecture. The object could and would still be the subject of criticism, but would be interpreted on the basis of the critic's references and not those process areas where design knowledge is couched.

Schon's (1988) structure of worlds, rules, and types provides a framework in which to look at the designer oriented approach. In order for this to happen, the designer's "ego", or interest, must permit a dissection of the tacit design knowledge which impacts to some degree on the creative process. This implies that the ownership of the designer's thought is a fair target for research and that the unraveling of these complex mental activities are of interest to the "expert designer".

An object may be viewed as entirely a manifestation of the emotional energy of the designer at the time it was created. Because the design is not clearly the result of a structured process or an isolated, related physical reference, it may be considered rational at a higher level. Judgment is based on the object and its relationship to the current time frame or context. Schon's description provides a means for discourse about the abstract references. These abstract references might be categorized into rules, types, and worlds, thus enabling a clearer discourse about them. Discourse about artifacts created as a result of design activity and the generation processes that are navigated in the realization of these artifacts are more easily understood when broken into formal
structures.

Another concern about this approach is the subjectivity of the designer. The design resolution stems from free thinking or "brainstorming" ideas. These ideas are then functionally tested against the designer's own preferences, as well as values and standards that are applied by the client, and society. The designer's aesthetic preference is reflected in the style of the object. The reputation and ability of the designer is one reason to put faith in an object. However, the designer's name may be used as a marketing promotion for the artifact. Additional value and stature is implied by this promotion technique and may unreasonably affect the consumer buying decision.

These processes seem to be less rational than a staged sequence of events where each of the activities is first analyzed and developed according to a procedure. The conjecture-analysis approach seems to oftentimes stem from the individual's experience.

A segment of this designer oriented approach, with a belief in emotional involvement, seems least likely to embrace the machine as a valuable ally, at least initially. Any kind of structure related to design activity may be rejected by the "ego" and be viewed as interference. In some cases, the final result is accepted because aesthetic values have been satisfied. The participation of the designer in the development and tailoring of the computing environment would assure a place for the "ego" and a closer relationship of the designer with the computer.

Another interpretation of this "abstract references" approach stresses the importance of language manipulation or a structuring of information through verbal and non-verbal language components. Verbal language may play an
important role in defining relationships that might be developed between formerly unrelated objects during design planning. The manipulation of verbal language to form an abstract description and interpretation leading to a desired meaning can be useful as a design method (McKim, 1980). Planning occurs while language-generating criteria, references, and object descriptions are structured.

However, words and rules may play a more passive, less concrete role than does a visual language of images and icons. It would seem reasonable that many of the advantages gained from using the computer for verbal language manipulation could be transferred to visual language now that the computer is able to process and quickly present pictures and images. Before sophisticated computing, these methods were reserved for internal processes using less concrete mental images, or achieved by shuffling though cumbersome photographs and sketches.

DeBono (1970) offers examples of "brainstorming" and other analogies described in this section.

**Approach of the Emotional** As discussed earlier, some believe that the major variation between art and design is in the area of planning. The designer is credited with planning the object or context that is being designed, while the artist may work with objects without a plan for executing his or her idea. Even during an emotional session, however, a mental plan of very short duration seems to exist in order for action to occur.

Furthermore, a claim that art can be done without thought is a paradox. Even abstract painting, such as Jackson Pollack's method of pouring paint on the ground, requires staging seemingly meaningful planning processes.
Although other approaches to design may come into play, it may appear to some that they remain at the subconscious level where they cannot be easily identified by the designer at work. However, one cannot function in the design realm without conscious thought. This might mean that computing could be incorporated even in an approach where the designer is engrossed in emotional activity and not aware of the subliminal existing plan.

**Approach of Interactive Redirection and Reiteration** This approach to design is basically a system of feedback where the problem is reassessed as the work continues. A painter may begin on one portion of the canvas and continue to work across the surface, changing the character of the painting as an experiment in qualitative problem solving (Ecker, 1966). In addition, the portion of the work painted first may need to be reassessed once other portions of the painting are complete.

Likewise, designers often are involved in this feedback loop. Traditionally, visual designers initially sketch an idea on a piece of paper and then rethink and redraw a new version of the idea, once the original is visualized. To test the form, it has also been traditional to build a rough, three dimensional model at various stages in design development. This interactive process represents a mind-eye-sketch feedback loop. With this method, the designer works upward to design the overall system and then downward to design the components of the system, constantly relating the parts to the whole.
Chapter V

Foundation for the Conceptual Model

A. Computing Involvement in Art and Design

The Medium as a Variable. The complexity at which visual language is developed in films to convey a message parallels that of other media. However, individual interpretation and cultural reference may hamper the communication between the film director and the audience, partly because the structure that facilitates understanding of formal written languages is not readily available in visual language.

Visual languages can be better understood in a number of ways. In psychological experiments, the movement of the eye can be tracked across an image to determine the pattern that is followed by the individual viewer. The information gained by studying these patterns of interest can be used by designers in ordering the way a picture is viewed. Controlling the placement of preferences is sometimes used when designing television commercials. A clearer understanding of the path of the eye is controlled by the designers of the imagery.

Clues about the interpretation and formation of a graphic language can be witnessed in game playing where symbols are tested for common understanding. A game is played by having participants illustrate a given written phrase while other team members guess what is being drawn. This
activity suggests that informal languages are developed in use. Also, various levels of abstraction are demonstrated while contestants visually communicate.

The function, appearance, and even meaning of the object is often communicated by using visual language. The game demonstrates that conventions of symbolism are developed quickly with team members as the game is played. However, the conventions that are used in the depiction of objects by artists may not be totally understood by those trying to gain the intended meaning of the image. The conventions tend to mimic those of sight in the real world and a knowledge transfer occurs with relative ease. Occasionally, tricks of the artist may contrive a misunderstanding.

The conventions of drafting and engineering drawing are well documented and understood by many phases of manufacturing and, in fact, are still used to communicate certain types of object information. Clients or corporation management typically prefer gaining understanding by looking at perspective illustrations, scale models, or prototypes, instead of the detailed mechanical drawing of the same object. In some cases, the viewer of the illustration misinterprets or the creator of the illustration miscommunicates parts of the information. These misunderstandings can cause agony later in design activity. Great care must be taken when rendering and viewing a two dimensional graphic image as a representation of a real object. It is important to realize that two dimensional images of objects have been mediated and that clarity in other forms often is necessary or might become so.

The conventions used in computer graphics to project a perspective image from a three-dimensional virtual model seem to reduce misunderstanding by reducing the errors that often accompany human mediation in this process.
McLuhan (1965) speaks of television as a cold media, one that is distant and requires little action on the part of the viewer. The interactive nature of computer graphics encourages participation thus "warming up" the computing medium in McLuhan's analogy.

**Advances in Technology** Powerful machines are available on desktops at home, at school, and in the office. Joseph Ballay, of the Design Department at Carnegie Mellon University, speaks of a time when the computer might be used as an associate, where the laborious tasks that designers do between creative acts would be turned over to the machine (personal communication, 1987). This kind of "computer associate" would become increasingly popular as more and more power is scaled into portables. Ballay (1986) discloses a number of versions of future design solutions for the computer product; imagine, for example, a computer designed as a walking stick.

Information about qualities and attributes of objects can be stored, processed, and related in formats that are conducive to computer modeling. Characteristics such as geometry, texture, color information, and transparency are attributes of objects. Qualities such as softness or smoothness might be suggested. Using these and other characteristics, an object might be flavored in the form of a "procedural stew". As a result, the computer graphic or visualization of a developing object might render qualities that, by certain criteria, surpass that of traditional imaging.

Computer models may affect the values that designers use in aesthetic decision-making while configuring the form of a future entity. Computational tools controlled by the mind and hands of a skilled designer promise an
"ultra-real" appearance for graphic simulations of objects, contexts, and spaces. Strides in technology are advancing tools and communication, while software and hardware costs are moving within reach of the individual designer. With this advancing technology, an effective mental model can be proposed where the designer works in a "virtual world". The designer, using self-described procedural computer tools and modular programs, controls this virtual world through fast paced communications networks. Matching the designer's cognitive style with the direct manipulation of these procedures seems to assist in the production of the desired aesthetic objects.

The stage is set for the designer as an active participant in a multidisciplinary approach to computer systems design, not a passive user. The challenge confronting the designer as an active participant is to blend the technology into the ambiguous network, changing styles and approaches to design. This integration of technology and design processes may be done by unraveling tacit design knowledge and placing that knowledge in a format that is accessible and understood.

**Parallel/distributed processing** Designers will need to consider the significance of the evolving power of parallel processing when they attempt to blend computer technology into the styles and approaches of design. Today, complex networks of processors are being linked together to simultaneously accommodate multiple tasks at very rapid speeds. Researching and organizing selected activity aiding in the design of objects through such processes is now necessary in order to take advantage of this new power.

Phases of design that have been thought of as linear or serial may be selectively and simultaneously processed using the full spectrum of these new
systems capabilities. For example, designers might gain from distributed processing by searching information about historical design references while comparing color relationships. Simultaneously, designers might select a series of procedures that could be used to develop an object's geometry.

Multi-tasking can provide a cadre of resources including links to super computers through desk-top workstation networks. One major factor in controlling this power is the interface where the designer interacts with the machine.

Striving toward a direct manipulation interface is a research target of high priority both in the field of systems design and psychology. The direct manipulation interface is one where words, icons, graphs, or symbols are directly translated. This manipulation in real time, affects change in the corresponding computer's understanding of the meaning of the current state.

The interface should accommodate the designer wishing to follow traditional design approaches. The decomposition of a problem into pieces, then recomposition to test the whole is one such example. Tacit design knowledge that is difficult to articulate in words may be represented better through changing visual imaging or graphics. This may include the retrieval and review of computational history. Visual, spatial working styles may be better suited to using a visual language syntax of directly manipulated pictures and symbols.

It can be reasoned that direct manipulation interfaces and complex object data and procedures can be synthesized into a support structure for a mental model that is represented by a virtual space (Brooks, 1988) and virtual worlds (Schon, 1988). The images are projections of virtual objects that are
manipulated and controlled by a concert of the mind and hand of the designer. This can be compared to a traditional design approach, where the designer uses a mind-eye-hand-sketch feedback loop while developing objects and spaces. (See Fig. 3)

Fig. 3- Traditional design feedback loop

Although an artist using a computer paint program might use a mind/eye/hand/sketch/feedback loop, he or she might sense a very different mental model of the system. The surface orientation of painting suggests that a mental model may be understood of placing color on the back of a piece of glass or the surface of a video tube. In the described three dimensional mental model, this two dimensional metaphor can be thought of as a surface, translated in space into position at the picture plane. In a way, the aspects of three dimensional computer modeling for designers working with a three dimensional mental model is like Alice in Wonderland piercing the looking glass of the computer screen to find the mind play of the virtual world.
**Computer Graphics** Graphics are very useful when solving spatial design problems (Carroll, Thomas, and Malhotra, 1980). The designer has the benefit of a wealth of ongoing research in computer graphic digital scene simulation. Images from the screen, acting as feedback in the design process, can represent entities that are models of real world conditions. An example is computer graphic simulation of phenomena; such as geographic, topological, and meteorological conditions affecting wave activity on a variable shoreline (Peachey, 1986). Basically, mathematical tools, procedural descriptions, and representations are available for designers concerned with the visual aesthetics of created objects, relationships, and contexts.

Rendering techniques now in use, representing transparency, refraction, multiple light sources, and textural qualities, can be used to model aesthetic virtual environments. Continued research for new developments in this area combined with the power of this technology promises more quality examples and better communication between designers and clients. "Designers have found that clients have been more receptive to their concepts seen on a computer screen than in the form of sketches on paper and clay models" (Aldersey-Williams, 1987, p. 42).

Metros (1985) describes a computer system for the manipulation of graphic images through transformations. This method of transformation and multiple variations of the design seem to parallel the work of Reese (1986). He describes and illustrates comparisons of related composite images. The original, apparently unrelated, reference object is transformed and becomes a new object with a different function by dismantling and distorting the geometry. The exercise does not utilize a computer.
If the computer moves toward becoming a more valuable associate for the designer (Ballay, 1986), a need exists to formalize and externalize the sometimes tacit knowledge held in the mind of the designer. In addition, communicating that knowledge to computer system developers will enable custom designed software computer tool kits. Current professional practices converted to computing could stimulate effective new approaches to design in the future. Structuring design procedures may become commonplace as computing in design matures. Processing the complex and diverse information that surrounds wicked problems will further empower designers by enabling them to participate in design processes at a higher level and with greater control.

B. The Fundamental Need for Tools

Parallels can be drawn between the effect of tools during the Industrial Revolution and technological advances in the information revolution. During the Industrial Revolution, tools affected design because of the shift from physical limitations to mechanical limitations. New tools for manufacturing resulted in multiple objects of the same type, character, and quality. The mass production resulting from tools of this period created a change in aesthetics that deviated from the crafted way of the past. The change represented the quality of the new object character, references, and culture and is evident in the work from the Bauhaus school (Whitford, 1984).

Maycock (1988) suggests the occurrence of two different types of tools: the physical and the intellectual. Physical tools are those tools that are real world objects, such as a hammer or saw. Intellectual tools are internal, cognitive tools that aid in the performance of work. For the first time in history, the power of the computer permits some rudimentary internal tools to
be implemented in an external fashion. As a more complete understanding of these cognitive tools occurs, portions of the intellectual tool network can be added to a knowledge base for design action.

When design is coupled with computing, a shift occurs from the use of traditional physical tools to intellectual tools. Intellectual tools used when designing with the computer may reduce the stature of the physical tool network. Certain accepted practices may be absorbed or, in some cases, discarded altogether.

"Intelligent" computer systems. Two developments help describe the advent of knowledge sensitive tools. The first is "expert systems". "Expert systems" are those where the actions and objects of functioning human experts are traced. The knowledge, essential activities, and outcomes are extracted and analyzed. A system is then structured to imitate those activities and outcomes of the experts in application domains. The information elicited from the experts is often directed toward an "optimization model" and tends to be a closed system, directed toward the completion of a specific task or tame problem.

"Optimum solutions" are defined by simplicity, economy, and function. For expert systems to be more responsive to the wicked problems that designers often deal with, criteria need to be developed that define expectations of desired qualities. New strategies need to be refined to elicit subtle awareness, knowledge, and opinions of individuals associated with the action and the object. However, the multiple domains often associated with wicked problems make this more difficult.
Rittel (1988) states that issues, positions, and arguments are the structure under which wicked problems are satisfied. The Issue Based Information Systems (IBIS), a questioning strategy for designers, can be viewed as a tool for the social structuring, collection of information, and reconciling of positions (Rittel, 1988). This strategy is part of the inclusive view of designing and does not seem to be problem or domain sensitive.

The second approach is the observation and tracing of a particular designer's actions and objects. This approach represents the exclusive view of designing. The style, character, and quality of particular objects, such as monuments, sculptural works, or graphics, of a given individual are critically evaluated. An example of this approach is to analyze the various components of a style, such as in Mondrian's painting. Once the basic geometries, colors, and other formal qualities are understood, new paintings can be created similar in style to the original artist's (Goodman, 1987). Furthermore, artists painting in the style of Mondrian may insert their own personal statements into the work. These subjective qualities need to be included in a computing system to encourage users to input actions that will take the "Mondrian type" prescription and flavor it with their own style.

Problems associated with both of these approaches include the selection of the "expert". Also, the varying nature of design problems makes gathering meaningful information from the "expert" difficult. Another challenge is blending the information gathered to form a unified whole that embodies the desired state. Tool specifications should include techniques for structural decomposition and questioning strategies for problem formation and reconciliation. The means should also be provided to restructure solutions so
that they represent a united whole as opposed to meaningless isolated units or partial solutions.

Research in human factors suggest there is no single approach to developing an expert system "... one can base the expert model on an abstract expert derived from some normative model or attempt to capture in a descriptive model how a good decision-maker currently performs the task. Many examples exist for both of the above approaches" (Atwood, 1984, p. 51). The development of a computer interface for the design of three-dimensional form begins by identifying essential components of the activity involved. Although difficult to define, samples of existing approaches used by designers to generate three dimensional form are structured into the conceptual model. Traditional practices in aesthetics that form givers employ will be emulated as much as possible along with the incorporation of common elements found in basic design activities.

The conceptual model may be put to practical use through the power of very sophisticated computer image and object generation packages which are within the reach of many designers. "Intelligent" tools may become part of the designer's toolkit. These tools might gather information to form heuristic programs. This type of tool might be self adjusting and connected to a feedback loop. For now, however, only those tasks in form-giving that show promise should be relinquished to the computer. An example of such a task might be the generation of multiple variations of a three dimensional form where a rule can be conceived and applied.

To involve designers who have various cognitive styles, a successful interface for aesthetic three-dimensional form development will be endowed
with a structure that allows for expansion. At this point, this study is directed to those designers of three-dimensional form who are visual and spatial in orientation and have a particular sensitivity to aesthetics. Tovey (1984) associates those who are visual and spatial with a solution-focused approach to design. For computer systems to be effective in design, solution focused strategies should be built in. Cross (1985) addresses the importance of CAD systems incorporating this approach.

Each designer has enough freedom to tackle a design problem in his own preferred style. But all will need CAD systems that support a solution-focused design strategy, rather than systems which offer problem-focused analysis strategies (p.161).

**Relationship of Tools to the System** Tools have traditionally been designed to relate closely to the human user. Some even allow adjustment by the individual to better fit the body and the tasks to be performed. A tool that illustrates this close relationship is the scythe. The mechanized tools that followed mimicked the linear objectives of the scythe by addressing the task of cutting in the same way, but with bigger, multiple blades. The linear, continuous qualities of the assembly line have benefited man since the Industrial Revolution. Mechanical tools can perform tasks at greater levels of complexity, but are still subject to the overpowering order of line processing.

Parallel structures are complex actions that require an orchestration of activities in unison to affect an overall sense of unity. The novice operator of a "back hoe" earth-moving machine might perform his task in a linear fashion, performing each of many motions that can be done simultaneously by the skilled operator. The novice treats each degree of freedom that the shovel can
move as a separate task. In contrast, the experienced operator manipulates many of the control levers in concert, where the goal state of the bucket's position is achieved as a single physical process rather than a series. This type of operation represents a unity with the tool.

Another example is when a military aircraft pilot needs to monitor many systems on the plane at one time. Complex methods of simplifying this task have been devised for display and actuation of on-board systems. Without looking away from the canopy where the external visual environment is monitored, weapon systems can be aimed using information and motion tracing that is displayed and overlapped in multiple windows. Likewise, as the power of parallel distributed processing in computing is fully realized, these complex, multiple actions and traces may permit the designer to play a similar role in the design of objects.

Lateral tools relate to one another in a network, or tree configuration. Depending upon the action required after a node is reached, a different tool might be used to continue toward task completion. This tool kit may be comprised of many specialized, task related tools. A particular tool may be called upon only if a design strategy requires that actions toward a resolution pass through a given path or node.

The designer directly manipulates and controls complex networks which, working together, may add to the aesthetic qualities of objects. Strategies are included that allow designers to place themselves at an appropriate aesthetic distance while form is being structured. Direct manipulation of geometric transformations might be done in perspective projection, while analytical tests are placed in the background and only monitored with a flag or
gauge as feedback. The complexity of multi-tasking can present difficult problems such as how and when to invoke lateral or parallel resources at the disposal of the designer. At a future time, neuro-networks may prove capable of replicating human thought-processes that deal with these problems.

Designers may want to use the system as they think of a new idea and generation of solutions to design problems may happen at any time. This may result in the need for a portable terminal component that can be connected to the multi-tasking system. This portable could collect or retrieve information and graphics as the designer conjectures new ideas and resolutions while physically being in a remote location.

C. Making of Art and Designing

At the raw materials level, the computer is generally a computational engine. The main functional attributes with which it is associated are complexity, storage, search, calculation, and logic switcher or inference engine (Dreyfus, 1986). Many technological advances have been made along with projections for future development of this technology. For example, speech recognition vocabularies have reached 20 thousand words under experimental conditions (Baecker and Buxton, 1987, p. 395). Meindl (1987) states that the number of transistors on a chip has surpassed one million and, by the year 2000, a billion components will exist on a chip (p. 78). In addition, expectations are that processors will become 10 to 12 times faster. Storage capacities of approximately 200,000 bits per square inch magnetic and, in the future, of 300 million bytes (approximately equivalent to 300 novels) are predicted. Transmission on fiber optic lines of 250 thousand miles operating at 25% capacity at 10 billion bits per second is predicted as well. Other
improvements in reducing gate delay (200 trillionths of a second) and a reduction in cost per calculation (about 20% to 30% per year) may soon be realized (Peled, 1987, p. 56-59).

Through the creation of objects and images, both art and designing affect the development of culture. There is a rich problem space for object definition that is derived from the emotional, as well as the intellectual. A potential application of computing could be as an artistic approach to geometric construction and attribute definition. Aesthetic resolution is indicative of the attainment of a satisfying relationship between the designer and the work and may indicate the existence of formal qualities of order. Achievement of aesthetic resolutions are being revealed in thought provoking, complex solutions. These solutions would have been beyond reach if traditional methods of form-giving were used. Selected examples where harmonies are achieved between technology and art are reflected in the complex surfaces and growth patterns in the animations of Kawaguchi (1983, 1985) and the complex mathematical sculpture of Resch (1983). In addition, Leifer's students (1985) programmed a dance performance using an articulated, computer controlled, robot arm. The robot arm, unintended for aesthetic movement, was programmed to create a quality visual performance.

In design, the computer functions well as a computer draftsman, publisher, toy or playground, and analytical tool. The computer is also becoming an archiver of artifacts such as images, draftings, or reports. Exclusive, specific design tasks may be more amenable to using computational models than the inclusive, more general design problems.
For both designers and artists, an increased speed of execution can provide a significant contribution. Maycock's (1988) comparison of the work that artists accomplish, the skills they require, and the tools used in the creation of art with parallel activities that are performed by others engaged in skilled work is helpful. His analysis indicates that criteria applied to other work activities might also apply to design. The purpose in applying criteria is not to constrain, but to help in the task of understanding common threads that flow through design processes. The designer may reject the limits of time as a measure of productivity and view the study as an intrusion. Yet, the ability to measure time against a problem should begin to reward the researcher in the ways in which the designer functions.

An assumption is made that design problem-solving is satisfied by the designer working through selected segments of the "approaches" to design. The cognitive style of the designer is an important factor to be considered in viewing design activities and problem solving. Ward (1984) reviews research related to this topic with regard to designers. He reports that there is consensus among the majority of researchers that spatial ability is located in the right hemisphere of the brain. Some researchers have also concluded that creativity is located in the right half of the brain as well. Ward states that "The non-verbal (right brain) process plays a very important part in the act of creation, and designers develop means of accessing the right brain model. This accessing is done through representational systems which are sensory based...the processes used by designers in their work involves the use of a different representational system than that in which design data is available, and this results in an increase in solution poverty" (1984, p. 229).
Designers seem to straddle the two domains of the verbal and the spatial. There is some evidence that people select the kind of work they do based on which half of the brain dominates. "There is danger that quality, itself the very essence of 'goodness' of a product, becomes associated with the verbal and conceptual issues at the expense of whatever non-verbal constraints might apply" (Ward, 1984, p. 233). Ward (1984) summarizes the general opinions of researchers regarding brain processing. Visual memory, understanding metaphor, drawing, parallel thought and integrating process are typically associated with brain processing in the right hemisphere. Some abilities associated with left hemisphere brain processing include sequential thought, analytical process, reading, writing, and verbal memory (p. 231).

Theories of cognitive development show that thought is developed and externalized by an appropriate language. This language has been traditionally focused on verbal language. Research is revealing the characteristic features of another mode of thinking which is clearly part of design thought and behavior (Cross, 1984).

Cross (1983) identifies cognitive styles of designers as falling into the following categories; divergent or convergent, impulsive or reflective, and serialist or wholist. The interface must address all these styles, but more importantly, if possible, it should encourage the strengthening of individual abilities to cross over to other styles as well, such as when visual holistic cues can be enhanced with the incorporation of serialist views. The idea of integrating styles is based in directing the mind to learn and perform well in the spectrum of cognitive styles that are prevalent (Cross, 1983). Since much of education caters to serial thinking of the left brain, divergent relationships of
"right-brain centered" activity might be developed to respond to the image processing power of computers and the ability to communicate so much information holistically as an object.

Problems are defined more clearly in the dynamic process of decomposition and recomposition to a variety of resolution levels. In simple object solutions, the system might help predict when this can or should occur. The ability to associate pieces with the whole must be streamlined to assist the designer in decisions that affect the developing form. Procedures must also be developed to ensure that the contextual relationship is not overlooked in shifting from details to an overview of the object.

Much of the information exchange can be handled visually. The designer must possess the necessary visual and intellectual skills to permit understanding of information presented at the interface. The complexity of the material will require that a portion of the information be presented symbolically and, therefore, somewhat cryptically. Visual language that communicates a more precise interpretation should be combined with other symbolic forms and words to effectively convey the level of concreteness or ambiguity desired. The computer interface should address the complexity of information as a major factor, saving and retrieving data arrays while interactive work continues. As the wealth of information about form-giving accumulates, the diversity of information is also significant.

Traditional approaches to design will continue to serve the designer who is without a computer in his immediate environment. Obviously, even when present, the machine cannot substitute for thinking or professional involvement. However, as computer systems become even more portable and powerful, it is
hoped that the issues of proximity and spontaneity, present when sporadic design synthesis is occurring, can be resolved.

D. The Use of Metaphors and Mental Models

Interesting comparisons can be made between a number of metaphors found useful in forming objects using a computer. The building bricks metaphor, pushing and pulling surface metaphor, molding metaphor, and the scraping metaphor (sand castle/snowman metaphor) are used to represent activities that are done when making objects. The building of larger objects using smaller sub-objects parallels the metaphor of building a structure of bricks. Individual pieces of the whole are designed and constructed as units in virtual space; then the objects of various types and details are assembled to form a whole. Altering this structure becomes problematic because of the need to evenly affect the whole system of objects with whatever change occurs. If the objects can be viewed as a single network once construction reaches a certain point, then the object as a whole should be able to be stretched, pulled and pushed somewhat like a lump of clay.

Once this activity reaches a certain point, the designer may once again want to separate the whole into subunits in order to scrape or scoop away many of the pieces. Scraping away snow from a snowman provides an illustration of this concept. However, if the object is represented as a three-dimensional surface or skin, then this type of transformation may need to be viewed as surface deflection rather than removal of a solid material. These manipulations might remain operationally transparent to the designer or be viewed as another metaphor, such as stamping or embossing. Conversely, additional material or sub-objects could also be added to the whole, or its surface could be deformed
in an outward direction.

Many ideas presented here have origins in the building or manufacturing process. Other approaches might use forces and constraints to deflect surfaces, such as an example that relates to a metaphor of a curtain waving in the wind constrained at several points (Weil, 1986).

**Painting as a Mental Model of Computing.** To simplify computing, a metaphor or mental model such as painting is often used. Norman and Draper (1986) point out that the user builds a mental model of a system. For instance, a mental model of an artist painting is reflected in "paint systems". The programs that function in this fashion transfer actions of the hand through an interface device, such as a digitizing tablet or mouse, to an image on the screen. The creation of objects or shapes occurs after the interface device has moved to select an icon on the screen that represents the actions of a pen or brush.

This metaphor of painting using a computer program seems restrictive compared to the mental model of painting, especially if the user is a "painter". However, the metaphor and the analogous activity rapidly increases the ability of the individual to interact, learning to make marks on the screen. This is especially true for the novice. A method of understanding some of the action of the graphics program is created. A composition can be produced by the computer using tools that represent or correspond to tools that are often associated with the "painting activity". As the external myth is used, a change in the understanding of painting occurs resulting in a divergence in meaning.

More pertinent to this study are the tools that represent complex activities on a higher level rather than those that imitate directly, such as
modeling the classic activity of the painter. For instance, an individual may wish for a paint brush of colors that could be used to create a rainbow with one stroke. Although the artist can double load a brush with two colors to get a blending effect, the result is not the same. There is no traditional process that mimes this action. A relatively simple program could illuminate tube phosphors in a variety of rainbow effects. With the gesture of the hand moving an input device, a rainbow of color can be "painted" on the screen with one motion. This higher level operation represents a new type of activity, that in traditional practice would have required multiple steps, including the mixing of colors and brush cleaning.

Other examples of this higher level of operation include pre-programmed primitive shapes, such as squares and rectangles that can be distorted and cloned. Special effects are also available; such as, interpolation or the blending of two colors over a shape. Furthermore, shadow effects can be added by selecting the shape that is to be affected. The corresponding areas of the surface are tinted to represent spatial cues appearing as a shadow. Many of these tools were developed as a result of understanding that a type of higher level illumination tool would be helpful in the image making process.

There are tradeoffs as these new, higher level tools are created. The complexity that exists and the parallel activities of the "haptic channel" (from the hand) are not captured in the rather clumsy, two dimensional interface device (e.g., a mouse). Pressure sensitive tablets have been developed where the amount of pressure thickens the "painted" line on the screen thus reflecting an "empathic" stroke. However, these tablets are not commonly available.
**Sculpting as a Mental Model of Computing** The shaping of objects using this mental model emphasizes mind-eye-hand coordination and therefore, best serves those who work visually and can manipulate objects spatially. Classical additive and subtractive methods can be simulated reasonably well, such as form carving, scraping, pulling, bending, attaching, cutting and material adding. A representative visual description of the resulting object needs to be "seen" to help in understanding. This approach seems to present a direct task manipulation with a rapid learning curve for those familiar with sculpting. However, the system must bring additional learning to the designer to enable him or her to take advantage of "mathematical sculpting" tools, a less traditional way of object form-giving.

Parent (1977) describes sculptural tools (including mathematical sculpting or shaping objects to act as tools) as subtractive, additive, multiplicative, scraping, pulling, or form pushing. Additional examples include three-dimensional sculpture programs that parallel paint programs and Boolean operations on geometries.

Designers can expand system capabilities by developing mental models for extending mathematical tool development. This often requires designers to overcome their hesitation to learn a new system, especially when gratification is found in current methods. At stake is the entropy that can exist because a system just does the job.

Feeling the tool, as in the case of pulling the data control points, may have value (Parent, 1977). A technological jungle gym environment, using natural relationships and analytical feedback while, for example, interactively playing with a stereo pair using a data glove (Foley, 1987), might present an
understandable mental model for 'would be sculptors' that work with physical materials.

The work of Brooks (1988) is very much in keeping with the integrity of the three dimensional mental model. The designer must be aware of the relationship of the object to the action. The referent or context is important to the process. Thus, direct manipulation of computer modeled objects must be tempered with both distance and engagement.
Chapter VI

The Conceptual Model

Giloth and Veeder (1985) describe an artist or "visual worker" user model that in many ways parallels the description of the designer in this study. This model suggests a "computer graphics research environment" rather than a prescription of a "paint system" for an interface. "A flexible, generalized environment, with rich information feedback" is theorized. In this milieu "artists like to function and their propensity for progressive tool development and customization" would be met. Such a system should: "1. Provide an information-rich environment. 2.Develop a clear and minimal menu structure. 3. Support user-customization of the environment"(Gilloth and Veeder, 1985, p. 66).

This chapter provides a conceptual model for the interface between designer and computer. Cognitive style, context, and problem types are identified as the major variables in developing the model. These variables require that the model be used to generate specifications for an interface for designer-computer interaction.

A. Overview of the Conceptual Model

The model consists of major variables affecting the interface. The model's operational structure clarifies the type of information that is being transported between the designer and the computer. This information is
important to the function of the interface and is an integral part of the required action.

Current design examples, where computers are used as significant contributors to design processes, are described. These examples provide a better understanding of the conceptual model along with a means to begin to functionally test the model.

The specification of the conceptual model continues by describing spatial interface components that support a three dimensional mental model for design activity. The software interface helps train the designer and, conversely, the designer "trains" the system as he or she is involved in the processes of creating portions of a tailored interface system. A uniform approach focuses on the designer as a participant in the custom features of the system.

The designer constructs portions of the input and output in order to respond to both standardized and customized form-giving tools and procedures. In the model, interaction with the computer typically occurs at a very high level, using languages where symbols organize and control object-oriented programming. A uniform strategy, common elements in the interface construction toolkit, and adherence to fundamentals will be important to ensure continuity between interface components that are developed by the designer.

Although the structure of the conceptual model is developed methodically throughout the chapter, a diagram is provided in Appendix A.

B. Operational Structure of the Model

The major variables affecting the conceptual model are: cognitive style of the designer, design problem types and design context.

These factors are integrated with the model's basic operational
structure. The basic operational structure consists of three major nodes: design reference libraries, design action, and evaluation. (See Fig. 4)

![Diagram of basic operational structure]

Fig. 4 - Basic operational structure of the conceptual model

Integration of Major Variables with the Basic Operational Structure. Integration of the individual's cognitive style and the flexibility to custom tailor the interface system are factored into the specifications. The model resides in the universe of design context which encompasses the world of the problem type.

Integration of Cognitive Style with the Operational Structure. Comparisons can be made between the designer interacting at a high level with the computer system and the actions of a fighter pilot, a backhoe operator, and a film director. The designer at times is like an experienced pilot or a backhoe operator who function closely with their machines. The machine is an extension of the physical expression of complex actions handled in parallel. Mind-eye-hand skill and training, as well as perhaps, a special, almost athletic
talent, are necessary to achieve the desired effect. The interface requires gestures and motions of input devices to cause interactive design action. In many cases the designer is directed to browse through visual, spatial displays to receive results. This is true when interactive visual work is being done.

A different metaphor at another level of interaction is that of the designer acting like the director. In this model, part of the interaction occurs as a type of preliminary function where the designer plans scenarios to be carried out by the computer and then turns the plan over to the computer for execution. Input devices are then used interactively to set events, formalize procedures, and input variables for activities. These devices can also readjust the flow once the scenario begins.

The conceptual model addresses the differences in designers' cognitive styles by building in the ability of each individual to custom tailor libraries and design action, as well as participate in evaluation (See Fig. 5). The designer does this by contributing to planning, programming, and additional system specification. The specifications may then be programmed by software specialists or by the designer using visual interactive programming techniques. Language level, tools, interactive techniques and evaluation all present options. Many of these options take advantage of the visual capabilities of computer graphics.
The Integration of the Problem Type with the Operational Structure. The need for the recognition and delineation of different problem types is another major concern. The designer is encouraged to use the system in cases where the problem type and related potential resolutions warrant it. Particular problem types affect working strategies. Comparing problem types to several approaches to design helps clarify the model's complexity. As implied previously, the exclusive view of design represents more "tame" problems, while more "wicked" problems are associated with the inclusive view. These tamer problems usually start with a limited set of constraints leading to a more circumscribed set of resolutions.
The problem type can be more clearly understood by a rational analysis of the context in which the problem exists. The search for information about a problem is often determined by stipulation, or rules of thumb, assigned by the designer or others involved in the issues surrounding the problem. This stipulation or determination is at times artificially limiting. The design strategy then becomes resolution focused, where objects are conjectured and then analyzed. This method is used to control and tame the wicked problem. In the process, the problem becomes more exclusive. The resolutions are tested in the inclusive arena by the computer. The scope of the problem may once again be broadened, requiring testing of many variations of the resolution. This represents a lateral or parallel approach to problem solving. By making comparisons to information and knowledge about the exclusive and, especially, the inclusive problem, the computer can analyze many potential resolutions.

When constraints are in place at the onset, the complexity or "wicked" nature of the problem of designing a "new" artifact is reduced. A hypothetical example of the development of a virtual prototype furthers understanding. For instance, existing constraints can be recognized in the design of a bottle opener. In the exclusive sense of design, the opener would need to fit into a company's product line of existing bottle openers already being manufactured and currently in a catalogue. Market analysis provides the designer with information that, at a given price, a market exists for the "soon to be designed" artifact. Even the color and texture of the grip may be a part of the manufacturer's original set of constraints. This represents a far "tamer" problem than another, more inclusive view.
In contrast, the inclusive view of the problem might be represented by contemplating the need for a handle, evaluating the need for containers with bottle caps, or determining whether there is a need to package liquids in bottles at all. The socially related problems of drinking, danger from broken glass, and garbage disposal might also enter into the equation. The computer allows analysis of the project in this vast inclusive arena. At the same time, the designer may conceive several additional artifact resolutions of the exclusive problem for further analysis.

The computer's ability to simultaneously widen and narrow the designer's view of a particular design problem during the course of its resolution is the synthesis of this study. For an accurate representation of the union of computing and design, the complexities of attaining this outcome must be considered.

The design action node is decomposed into three identifying components: 1. interactive design techniques and tools, 2. custom tailored design procedures, behavioral factors, and tools, and 3. expert systems, procedures, behavioral factors, and tools. Further details of these components are explained in Section E of this chapter. This sub-division is introduced at this point to emphasize the importance of this continuum as it relates to the world of problem identification and to enhance overall understanding of the model.

Design action ranges from comparing metaphors for traditional visual work at the top of the diagram to procedural control in using expert systems at the bottom. (See Fig. 6)
Most mimetic of traditional visual work, interactive involvement =direct object manipulation, direct feedback

Least mimetic of traditional visual work, interactive involvement =interactive procedure director, indirect feedback

Fig. 6 - Ranges of design action
**Problem Type Consideration.** Similarities exist in the literature in ranking problem types from the most difficult, unspecified, wicked problem to the least difficult, specified, and tame problem. Figure 7 illustrates this concept and provides examples in relation to modeling difficulty.

- **Most difficult to model**
  - wicked inclusive
  - tame exclusive
- **Least difficult to model**

Examples:

*Most difficult to model*: where the evolution of idea generation, or of the psychological and political effects of the resolution, need to be considered and reconsidered.

*Least difficult to model*: Specified resolution where an application of an existing tool will simply resolve the problem (e.g., geometric development by extrusion of surface, surface revolution)

Fig. 7 - Problem type, modeling difficulty, and examples.

A world is established in which the model exists. This world is critical to the model and must be specified. It is defined as problem type determination.

One quality of the model is that in the earliest stages of conceptualization of
solutions to more "tame" problems, a structuring of trial resolutions would most probably utilize expert domain specific knowledge. On the other hand, establishing and examining issues through information gathering, brainstorming, gaming, and simulation would be more useful in tackling "more wicked" problems.

Figure 8 illustrates placing system nodes in the problem type world:

![Diagram](image-url)

Fig. 8 - Integration of problem type into the model designation.
Figure 9 depicts combining problem types and design action hierarchy.

In this representation of the model, designer tailored procedures move up the hierarchy to join interactive techniques (See Fig. 9). These procedures, often developed interactively, will provide problem specific simulation to help reduce the wicked problem to a more manageable, exclusive, and "tame" variety. This is done by the identification and testing of variables that are associated with the context and inclusive aspects of the problem.

Computing adds an unconventional quality to traditional design approaches. As time progresses, the concentration on geometric modeling may be eclipsed.
The Integration of Context and the Operational Structure. The addition of the context completes the universe of the conceptual model. The problem of context often needs to be treated on a case by case basis. Often the designer will bring knowledge to the problem or will research enough of the context variables to establish a starting point. The context problem is not solved, but resolved. Both the context in which the problem exists and the context in which the design activity occurs is included in the universe of the model (See Fig. 10). Constant evaluation of the context is necessary for the resolution of each design problem and is especially important in determining problem type. Simulation of the inclusive problem will give needed information to the designer working at the exclusive level.

Fig. 10 - Integration of context into the model
C. Reference Libraries

The following description presents the importance of reference libraries in design activity (See Fig. 11). These libraries may be custom fit to suit individual designer's needs or approaches to design. Further research may reveal a need for a common structure, especially if there is a standard of shared work at the sponsoring organizations.

![Diagram of Reference Libraries]

Fig. 11 - Reference libraries

**Societal Trace Library.** This library consists of problem statements, needs assessments, and marketing information. The information that is studied by management, marketing or the client is placed in this library. This library
needs to be updated often enough to reduce the time frame problem associated with constant change in the context state. As electronic survey methods continue to improve, the societal trace library would contain processed input directly from the potential users of the artifact being designed.

**Artifact Semantic Library.** A number of terms have been commonly used in discourse about design. The use of artifact semantics or product semantics plays a role in the refining of this model. These semantics of operation and function, and its related metaphor, communicate symbolic meanings through the artifact, to the casual consumer, observer or critic of the item.

Using basic design elements as the lexicon, the semantic attributes are developed and incorporated into the artifact by the designer. A simple example might be in designing a control switch that is scaled to the hand. A rule of thumb would be: if the switch is to turn, design it round along one axis; if the switch is to slide, design a visible track; or if it is to rock, make it look like a teeter-totter. In theory, this promotes the understanding of what the object is, how it is to be used, and even how to appreciate the artifact. It is also speculated that behavioral and social interactions with the artifact can be controlled by the introduction of these product semantics. Thus, information about the artifact can be passed to the user partly through its appearance.

Two examples of this semantic relationship with the artifact are the primary metaphor and the secondary metaphor. A similar description of this was made by Eisenman (personal communication, 1990). The designer most often would use a primary metaphor to promote the understanding that an artifact belongs to a class of objects. The metaphor would aid in the
establishment of the physical appearance of the artifact, such as shape, texture, or color. A functional metaphor (form following function) might be used, as in the case of a car having four wheels, a bicycle two, and a boat having a hull for reduced friction in the water. A critic may consider a desk lamp to be "like a stick or arm holding a torch". This is the primary metaphor of "understanding" that a culture associates with a given form or shape.

Adding "flavors" or secondary metaphors to an artifact may be a way to enrich or add character to it. Many may view adding secondary metaphors as decorative effects. "Modern" design may be thought of as the removal of all secondary metaphor. The attempt may be to either optimize or minimize the form and function. The addition of the secondary metaphor, however, often results in visual complexity and aesthetic variation. When secondary metaphors are added, the desk lamp may take on similarities in appearance to a duck, neoclassic architecture, or to volcano lava (See Fig. 12). The designer has limitless choices in the use of these metaphors as a part of artifact semantics. The importance of the historical reference provided by the artifact semantic library can be quite valuable when establishing the primary metaphor but, perhaps be even more critical when adding visual interest to the artifact through secondary metaphors.

Primary object type is a desk lamp.
The primary metaphor might be an arm holding a torch.
The secondary metaphor may be far more abstract, such as lava, stone, duck.

Fig. 12-Artifact semantic library: the importance of the secondary metaphor
Archives and Style Trace Library. In this library, drawings and virtual models are stored as data bases for later reference and modification. Revision can be incorporated into the current state of the design.

The style trace library would contain a process history of major accomplishments of the designer working on the computer. Accounts of processes would be included as the activity of designing is carried out. Patterns of qualities might be stored as images, textures, colors, and geometry. The unique style of the designer would be depicted through these and other artifact semantic attributes.

In studying a series of design actions and objects, critical remarks might also be added to the files to help designers who are starting work with a new organization. A replication of these processes could be studied or searched for similar order, commonality, and continuity. These traces would become histories, representing a complete catalogue or portfolio of accomplishments. They would be recorded as process network configurations, partially completed variations of artifacts, and images of completed artifacts.

Image Library. This library can be viewed as a scrapbook of objects and processes in nature or the built environment that the designer finds inspirational or helpful. Some of the processes could used as tools in interactive or expert design activity. One example would be the use of the stored image in the library as a texture map on the surface of a geometric representation of a virtual object as design action is taking place. Procedures could be further developed to incrementally step through sections of the library, placing associated color and texture maps stored as images on the virtual form.
**Historical Reference Library.** Historical references contain information about designs similar in type to the current project. Critical awards and honors given to designers of the artifacts would be included. Particular historical references would incorporate both successful and unsuccessful resolutions of an artifact in past activity of the sponsoring firm or designer. Additional references would include images or selections from similar artifacts that have been collected by the designer or sponsoring organization. These histories might vary considerably and be useful if made available commercially as databases.

**Technical Reference and Design Analysis Library.** Graphic standards and safety information would be found in this section. Analytical packages of software and technical information need to be made available to meet the individual designer's needs. This library might include references to objects and shapes that can be used as parametric tools or as a part of the object that can be generated through mathematical methods. One example would be the difficulty that may arise in interactively predicting what spline surface will be formed from an organization of input control curves, edges, or vertices. This may be especially true for designers that have not had experience in mathematics. A curve that does not visually replicate the input data, as in the case of b-splines, can be viewed as quite unnatural by those with a visual, spatial style.

B-splines and patches or surfaces that can be designated are worthy form-giving methods and offer rich possibilities to the designer. An extensive visual library of curves, with the corresponding control surfaces and structure, would be very helpful in developing form using this type of surface modeling
system. The categorization of these curves by visual characteristics would provide a visual reference for the designer. Techniques for forming many of the object types can be accomplished using the hierarchy of B-spline refinements described in Forsey and Bartels (1988) or the use of nonuniform rational b-splines (NURBS). Other analysis applications such as construction or manufacturing process simulation and structural, ergonomic, and contextual analysis are activated from this library as well.

D. Selected Examples of Designers Using Computers

Several examples of designers using computing follow. In each example, critical components of the model are represented. Some incorporate model elements to a greater extent than others. Although none utilize the model fully, it is robust enough to support the design activities presented. These examples provide a better understanding of the model while beginning to functionally test it.

A large architectural firm in the Midwest has entered a joint venture with a large computer company. Software for the system is specified by the architects and developed at the architectural firm. Implementation is carried out on the hardware of the computer company and marketing is done by them. The architectural firm has developed a database of major segments of cities. Three dimensional virtual models of buildings are stored on a block by block basis. Many of the buildings have not been designed by the firm, but have been entered into a data base to represent the urban context for new buildings. Those that have been designed by the firm are represented in much greater detail.

The firm also practices interior design. The data base has much greater detail in those spaces that have been designed in existing buildings. Doing
interior design for an interior space develops a more detailed data base of the building housing the space. The context analysis adds to information for the overall data base and particularly helps prevent duplication if other spaces in that building are to be redesigned. Because these spaces are often subject to redesign, the investment in three-dimensional modeling is a sound and lasting one.

In several instances entire buildings were designed, simulated, and tested on the computer. Typically at this firm, most of the drawings associated with a project are done on computers by architects. Early massing studies are done to determine functional relationships. These studies are charts traditionally done by hand and are now, in some cases, done on the computer. Facade studies are done using the three-dimensional models on the system. The facade studies are isolated on the screen and placed in electronically scanned surroundings that have been video-captured or transferred from a photograph. The medium in this case combines the three-dimensional data base onto the two-dimensional scanned image. The final composite image looks as if a photograph was taken of the building in its designated location before it is built. This simulation of the building and its surrounding context may be used both to reduce the artistic license of the renderer and to give a more descriptive view of the context. Thus, traditional rendering techniques have been replaced in some cases.

In addition, energy analysis, sun angles, and shadow casting are part of the analytical portion of the system. For instance, the way the sun will enter a room or the way a building's shadow will affect the neighborhood can be simulated to test environmental effects for any day of the year. Furthermore, structural analysis can be simulated, using the virtual building modeled in the
machine. Spatial placement of components from standard libraries or layouts can configure interior space, while to some degree, heating and cooling systems, electrical systems, and lighting can also be simulated.

Finally, real time wireframe images can be rotated and examined while evaluation is performed and changes made where appropriate. At the computer, the client may directly participate in this evaluation with the designer.

Another example is found in the packaging industry where the computer is used to reduce product lead time by helping the designer develop packages. The competitive nature of packaging, the rapid rate of change, and the resources of large companies have driven this industry to computer aided design in order to maintain a competitive edge. The major benefit of computer technology to the company is internal, the objective being to compress product lead time.

Company X and Y use the same "turnkey system", or computing system that is marketed by the vendor as being ready to accommodate design action. In both cases, the turnkey capabilities were expanded to help with specific needs and problem areas. In company X, isolated technical departments, working on the same project, would often duplicate efforts or work on unnecessary variations. Thus, systems chosen to support this effort or the need for commonality may make them harder for designers to use. The turnkey system used by packaging company X is custom tailored by the software vendor based on requests and input from the package designers. In addition, company X uses the computer to a greater extent than company Y to do finished renderings or product illustrations as a part of presentations to clients.

At packaging company Y, a packaging designer writes procedures that
significantly customize the turnkey system. Although both companies use the data base to help create prototypes, Company Y uses the data base to reduce the lead time by machining molds from the three-dimensional virtual model data base. In as little as one week, a blow molded bottle can be filled with contents and viewed by management. The graphic art director often takes part in the evaluation of the object while on the screen. The data base is used to analyze the package for volume. In company Y, a rich historical library has been established to reference past designs. These systems, with tailored software, have become sophisticated enough that packages can be developed based on the data base of the virtual model. Closely related systems are used for design, presentation, analysis, archiving, and prototyping. Thus, the speed at which a product enters the market is significantly increased.

The third example of designers using computers is in the shaping and forming of consumer products. At an electronics firm that designs electronic devices such as telephones and communications equipment, the computer is used to integrate idea sketches, model shop, and photo studio activities into a single interactive process. "A computer now helps us capture our concepts in three-dimensional form and gives them color, substance, and motion, all at the will of the designer." (Soren, 1989, p. 35)

The integration of a number of systems is the most difficult problem because of the data base incompatibility. Experience with traditional techniques is reported to have proven useful in "mastering the new technology". As with traditional techniques, visual subtleties of form, and the judgement of them are completely at the designer's discretion. But because the computer defines and depicts objects three-dimensionally, the designer gains more intimate knowledge of an object's geometry. This deeper knowledge promotes more detailed
exploration of solutions, much earlier in the design process. The system's rapid response to inputs heightens this incentive to explore. (Soren, 1989 p.35)

The selection of the turnkey systems was based on the geometric modeler. A surface modeler was selected with needed features of animation. The animation capabilities of the system have been found to be more useful to the marketing and promotion people than to the designers because of the increased time required to render the images (15 hours to produce 30 frames or one second of animation). It is recommended that technical support people be added to "support systems administration, file management, file backup, and security. Technical problems have caused some unproductive overhead." (Soren, 1989, p. 37)

"Users eventually outstrip systems performance, especially users of the new generation of systems with improved interfaces. They are so much easier to learn that the users are soon wishing for and demanding additional tools and functionalities." (Soren, 1989 p.38)

The fourth and final example of designers using computers comes from the design of documents. This is the most tested and widely used of the examples. The design and resulting documents are two-dimensional. Presently, desk top publishing is causing a dramatic change in media with a related paradigm shift.

Many companies which have in the past used external vendors to prepare documents have now changed their approach. Paper documents can be produced on the desk top with pictures scanned and added to the page. A final high quality reproduction can be completed by "outputing" the digital screen page to a laser printer or film for offset lithography. Most of the print shops
queried by this researcher have stated that a designer using the software available for the Macintosh can meet a vast majority of client needs.

At many universities and colleges, papers are created using digital techniques or word processing programs. Papers are digitally cut and pasted; different fonts, in different point sizes are selected for the most appropriate appearance and readability. Chapters are added together, spelling checked, and the printed page simulated while the writer is interactively working on the screen. When the paper is completed, high quality black and white printed copies may be made on the laserprinter.

Color copies are being printed from a digital image composed on a screen. Product illustrations created by procedurally rendering the three dimensional virtual model can be composed on a page with text, headings, scanned backgrounds and images created using "paint" programs. The final document is printed in minutes using laser technology and, if only a small number of prints are needed, the procedure is quite reasonably priced.

The procedure involved in establishing a common format for organizing a page layout is custom fit and stored for retrieval by a number of designers. These formats are most helpful if continuity needs to be achieved; for example, documents with multiple pages, such as booklets.

Letterheads, mailing lists and addresses can be stored, to be combined and set using traditional methods. Networks of electronic mail makes this simpler and saves paper resources.

Professional graphic designers are designing type using similar media. The paradigm has shifted to the point that designers specializing in typography use the machine to design type. Layouts are possible on the
computer. In some cases, what the computer is programmed to do appears as a part of the final presentation. Examples of this include multiplying a field by replication and then placing the replicated field on a perspective grid. Another example is the use of interpolated color. An application program facilitated both of these activities. In each case, the images were tailored by the designer. Both activities are tasks well suited for the computer and would take hours of effort to duplicate by traditional means. In the former case, the original unmanipulated image was provided by the designer and, in the latter case, the color pallet was specified. Because the tools are contained within the system, experiments tend to be representations of more interesting processes used in a variety of ways. In many cases, the procedures and programs tend to affect the appearance of final artifact, and as a result, the software developer could receive a portion of the credit.

The ability of the individual to create quality documents is limited as always by design ability. However, the quality of the output often looks better and may be better because of the tools provided. The designer who can use his/her innate skills to create a good document is enabled in the process by computer tools. Thus, today's professional graphic designers are relying on the computer as a matter of media choice. Many create advertising and new specialized characters, symbols, or logotype on the machine.

As can be seen, the above examples of practical applications of computers in design lend support to many of the operational elements of the conceptual model. Nearly all of the elements of the model are used in most of the examples, such as the reference libraries, interactive techniques, the custom tailoring of design procedures or specifications, and the evaluation of the artifact.
early in development. The strength of the applications in the examples cited
most likely would have been enhanced if elements of the model not present in
individual cases had been incorporated.

E. Design action

The description of the model continues by examining the design action
node in detail (See Fig.13).

**Interactive Design Techniques.** Following the model, problem
types and approaches should be considered as designing begins. The computer
may be used to help in this process by analyzing marketing data or other needs
assessment. The conjecture-analysis approach typically proceeds laterally from original segments of thoughts to sketches on paper, the media of choice at this point in the process. The potential resolution is then tested to determine the extent to which the problem is resolved.

As the technology continues to improve, sketching on a portable computer should become more commonplace. The portable computer would enable the designer to query the larger library of information as "solution focused" idea generation occurs. Sketching and drawing could occur directly on a sandwich of transparent digitizer and flat screen technology. This method could simulate the direct interaction of a pen and paper metaphor. The device could be equipped with a library of software, including helpful tools and virtual devices for the control of three-dimensional objects. Historical references could also be externally referenced through electronic communication. These communications could also permit access to current related files about a similar design in progress, as well as analytical software capable of testing a variety of technical issues that require the complete libraries.

Abstraction Level of Visual Language. Typically, design evolution would tend to move from a less concrete to a more concrete representation although major fluctuations on this path would be expected. Figure 14 illustrates this concept.
Less concrete

Immediate mental idea in or away from formal design environment. 
(traditional use of media, for example, a sketch on nearby paper.)

Attempting to use gaming and simulation to stimulate and focus on the problem.

Integration of the use of computing for simulation (imaging studies and gaming).

Computer representation (line, solids, shadows, color, texture).
Digital cinema presentation simulation.

Three-dimensional prototype.

Actual completed artifact.

More concrete

Fig. 14 - Design representation - level of concreteness
The interactive design activity is facilitated by organization and relationship specifications, object tool specifications, and communications interchange or input-output display tools.

The organizational structuring needs to be accomplished before the computing system applications and related calculation can be distributed across the network. During computing activities, actions need to be monitored to detect extreme anomalies and bring these to the designer's attention through visual and audio feedback.

The development of the system requires the input of the user community which in turn requires an awareness of graphic interface standards. This information should be available in the technical library. Procedures should also be established to test interface components introduced by the designer. The purpose of the testing would be to identify where the individual is moving away from standards as opposed to establishing limits. The most effective interface tool set should reflect the individual's own cognitive style. It should also include various levels of direct manipulation of objects and spaces; manipulation of attributes as data; direct manipulation of data as object; and visualization of the data as a form.

Harary (1974) claims that all design can be broken into graph theory language. Assume that the designer can organize a strategy that takes advantage of formal relationships between forms as archetypes, including attributes. Comparisons can then be made using behavioral information collected from a specific group of individual connoisseurs. This input permits the designer to compare information about objects and contexts.
States of the virtual object can be represented in a continuum of abstraction as illustrated in Figure 15.

High level of abstraction

A graphic symbol (simple to very complex structure)

A geometric abstraction, icon, or
drawing convention, such as a wireframe (reasonably
detailed objects, moderately complex structure)

A geometric database/attribute database or
pointers to databases/ rendered picture (detailed object,
but simple structure)

Low level of abstraction

Fig.15 - Level of abstraction for object representation.

At the highest level of interaction, a symbol can be used to represent how one object affects another. Operationally, this is done by the direct manipulation of graphs and relationships. As a computation, it will be necessary to establish rules for the operators that will permit the blending of unlike geometry. Here, the information is presented and interacted with visually. Thus, the role of tool and object become indistinguishable. As technology and knowledge engineering assist in such complex processes, this level of interaction can be viewed as control through direction in which the designer becomes a director of the visual design processes. Ideas might be
represented to the computer as words, in the form of attributes and metaphorical
descriptions. The machine, through complex fuzzy macros and sensory
stimulation, might "make" interpretations and representations through searches
and the use of heuristic strategies.

At a slightly lower level of interaction is a language of parameter
curves, surfaces, and objects that act as representations of abstract modeling
tools. The designer's thought processes must permit the transfer of
knowledge about visual spatial relationships from the more realistic world of
image representation to the more abstract world of coded information. The
relationships are applied to equations shown as curves or drawn curves,
surfaces, or three-dimensional geometry. At this level, a one-to-one
relationship between the tool and change still exists. There is a direct sense of
continuity of visual manipulation between the action and the object (See Fig.
16).

\begin{itemize}
\item \textit{Visual-haptic control over tools and procedures}
\begin{itemize}
\item High level of abstraction
  \begin{itemize}
  \item Symbols
  \item Icons
  \item Images and Pictures
  \end{itemize}
\item Low level of abstraction
\end{itemize}
\item \textit{Visual-haptic control over virtual models}
\end{itemize}

Fig.16 - Level of abstraction and control.
At the lowest level, a virtual object has an appearance, represented by an expert system interpretation of the data or as a picture rendered by the system. If the image is rendered, then a description of the image and its specific qualities, such as lighting and color scheme or geometric relationship and view, can be couched in a structure. This structure may be stored in a file of multiple attributes which, at a given state, represents a frame in time. Such a frame, which can be considered a sophisticated keyframe, can act as a starting point for the next version of the design. Furthermore, it may be used as a reference and returned to prior to beginning another sequence of variations. Objects themselves or a representation of the knowledge attached to a particular rendered image would be kept here.

Operator functions are represented at all levels of abstraction. The lowest level is the direct manipulation function and results in fully rendered multiple views or three-dimensional images in perspective. The system at this level should have a variety of rendering algorithms. For example, one Macintosh application provides a menu of shading, texture mapping and sorting algorithms including ray tracing. This variety provides for rapid surface contour shading as well as slower, more photorealistic renderings.

Eventually, a direct link to other representational forms, such as CAD drafted mechanical drawings or a "real world" appearance model, should be possible. It is difficult to avoid a method of depiction, in the form of other graphic projections, for the alignment of sub-objects. If a more rapid or less representational view is desired for a given context, then alternative levels of depiction are recommended.
Tool Specification and Tool Kit Development. A vital portion of the conceptual model is the specification of useful tools. Tool specifications are important to both supporting interactive techniques and establishing procedural and behavioral design actions. Virtual object form-giving tools are used to create objects of different types. A wrapping or encircling metaphor and a cookie cutter or extrusion metaphor are examples of readily available tools. These tools, such as surface of revolution, tubes, and extrusion, are developed in the DG program (Carlson, 1982). To describe a tube, a curve is sketched on a digitizer pad and then the tube is formed around the curve by a procedure which provides a number of options, including tapers and other variations. Additional variety may be gained by interpolating the Cartesian vertices along predefined cross sections at various positions, creating a fluted tube. The tube can be changed further using other procedures such as shape interpolation with another object.

To create an object that is represented by a surface revolved around an axis, such as an egg or a goblet, a one-half cross section is sketched on the digitizing tablet. The procedure replicates the cross section around the axis and connects the outside edges to form a surface. Thus, the virtual object has symmetry much like turning a piece of wood on a lathe. Predefining the path of the sweeping revolution surface can create an asymmetrical object, similar to a potato. In a more complicated procedure, variety could be made available through control of interpolated cross-sections as objects are extruded. Control can be gained by defining regular data point configurations along a described curve that has a specified cross-section at a desired position. The tubes, extrusions, and objects formed by surface of revolution are often combined to
create complex objects using a block building metaphor. Tools can be developed to mime additive or subtractive sculptural metaphors. Objects can be shaped by moving vertices. When procedures are developed to permit the designer to interactively pull on a vertex, neighboring vertices respond but are less affected. This ability to move vertices allows for the poking and pulling of the surface. Thus, a potato represented on the screen could have areas indented and extended with this method (Parent, 1977). It could be carved by decomposing an internal structure. In addition, if the potato's surface or skin is filled with very small cubes that represent volume, the skin could be removed, and the cubes could be carved or scraped away to reveal a different shape. Thus, as this "potato" illustration demonstrates, modeling tools are an important part of the interface. Several additional examples may be useful in understanding and specifying interactive techniques. Appendix B contains more modeling tool specifications.

The power of the mathematical tools in some ways may supplant the mimetic processes of carving and scraping. The ability to specify various functions is valuable. The designer may erode a "virtual" model, specify a hardness attribute in certain areas of the model or use sand blasting, water runoff, and other algorithms that have less tangible metaphors in nature. Although many of these programs have been developed to test natural conditions, only a few artists and designers have had an opportunity to use them to create images of virtual sculpture.

Additional mathematical form-giving tools may be constructed using an object interpolating tool. This technique might use a rule applied to warp or distort the geometrical data that exists in the "virtual" object. If an individual
designer can define a decorative feature that can be decomposed into shapes, and then applied or subtracted to form the surface, then those qualities can be used as "molds". The object is transformed to the custom appearance based on procedural interpolation techniques.

Forms could be developed or altered by tracking gesturing action. Sketching of gestures in two-dimensions on a digitizing pad or mouse is now being used as direct input for controlling the actions of the machine. Using a two-dimensional input device on a flat surface, such as a mouse, information can be translated to multi-dimensional virtual object affectors through coded programs where input is stored for display in relational networks. This approach could take advantage of the motion of a three-dimensional digitizer or the "dataglove", developing curves or paths from spatial gestures.

Parametric curves also can be generated as a language of gesture. The curve would be drawn by a hand gesture on a digitizing tablet as a reaction to a state of the object data. Some systems take advantage of this coded gesture for controlling predefined and user-defined macro commands for computer-aided design. For example, Chinese temple designers are using gesture to control the proportions of architectural structure (Makkuni, 1986). The language of curves may result in a sort of sign language and be developed to the point where the designer's social language network is altered. An individual gesturing at a computer could be easily misunderstood by colleagues unfamiliar with this interaction.

The relationship between computer form-giving and animation may prove to be more useful once the value of animation as a simulation tool is more fully understood by the designer. An object can be compared through shape
interpolation or extrapolation with another object and then given limits. A third, new object, can be created having properties of the first and second object’s geometry and attributes. This static slice of the dynamic change from one object to a different condition can be studied using graphic display. The objects can be controlled through feedback by the designer or by using a customized procedure.

Describing objects and attributes as well as actions through the use of mathematical tools is important to the designer. The visual language and tool becomes somewhat indistinguishable. Interpolation of geometric data by warping the data to a curve may be helpful in generating new variations of an object. Geometric data can also be warped by a surface acting as a tool to produce a new version. The extrapolation of the form into a new variation seems a viable adjustment to geometry as well.

Rule-base tools are mathematical, representing a mental model normally not associated with simple arithmetic. These types of mathematical tools alter the model’s geometry by using a set of operations to change the current state of the environment according to a rule. Logic may be applied so that if a condition exists, then a switch to another procedure can be made. The procedures can be specified as routines that change geometric data and attributes. The rules can be assigned symbols and manipulated by the designer using the visual and haptic channels. The designer can also develop procedures at a high level. At the same time, the rules used to order the procedures or to cause change in those procedures can return information about what is being done through a trace of screen symbols.
However, in order for the designer to effectively use these tools, he or she needs to have an understanding of the types of procedures that will better achieve desired results through rule-based tools. The framework for building these tools must be clear enough to allow for participation by the designer who does not have extensive training.

One rule governing the use of this type of tool would be a geometric element that reoccurs in a form, such as a module or a progressively changing transformation. Following a rule, the geometry may be transformed and replicated, and then transformed again, creating a visually complex structure.

A description of an algorithm for the design of a tree may be similar to the *nature as a reference* approach. The following example is a simulation of some growth characteristics. Natural growth is a combination of intrinsic and extrinsic forces acting on organic material (D. Thompson, 1968). Growth transformations affected by chaotic attractors provide the setting for a simulation of new objects and contexts, based on the seed values. An example could be found in a spiral leaf which is formed by sweeping a surface into three dimensions with a programmed growth factor. Parts of the leaf are scaled as it is swept. The chaotic attractor might come in the form of a table of rainfall and wind effects that could be controlled randomly by the designer. Mathematical tools can be used to make other tools. Therefore, the geometric data of the leaf may be used as an object itself or a tool, such as an operator on other objects.

These actions may be organized by the designer. Object variations become processes to be compared with the working methods of others or operate according to rules based on a style gained from the study of a specific designer. A variety of action scenarios, such as growth, can be cataloged and
may be addressed based on a topology of forms created. These forms, along with the relative construction variables and pattern formulae, are then stored as a knowledge base and viewed through a display. Thus, characteristics of a form created according to a rule are provided to the designer.

The designer directly manipulates variables of the growth scenario, affecting a different character to the type of a class. The data and knowledge base is then used, as action, for example, to warp a geometry of a different class through a change shape interpolation. The intelligent portion of the operation is to heuristically search for a common fit between the two data bases. If the data is basically out of bounds, then a rearrangement of the data occurs in the tool and grown object that corresponds to the working or object geometry. Appendix C illustrates a "grown" object (Kitagawa, 1988).

One technique of converting the virtual object to an artifact is stereo-lithography. The growing of virtual leaves could be reproduced using lasers in photosensitive polymer to form a sculptural entity in "real" space. Although expensive for many applications and restricted to certain geometries, stereo-lithography presents an alternative to handmade prototypes.

If acceptance of the visual character of objects changes over time, tools that can represent trends in visual motifs may be designed in limited cases based on decomposition of styles of appearance. Systems for understanding geometrical relationships transposed into object statements are important for knowledge sensitive tools. An example of how a recent characteristic could be employed is to assume the need to place a serrated or ripple fold shape on the surface of a tube as seen in many office chair frames.
If a cylinder is created using a simple tool forming a surface of revolution, then a special tool for adding ripple pleating or serration to the cylinder could be accomplished. An area on the tube could be assigned where the pleating or serration is to occur. The cross section of one flute of the serration would be defined by directly manipulating a curve or "v" shape flute graphic. Once the fluting is calculated and necessary data is added to the cylinder to form the level of complexity needed to represent the object, the new form's attributes (such as, scale, density of fluting, or interpreted character) might be adjusted interactively through direct manipulation to appeal to the designer's aesthetic preferences.

In a complex scenario, while the detail of the fluting is being carried out, context relationships and historical references could be checked from stored research data. A questioning strategy could be evoked as analysis and testing occurs. In addition, procedural methods could be compared and alternatives suggested.

However, a less exhaustive level of comparison might better suit certain situations. For example, construction and placement in an office interior of a virtual chair would give the necessary appearance feedback. Then, an automatic-fluting might give sufficient visual feedback so that additional historical or archival searches would not be warranted.

Tools have been a traditional driving force in determining design style, material selection, and a reason for the form. Parallels between the development of the computer and the information age provide clues to the machine's significance in design processes.
Tools and the operations of tools may be traced. The style of the designer may be duplicated to some degree through use characteristics. The tools may then mimic actions heuristically. As designers add to a system, the computer can be invoked to trace the history of the action performed and objects constructed. Constructions and modifications of forms can be tested to either the designer's prescribed standards or to the predetermined standards stored in the computer. Heuristic rules might be established based on the machine's "understanding" of the designer's mental model and aesthetic viewpoint.

Although many seemingly "foolish" rules might be developed, the designer would learn from the "efforts" of the machine, tossing away the absurd and perhaps trying some of the more unusual as input for an aesthetic algorithm (Gips, 1975) (Gips and Stiny, 1979).

**Input and Output.** The input and output components of the interface form the primary connection between the software tools specified and the designer. A visual, spatial, mental model is used to help define the input and output and control of the network. The input and output specification is a major part of the conceptual model and is constructed in three ways.

The standard segments of the interface remain generic to many procedures and applications. Efforts should be made to make this section of the interface portable and able to be separated from applications or procedures. This segment would be similar to the Xerox Star based interface protocols of Macintosh or other standard configurations. Most of these interface components would be surface related.

The second segment would be constructed by interface design software specialists, typically a team of software designers and psychologists.
This team connects the special application and procedural tools to spatial input and output. The team would also supply the user or designer with a high level, interface construction tool kit. Such a tool kit would enable the designer to tailor visual and spatial input and output to specified procedures or applications.

The third segment would be what the user or designer would create with the software interface construction toolkit. It is anticipated that most of the input and output constructions of this segment would be visually, spatially, and procedurally specific. In most cases, this would make them inseparable from the procedure or application. These would be transferable to other systems if the procedure were portable.

Figure 17 depicts the three segments of the spatial interface input and output hierarchy.
Fig 17 - Spatial Interface Input/Output Hierarchy
Placing the visual, spatial interface input and output components into the basic operational structure completes the functional charting of the conceptual model. Figure 18 depicts this relationship.

The spatial display is a major portion of the interface input and output. Cartesian space can be visualized using a mental model of the computer window as a passage instead of a surface.

The categorization of shapes resulting from a procedure may be sorted using a matrix location and based on multiple criteria, including complexity of geometry or surface detail. The designer could determine the shape categories by computer analysis of three-dimensional data and attributes, or by advanced
computer vision analysis of the form. The designer may be interested in mediating at any level of the process. Access to the current state of activity in a form permits the designer, with the help of the computer, to recognize the need to alter strategies that prove to be ill-conceived. The system must monitor actions based on heuristics, returning subliminal feedback to the designer in the form of a tone, flag, or icon tracing the activity. This feedback should not interrupt current interactive processes, unless the data is out of reasonable range.

The interface is enriched by a dynamic network of relationships. There is a complex correspondence of various objects, attributes, references, contexts, and, finally, interpretations and evaluations. Types can be compared and adjusted and act as influences or references on other objects and actions. Properties of object data can be viewed as dynamic elements for control of other levels of complexity.

A spatial, visual structure of interrelations of object variations can be displayed. Objects in transition might be better understood by using graphs, especially by those designers that have a visual, spatial cognitive style. Extensive three-dimensional graphs are possible using computer graphics. The vertices and edges of a three-dimensional virtual surface can be used to make a pattern or map for the placement of results of design actions in virtual space. As an example, an object may have sharp edges or rounded edges with a variety of radii. These radii variables could be controlled parametrically by the shape of the control surface. Where the control surface has greater altitude, the corresponding edges on the artifact could have a greater radii. These surfaces would be parameters of control affecting the original form.
Likewise, the position of the vertices of a three-dimensional solid can
be used to represent a three-dimensional grid for the placement of differing, but
related, structures or appearances of experimental artifacts. A simple example of
this can be expressed by presenting a computer graphic of a three dimensional
'grid matrix' that can represent the various scaled shapes or objects, in this
case of "the cube". Appendix D gives an example of this grid matrix. The
geometry to organize the virtual display is a cubic matrix, made up of a grid
from (0,0,0) at the origin to (2,2,2) at the furthest corner. In this simple
example of the concept, using the position of the Cartesian coordinate as the
multiplier, the objects that are seeds, in this case, the small cube in the lower left
corner of Appendix D is scaled. It is then represented by lines of various length
along the edges, a point at the origin, an object of full scale at the center and a
twice-sized object at the upper right corner. At any other vertex, a rectangle is
formed and scaled to the dimensions of the coordinate elements. The number
and character of rectangles would depend on the resolution of the cubic grid.
The cube and its respective rectilinear solids can then be viewed by interactively
by browsing through the parent solid (cube-grid matrix) in search of interesting
relationships in the offspring rectilinear solids.

This form can be a parametric solid used to represent more complex
structures, such as object interpolations. Different objects can be assigned
places on the grid. The "in-between" interpolated objects can be viewed as
percentage variations at any point on the cubic grid that have a hierarchy of form
based on shape interpolation. As in the case of scale, the percentage of shape
interpolation would depend upon the location of the coordinate position on the
control surface grid (object) as a factor or mathematical operator. The position
represented by the location of objects at various vertices of objects other than cubic grids can be viewed with some interest. These three-dimensional grids might be used to help designate the analysis of object class. This might represent a theory of object surface classification that is visual, similar in some respects to a graph of a color solid.

An extension of this idea is the introduction of a fourth variable in the "grid-object matrix". This variable can be introduced as time in the form of an animation. The object changes in scale related to placement on the grid as in Appendix D.

Each of the rectilinear solids could be animated, changing form from the initial scale shown. If we use the example of the position of the origin changing value to (4,4,4) and, conversely, the value of position (4,4,4) changing to a value of (0,0,0), the designer would witness a dynamic model of the rectilinear solids dramatically shifting to the opposite view position. The visual effect might be similar to the object transformation in Amkraut and Girard’s (1983) computer animation, "Hidden Agenda".

Interactive Techniques, Custom Tailored Procedural Processes, Behavioral Factors and Expert Systems as Part of Design Action

Interactive techniques include the use of tools in real time. For many design actions this has proven to be the most useful method and is well accepted because it allows for direct feedback. A given action occurs as quickly as it is placed in the system. Another term for interactive techniques is a direct manipulation interface. The visual language that is exchanged is typically done interactively. This interactive portion of design activity would be used to control or organize procedures and directly manipulate virtual object
form-giving tools that create geometry.

Expert systems and custom tailored procedures can be considered as degrees of the same activity with one significant difference. Expert systems may be applied generically and often are most useful when dealing with tame, area specific knowledge. On the other hand, custom tailored procedures are often constructed to resolve a particular problem or group of problems and can be considered as part of the designer's special tool kit.

The combination of interactive design techniques, custom tailored procedures, and the expert system forms a hybrid system in which human intelligence and special aspects of artificial intelligence are combined. Decisions would be prioritized: first, by the primary designer, in a direct manipulation session; second, by rules determined by the primary designer in the session; third, by the relationship and general rules tracing the primary designer; and, fourth, by general or "expert" rule or relationship. These decisions would be traced and tested by analysis programs that would alert the designer if a comparison were detected with other sessions, processes, objects, or history. The final object is a part of critical assessment from self evaluation, design energy, and time.

Once the variations of the object are accomplished, the working plan essentially follows the design of a natural, historical, "object as a reference" approach. The advent of "multiple read and multiple write" optical disc technology makes available a medium for mass storage of images at a reasonable cost. Much of this developing information may be stored and updated as images having aesthetic relationships. The archive and style trace reference library can be updated by entering the screen image, scanning related
material, or using video capture.

The two-dimensional relationship can be "mapped" into the three-dimensional world using the information in the image and its defined relationships. This method is limited to the rule set and may or may not be useful, depending upon the designer's understanding of the possibilities. The form of this rule is semantic and may include strings of characters, a code, or geometry. The symbol for the object is acted upon by a behaviorally contrived state.

An example of one rule that might be applied is derived from "The Blue Chair", an animation by Siedman (1986). In this animation, an object that has been texture-mapped onto the surface of a stone is "peeled off" into a three-dimensional configuration. The rule might be represented in the following form; a two-dimensional "texture-mapped" object becomes a three-dimensional tumbling object.

An example of a derivation of the same type of rule for expansion of two to three-dimensional imagery is in using value relationships of an object to form a three-dimensional depth as demonstrated in the work of Philips, Anderson, and Lupidi (1986). The rule in this case may be as follows; a two-dimensional image of contrasting value becomes a three-dimensional object that has crevices where the image is dark and high altitudes where the image is light. An example also would be in using a bump surface deformation as an operator on a surface (Alias system demonstration, 1989). NASA has used this effectively to map three-dimensional planet contours.

Yet another example of a type of rule that might be developed is the control of an object's depth by generating a pattern from data from a musical
instrument. The sampling of the musical keyboard might result in additional control through the haptic channel, perhaps even greater than the direct manipulation of the dataglove. The tone and character of the wave generation could be used to affect object rules. A demonstration of this type was carried out by Ciezeburger (1986).

The visual aesthetic of musical harmony has been the subject for continuing research for John Whitney Sr. (1980). Most of his work has been used to produce a scintillation pattern of colors. Such aesthetic patterns could be used by the designer as object tools or rules for the control of other objects.

**F. Evaluation**

As the designer develops simulations of artifacts as symbols and realistic images as representation, self evaluation and critical feedback from peers and respected critics will lend objectivity to the process. Along with the designer's traditional responsibility to the problem, design process, and the community, certain critical issues need to be addressed. Examples of the evaluation components are presented here as a portion of the model.(See Figure 19)
The first component of evaluation in design is self criticism. This personal feedback can guide the designer throughout design activity. A list of important questions that designers might ask themselves includes the following: Does a comparison of the resolution with the problem provide value to the known conditions? Is the problem type identified correctly or specified rationally? Were processes that were easy and trite, even though visually complex, recognized? Is the time spent for tool building or the creation of new macros appropriate? Will another approach work better in the given context? Will the process be used again? Is there recognizable integrity between the image and reality, especially for the critic? Is the simulation complete and useful regardless of abstraction level? Does the information or simulation presented fulfill expectations? Does the resolution represent an extension of the designer's own view?

Other critics such as clients, structural engineers, and the community of consumers could use traditional methods of description, interpretation, evaluation and theory to communicate design excellence and areas for
improvement. As the designer works, he could share developing data and imagery with the critic so that problems and resolutions can be seen more clearly. Thus, the critic might contribute feedback to the designer as a part of the design team. Fewer surprises may result as both develop a shared understanding earlier in the conceptual phase of the design process when computer imaging is the medium.

Some of the main areas critics may be involved in during the evaluation process include an ability to communicate concerns. The problem and problem type specification should be identified. The critic should compare the artifact with its intended use and identify and communicate cultural and aesthetic biases. In addition, the critic can identify and consult on functional strength and safety issues. Critics should understand the value of initial constraints, procedures and tools. Finally, the critic should share in the work as it progresses.

The critic may become more automated. Such an approach to criticism could be supported by input into receptors for Gips and Stiny's algorithmic aesthetics (1979) and include Thompson's addition of the human mediator (1979) as the designer in the process.

An object that will be designed relates to a context. The object being designed may have sub-structures of lesser objects. Interpretations of the object quality is determined through formal criticism. This interpretation can be based on subjective and objective description and analysis which may be quantified. These interpretations may be determined by a number of methods from consensus of design experts to a comparison of relationships.
The object requires change if it is determined to be out of the satisfying solution set of the designer. A commonality exists if the designer is able to specify a measure for this activity either through evaluation of the designer's own style or through a historical trace that reveals a similar theme or a particular function requiring a limitation. A design that is tightly domain specific to class and object type would also be included here. Value can be assigned to attributes or to resolutions that rank high. The context that surrounds the object needs to be tested and can be done in the form of a simulation. These solutions can guide further conjecture-analysis and synthesis. Additional interpretation and evaluation might be sought from other designers or the consumer. These processes are both comparative and generative and act as feedback for other activities.

G. Communication Interchange of the Conceptual Model

In the conceptual model, the passage of time is the linear element that affects design practice. The dynamics of the communications are represented as a lateral network that can be tailored by the designer or other authority. The connectivity of the model is addressed in the diagram in Appendix A. This represents a typical configuration; however, it is not meant to exclude anyone from the free flow of information. The interface supports the flow of information through surface and spatial input and output using verbal and visual language.

A need exists to generally move information across the model from the less concrete to the more concrete representation of the artifact. This occurs using paths through computer media or traditional media with feedback to the designer along the path. These pathways are indicated on the diagram with
thicker lines representing projected flow. Eventually, after a myriad of decisions, the virtual object becomes an artifact during these processes. If special tools or procedures are needed, interactive visual programming will need to be developed by the designer or information will need to be shared with the software specialist so that specifications for additions to the toolkit can be determined.

The sporadic fluctuations in design action are accounted for by providing a feedback loop to and from most of the elements of the model and to the designer and those critics affected. Often the designer will be the recipient of this feedback. It is hypothesized that information reflecting societal trace, context, and problem arena will flow from the client, marketing, or management to the designer and back again. In many cases, this information will be regarded as authority. The designer initiates additional analysis if he or she questions the information or needs more detail. Much of the information will flow to and from the designer, to and from the libraries, and to and from the critics through the interface where, if appropriate, a computer representation is formed. These representations are viewed and evaluated by the designer and by the critics for the consideration of their own particular specialty.

The delineation of design activity results in significant overhead but, in many instances, may be worth the expense in the long run (Mitchell, 1987). The communication between nodes should be the best available and the most rapid that computer science can offer.

The display has advanced to the point that text, graphics, and video all play in parallel on the same monitor. Designers and the design network can monitor activity from remote sources through multiple windows on their local
computer. Specifications result in the implementation on a variety of devices with transparency as to device and network. The system must be able to display multiple applications concurrently and support overlapping windows. The system should support many application and management interfaces, be extendible, and permit a hierarchy of window sizes (Treadway, 1988).

The conceptual model provides the flexibility to permit the designer to set strategies as to when direct and indirect manipulation becomes the most appropriate course. In the future, mental models based on spatial portions of the interface input and output may transfer to three-dimensional viewing and interaction with data sensors and projected stereo pairs resulting in greater control over simulations. These techniques attempt to create conditions of high fidelity. The consuming quality of this "real experience" is incorporated into a system that involves the designer by delivering enough computing power to calculate real time stereo pairs based on eye position circumstance. The display may become a room or space where each of the critics experience the object, intellectual tools and procedures from their own perspective with the help of the conceptual model.

Until computation becomes more rapid and inexpensive, the tradeoffs for this type of interactivity will be too great for many designers. A symbolic type of interaction is suggested where word description, graphs, indicators, and three-dimensional perspective projections address the current state of any design condition. A preferred method would use interactive video of the conditions as they develop. Since many design activities proceed in a parallel fashion, many functions must be attended to while working on other portions of the project.
Chapter VII

Implications of the Model

A. Using the Conceptual Model in Design Activity: a Hypothetical Example.

Wilkes (1988) describes activities for interface design based on storytelling. Examples set into a story may better explain the implications of the model. Starting at the level of elements of design and moving outward to the development of a tool specification, this hypothetical example looks at two dissimilar, but related objects; a bicycle frame and a bicycle seat. The two objects intersect to form a part of the structure of bicycles. The form of the seat is often adapted to the human body, to the greater or lesser satisfaction of the rider. Through analysis and testing, several satisfying resolutions for the seat may be found.

The intersection of the seat and frame might also suggest that a heuristic of form transition or contrast of the two forms might take place. The two are in the related context of the human rider. The designer may want to blend the form of the seat and the frame by changing the shape of the frame to be more like the seat, with sculpted surfaces instead of tubing. To accomplish this transition, he or she may specify a tool that creates a surface continuity by combining control points on the frame and the edge of the seat. Adjustments are made by relocating several control points on the frame.

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Structural analysis by the computer could suggest an appropriate material. Air flow simulation could compare the proposed frame to a traditional frame. The computer could calculate the weight of the frame with the seat and could even calculate cost based on manufacturing methods and material weight.

Multiple views of the object could enhance the examination and interpretation of the object's relationship to various contexts. For instance, the rider can be superimposed over the bicycle which may then be superimposed over an image of a space, such as a narrow bike path. Judgments about certain design aspects could be made based on these images.

Suppose the design team and the designer decide that a wire frame animation is indicated. This animation scales the bicycle to conform to a small, fifth percentile female "virtual" person, as well as a large, ninety-fifth percentile male riding the virtual bicycle. Using distributive processing, this can be rapidly accomplished on the desktop workstation network. Although the data may be a bit grainy, leg clearance and arm reach may be tested, and extremes of seat adjustment established. Wind resistance and flow around the human and bicycle may be tested in a variety of contexts by linking with a mainframe computer. Furthermore, visibility of the rider and the bicycle's lights at night may be simulated and tested, creating rendered images from various views by a motorist. As this hypothetical example continues, the bicycle may be simulated in an urban environment on a trail near a park.

Assume a parallel design activity is occurring at an affiliated company where an exterior space is being planned. As a spin-off of the planning activity, a park bench is custom designed and modeled using spatial input and display. The bench is then placed in a three-dimensional space, in this case, an urban park.
After the client sees the three-dimensional image of the bench in the context and is informed of the high cost of the custom design, he or she opts for a change in plan. An existing bench is selected from a catalogue of previous designs. The custom bench is "saved" and assigned to the archive and style trace library.

As part of the planning process, the decision is made that the benches will be placed at intervals around the lake, facing the center of the lake along a trail and bike path. A rule is developed to effect these specifications. Using a procedure specified by the designer, the bench is replicated and placed throughout the park. Unknown to the designer and visually separated from the bike path, several of the benches intrude into an area near the bike path.

A simulated bicycle race is held using the objects developed by the affiliated company working on the bicycle design project. A number of scenarios are played out using behaviorally controlled animation. Because of the seed values used, each is slightly different. It is shown that bicycles are leaving the path and crashing into park benches. As a result, the plan is altered so that park benches are moved to a different location. In this case, the bicycle can be thought of as a tool operating on the park bench.

**Implications of Tool Specifications** Tools and procedures are operators that can be employed and consist of any transformation in Cartesian space. Union, intersection, difference, and other comparative relationships, such as interpolation or extrapolation, may be applied to objects. In addition, the complexity of articulated components can be handled by attachment in a hierarchy. If one object moves, all objects attached to it move. Thus, the bench is modified by the bicycle and the frame of the bicycle is modified by the seat. The designer is the director of the activity.
Any object may be viewed as a tool. Basically object data or other sources of data can be used to transfer shape characteristics through orientation of the data and magnitude of the effect. Warping data with other data is a good example of this action.

In order to effect each operation between objects, each object would most likely be of the same level of abstraction. Objects that require more information will be flagged or the current object in the operation will be converted to the next simpler level. If the object is a surface, it may need to be changed to a symbol.

Shapes could also be generated through the interpolation of edges. Blending of two forms has proven interesting in animation that represents object metamorphosis (Amkraut and Girard, 1983; Sadler and Hutchinson, 1986). Sampling or viewing objects at various stages in this process may prove useful as a tool.

Geometrical alignment is a complex problem in matching data bases for interpolation. The objects must be similar in structure or made similar by procedural means. Through data interpolation, any object or portion of an object can be used as a parameter to deform any other. To determine the effect, alignment feedback should be visual. Non-uniform rational B-splines (NURBS), which might work best for problem types that stipulate surfaces, are being used by a number of software companies to establish surface continuity. Much of the design activity in the examples selected is surface oriented. In the packaging and electronic equipment examples, the software uses NURBS.

Analysis of the problem might suggest that surfaces may not be the best method for display and storage. Alternate methods of representation, such as
particle systems and "unsurfaced" contour lines may communicate the designed result more effectively and economically. These techniques are used to form an object by massing lesser independent element objects.

**B. Implications of the Evolving Relationship of Computing and Designing**

To promote the designer's transition from traditional methods, provisions must be developed for paradigm structuring that encourages the understanding of object description at the semantic, syntactic, lexical, and conceptual level. Because participation is the key to the full utilization of computing in design activity, the concept of the designer as simply a "user" of tools most likely needs to shift. He or she needs to be involved in tailoring systems to specific problem requirements and constructing or specifying interface tools as opposed to solely following procedures of a given computing system.

The implementation of rule based algorithms creates a high level action outcome that is derived from multiple low level processes. To take advantage of these high level processes, the designer must become an integral part of the specification process. A more sophisticated knowledge base is needed in the multidisciplinary activities that are required for the development of these higher level algorithms. The designer can best assure that subtle, *meaningful* low level information is not lost in the translation or creation of the evolving rules.

To be productive in planning and specifying complex procedures and design activities, the designer should understand and practice protocols for software development. Successful designers in traditional settings who have acquired computer knowledge, as well as the ability to program, will be in demand. Some of these designers have been hired by software systems
developers; however, until there are more designers possessing these skills, the creative energy of the few who do will likely focus on systems development as opposed to visual work. Designers adept at software development may initially find it difficult to be competitive in areas where more traditional designers develop objects to fulfill other needs.

Computing affords the capacity to handle complexity and increased amounts of information. It can be reasoned that when a more complete understanding of the knowledge surrounding a design problem is available, better decisions can be made. The debate about ownership of this "intellectual property" is an issue to be dealt with. Stored knowledge should be available for researchers that wish to incorporate these references. Having access to information at a higher level of complexity may result in outcomes that might previously have been unattainable. As factors associated with the availability of more complex information are realized, the intent of the designer might also be more clearly communicated; for example, to the critic.

Sharing of objects with other designers is encouraged. Collaborative projects might be implemented over distance and time, using communications networks, common data bases, or interpretation programs. The model asserts a formal commitment to criticism as a part of the design process. This should encourage the involvement of closely related project members such as the client and other management, engineering, and manufacturing personnel to foster better understanding of the problem resolution and enrich design activities.

C. Implications for Input and Output of the Interface

Motion, especially in rotation, enhances appreciation of the dimensionality of the object as a graphic. Multiple views promote a clearer understanding.
Real time animation shows promise for additional understanding of complexity. While the detail of a single part or group of sub-parts requires visualization, other objects that would obscure from view the parts in question can be turned off. The form of representation can also be changed to a higher level such as a wire frame or another similar symbolic form. When complex networks of parts are to be compared and evaluated, the ability to interactively zoom in to a detail and then back out to see the whole of the object is critical.

Motion is helpful for visually evaluating other dynamic effects. Even in real physical world model building, articulation of joint action in objects is sometimes impractical for prototypes. The action of articulated components of a form can be tested through visual feedback. Limits and aesthetics can be evaluated at various positions during movement or under static conditions.

The direct manipulation of the dataglove seems to take close to full advantage of parallel input. This potential suggests that the physical skills useful through the haptic channel should continue to be developed. Physical dexterity may not be necessary if the sophistication of rule-driven systems is fully developed; however, in the near future, the parallel input of the data glove might be useful in the organization of symbols for rules. Perhaps the dataglove on the hand of an agile designer might permit "playing" macro commands like a virtual musical instrument instead of emulating the action of the hand interacting with virtual geometry.

Transfer of input via the haptic channel is parallel and complex. Many designers would value immediate feedback when manipulating the object data. This might be attained through the sensory stimulation of touch and spatial three dimensional imaging. Visual cues will include more spatially oriented features
in a surface oriented interface. The power of the machine can easily generate these three dimensional simulations using computer graphic images. The image is projected in three dimensions from a series of rapidly calculated three dimensional stereo pairs. The position of the left and right eye paralax is read as a reference for the transformations. These images are then interlaced and read through a polarized set of eye glasses.

Using the data glove as a means to manipulate the object, the feel and appearance should be remarkably "real-world" like. The interface initially has a mental model and external myth of sculpting, based on a visual, spatial cognitive style. The hand is required to manipulate the object much like clay is manipulated in sculpting. To represent structure in the physical world, simulation of gravity and material strengths is necessary.

The auditory channel should support the visual, spatial channel. Auditory cues are helpful in narrowing the designer's focus to selected points in the spatial display. The auditory channel can also add clarity to those events unable to be entirely explained by the visual channel. To reinforce the visual channel, repetition of auditory information as a visual cue is necessary. Voice synthesis provides natural auditory language feedback. For example, sentences of English language as feedback could explain anomalies in the data, signal the end of a process, or identify a variance from a proven procedure. Other more inspiring auditory signals from the environment, such as music libraries on discs or the sound of a co-worker's voice may be more appropriate than sound from the computer.

When working in the virtual world using three dimensional viewing of stereo pairs, the space seems to surround the activity. The spatial interface
should provide practice using a mental model that would help make a transfer to this "virtual reality". Functioning in this virtual reality would be useful in helping the designer to "take on" the physical characteristics of the consumer that the product is designed to serve. A virtual button can be placed in an artificial reality simulation for the purpose of interactively testing ergonomics. As in the hypothetical example, the designer would be able to select arm length and configuration of movements based on a variety of human scales, ranging from infant to adult. When the designer reaches toward the virtual button, the spatial distance and complexity in the simulation could be experienced. The input and output of the proposed interface would help in the development of a mental model for this and other types of spatial interaction.

However, the constraints of physical reality and the "brute force" requirements involved in implementing the complexity required to closely simulate reality makes achieving such a feat difficult. Recreating the precision of nature through simulation is extremely difficult and made even more so when objects are exquisitely detailed. Still, the depiction of natural forces through simulation provides a worthy goal to strive for. Eventually, new ways of representation may result from the application of more computer time and power to this problem.

Recent advances in technology seem to support bringing the world of objects and the world of illusion closer together. The objects described in the memory of the computer are displayed as an image. The ability to manufacture a physical object from the virtual object with little human mediation is close at hand, even if in limited scale. For example, the commercially available process of stereo-lithography is used and offers a method of forming plastic prototypes
by intersecting laser with the surface of light-sensitive polymers. With additional programming, this process can also be done using numerically controlled milling machines.

D. Implications of The Conceptual Model and Simulation

The computer can provide a "sandbox" for simulation. Simulation has been used in the trial and error process of determining the quality of selected variables in a design. Although comparatively less expensive than other methods, the types of computer simulation characteristically used have lacked the definition possible with computer graphics and, therefore, give a less than "real" result. The model's prescription provides simulation that vastly improves the depiction of a design's appearance. The ability to compare relationships is consequently much better. The tools suggested by the model allow the design's appearance to be easily altered and interjects an element of play into the trial and error process. Thus, brainstorming activities may be enhanced.

The ability to place the designed object in the intended context helps to evaluate its qualities. In the architecture and packaging examples, computer graphic images of three-dimensional models are rendered as a composite along with the appropriate neighborhood or supermarket shelf. Alternately, by reversing the contexts a designer would be able to place the package in the neighborhood and the building on the supermarket shelf. Although absurd, it demonstrates the flexibility possible with visual information and the potential for relating the seemingly unrelated. A game could be devised where cross references of this "seemingly unrelated" type might inspire a new thought or idea. The resulting studies could become a visual syntax for other semantic uses specified by the designer.
Expected relationships could be represented, for instance, placing a building at various angles to the sun in the same location. By browsing through the spatial visual display, the designer could interactively address these complex relationships. A prescribed evaluation process running in the background might also be used to assess these relationships. A rating system might need to be developed to compare the results. Visual images of objects and contexts could then be surveyed for certain specified attributes. These could include implied motion, unity of components, or the visual qualities of the object under certain conditions, for example, a lighting parameter. Attributes may be similar in many ways, yet have subtle, but important, differences. A visual test might be developed that samples client expectations of the desired result. Alterations could be accomplished interactively by drawing a new curve to represent a function for change in the current state or by adjusting parameters through a chart.

The visual diversity, semantic meaning, and internal structure of each form could be stored for additional reference or action. The model proposes that libraries be maintained for categorization of objects and attributes, and for the comparison of the object to processes. These libraries would link together a variety of object types and individual references, as well as the ability to record interpretations. The structuring of the data would be of the most appropriate design. As this data is analyzed, social opinion about objects, attributes, and actions should be better understood.

Parallel processes appear to remove some of the pitfalls of first generation analysis-synthesis theory. A particular decomposition of a problem, however, is only one channel of many parallel, related activities. The ability to conjecture
and test, during the course of designing, must also exist. This
designer-centered interface system provides for analysis and re-conjecture as
design resolutions are formed. As a result, the problem continues to be
reformulated as direct manipulation of the variables for simulation procedures
and behaviors occurs.

The difficulty in controlling the vast and complex variables of the wicked
problem may account for the drawbacks encountered in the use of the linear
process of analysis-synthesis. In the proposed model, the designer can perform
extensive analysis as required throughout the process. Technology provides the
means for collecting and storing the amount of information available and affects
the design through the economics of a parallel data search. The comparison of
data could, and perhaps must be, based on heuristics provided by the designer..

Complex action can sometimes be controlled by simple input.
Programming by the use of graph language can result in the designer's
precoded, individualized procedures causing a myriad of change. Many
derivations are formed. Simple programming controlling complex action can be
enhanced through the choice and structure of hardware input and output
devices.

The touch pad is an example of the control of multiple virtual devices
(Baecker and Buxton, 1987). Decoding a single gesture on an input device
might specify a variety of conditions that are then realized by user sponsored
rules available on the system (Minsky, 1984). The formal structure of Chinese
temples has been based on a series of hand drawn curves on a bit pad. A new
series of relationships are formed for the shape of the temple (Makkuni, 1986).
This contributes yet another way to view form-giving.
If the computer is to become a partner in three-dimensional form development, current design activities must be better understood. The designer needs to trace the activity of design processing when addressing a problem. A more thorough accounting of design activity will help to expose heuristic problem-solving strategies. A better understanding of the designer's response to new conditions as they enter the problem space will also be achieved. As designing continues, the ability to monitor and incorporate these new conditions into the active processes and interface can be identified.

However, tracing of design activity may be impeded by the difficulty inherent in delineating and fully describing certain design activities. The designer may also consider some self developed strategies to be proprietary and be reluctant to reveal them.

The ability to trace the activity of the design process will require new sensitivity on the part of the designer and the systems developer. Design resolutions should be portrayed as objects, design criteria, and elements of design criticism. These should be effectively communicated to the designer, through a meaningful graphic interface.

It may be easiest to learn with a direct manipulation interface or through a metaphor that attempts to replicate real world interaction using icons. To avoid closing potential options, however, the designer will need to specify and place sophisticated abstract metaphors and action based symbols in the interface. Involving the designer through a self-training activity may be beneficial. A hierarchy of symbols might prove most useful if processes are related.

Developing a new media for design requires an interface based on mental models that permit designer involvement or role playing in the three
dimensional, virtual world. Interface design strategies and criteria should be created to encourage research and testing of appropriate software and hardware development. Those designers with well developed visual, spatial skills and a three-dimensional mental model of images are initially most likely to be successful at this endeavor. As design activity is better understood, work toward the formation of more appropriate mental models needs to continue. By evoking and comparing these mental models, a structure can be developed to better understand the characteristics of the working style of designers.

Designers using traditional methods will continue to be successful at creating design work using an intuitive, conjecture-analysis-synthesis approach (Tovey, 1984, 1986). However, as appropriate computer tools and resources are made available to the designer, developing and incorporating the requisite skills may result in even greater progress toward mastery of design problems. Thus, an expansion of the quality and range of the design domain might occur.

E. Future Research Objectives

Implementation and testing of the conceptual model is the next stage in Rubenstein and Hersh's (1984) model for interface development. Making prototypes of portions of the spatial display and combining them with systems already under development provides a platform for future research. High on the agenda is using and testing the solid matrices as a structure for browsing and selecting. Such a structure provides a mechanism for testing object modeling tool specifications. It also enables rapid visual assessment of images and objects created using procedures and behavioral tools. The implementation of a three dimensional spatial input for interacting with the display is within the capability of current technology. Objects will be of low resolution, however, or
of a relatively high level of abstraction. It will be important to measure the information conveyed through these low resolution images or symbolic abstractions.

In addition, the amount of information needed to transmit knowledge of various types in the spacial representation can be tested experimentally. One hypothesis is that, if used as a constant, the positioning in the matrix will create a certain understanding. Selecting a point on the screen with an input device and accessing three-dimensional virtual objects in the spatial display is another important research topic. The cubic matrix example fits well here (See Appendix D). Instruments and measures for doing this task are in current practice and provide another avenue for future research.

Future research should also continue to trace design activity in the workplace. Determining what designers are actually doing with computer systems as opposed to what is reported to be happening may be an appropriate starting point. The amount of data generated in the style trace library from designers' interactions across the interface will require special rules and tools for assessment. Some rules for evaluation of interfaces based on this data are already in effect. One rudimentary rule is to search for repetition. Other rules need to be developed and even tailored to a particular designer or problem area.

Another research topic might eventually evaluate if people with exceptional visual, spatial skills will be encouraged to participate in computing as the model is implemented. Tasks requiring extraordinary organizational and programming skills might be less confusing using a spatial interface which might result in a greater affinity toward the medium for designers with this orientation.

Continued refinement of specifications for procedural, spatial modeling
tools is one more area for future research. Color tools and those that relate various textures could be developed. Taking advantage of the cube grid and other solid matrices would provide an appropriate starting point.

The relationship between cognitive style and mental models is another research objective. Comparisons of descriptions of design activity could be based on mental models. For example, the "paint" metaphor or external myth could be compared to a more three-dimensional surface metaphor.

Another research topic facilitated by the computer is making social judgments about artifacts. Questions about why people find objects interesting to own may be more easily answered. One test of utility and fidelity for an artifact is in satisfying the intrinsic visual needs of the artist, critic and casual observer. Examples of questions that they might ask of the simulation include: How does it make me feel? Do I find this is interesting? Does this cause me to perceive in a different way? Does this expand or focus my thinking? Answers to these questions from a variety of perspectives could be compared.
Chapter VIII

Summary

The study begins with an overview and definition of terms. The concept of visual language is presented. From a review of cognitive style associated with form-giving activity, it can be reasoned that designers make use of this language both internally when visualizing mental images, and externally as a sketch, to test, add concreteness and detail a mental image. This process provides feedback for additional thought. Designers use the sketches or three-dimensional prototypes to test objects that will be built as a part of the environment. These representations of objects seem helpful to some, even though the design process is only partially formalized. Additional analysis is performed by specialists that further test specific functional attributes of the object, such as materials strength and manufacturing or construction processes. The sketches and prototypes of the artifacts are beneficial in presenting ideas to clients, marketing, and management.

With the advent of the computer, the view of visualizing and imaging is changing rapidly. The designer's understanding of the object's current state is greatly increased by computer graphics. Visualization of relationships between the whole object and its parts is enhanced. Computer graphics permits and encourages a back and forth activity, at various levels of abstraction, and often occurring along a number of parallel channels. This should increase the
designer's ability to test the symbolism of the object in context.

Some maintain that a natural language interface would enable anyone to interact with the computer. This study suggests that a portion of that natural language is the sometime overlooked visual language. It follows that if visual language is often a language of choice when designing three-dimensional objects traditionally, then a visual language most probably should be a significant part of the designer/computer interface. Therefore, instead of planning processes and mathematical procedures using verbal language, visual organization may be useful.

Until recently, the development of the computer has evolved using verbal languages. Computing speed and power now makes it possible to use complex icons, symbols, and pictures as part of the communication between people and computers. These icons have made computing a mainstream activity, especially in the preparation of documents.

Virtual world objects can be modeled using sophisticated data generation tools. The tools become part of the interface between the computer and the designer. The virtual object is stored in the computer as a data base and can be mathematically transformed. An image of the object can be viewed as a computer graphic representation. This may be a full color rendering in a context. The object can also be represented as a name, symbol, or icon. The data base with attributes and the clarity of the artifacts in a context can be used to communicate to others through electronic media. The data base can also be tested by special application programs that figure volume, test standards, locate structural weaknesses, and simulate construction processes. The object's
function and ergonomic features can be simulated.

The interface between the designer and the computer has traditionally been a stumbling block in an integrated system. This study clarifies many of the problems associated with the interface. A network of design activity is proposed that focuses on the flow of information across the interface. Mental models of designer's working styles are reviewed.

The interface model is described for communication between the designer and computer networks. Designers and artists who have learned a syntax of visual language, such as perspective conventions or representation, are introduced to a framework for interacting with the computer network.

The designer becomes involved in developing objects, spaces, and contexts in a three-dimensional "virtual world". Using high level tools and programming procedures, the designer can specify design actions that test a number of potential versions of the object being designed. The objects developed in this "virtual world" of the computer may become physical world objects through a computer graphic image or through advanced prototyping and manufacturing methods.

A formulation of a spatial input and output system is suggested. Although many computer systems use object modeling techniques that take advantage of a three-dimensional data base, only a few provide direct manipulation while interacting with the three-dimensional image, such as perspective views of the data. Most of those software systems that do provide this direct manipulation limit this action to the geometry.

The conceptual model proposes high level visual programming that takes advantage of three-dimensional representation. This specification suggests
that direct manipulation not only be done to images of the geometry, but also to a visual, spatial language that encourages the designer to develop procedures. These procedures would be used to control a vast arsenal of mathematical tools. Emphasis is placed on a higher level interaction based on spatial browsing, procedure planning, and condensing design action.

A conceptual model is developed that formalizes the basic structural components of the designer/computer interface. The model presents a format for general relationships between the designer and computer for problems, objects, actions, and contexts.

**Design action** is a major portion of the model. It represents the activity associated with design. It includes tool specifications which presents types of interaction techniques for object form-giving. Tools for viewing are specified as visual feedback structures. Tool examples are specified as a portion of the model. The tools and character of the interface provide the designer with a reference for further development of a knowledge-enhanced, personally configured, computer interface for designers. Spatial input and output is an integral part of the design action node.

**Reference libraries**, the second node of the model's structure, are specified to store, record and retrieve a myriad of appropriate information.

**Evaluation** is the third major portion of the model. This provides avenues for shared work, information, and greater client and management involvement in the design process.

Toffler (1980) expresses one view of the extent and depth of changes brought about by an information based society. The information revolution and the development of the interactive portion of the spatial interface have the
potential to similarly shape design methods and cognitive processes associated with computing.
APPENDIX A

DIAGRAM OF THE CONCEPTUAL MODEL
APPENDIX B

EXAMPLES OF OBJECT FORMING TOOLS
Examples of object forming tools

Virtual extrusion

A virtual object would form as interpolation occurred along a curve (B-spline or other curve description) to create a smooth form as it is being extruded. The placement of the cross sections should allow the cross sections to conform in a very complex fashion in and along the path of extrusion. The cross section could be drawn as a polygon, smoothed, have elements shifted, and then, again smoothed. It could then be standardized according to an algorithm, function, or a drawn curve. The data could then be distributed along the edge in a format that can be connected together with other redefined cross sections. The 'in-between' cross sections can be calculated by interpolation of the defined cross sections. The density of the sections can be controlled by a parametric curve, algorithm, or function.

Virtual clay

This tool calculates surface data from a spray gun of cubes that are focused on a predefined armature. The armature is defined in a shape desired by the designer. Control points are then assigned that attract cubes. Next, the mass of cubes are intersected by cross section and defined by curves. The defined curves are then treated as lofts and surfaces are connected to form a polygonal mesh. The weight of the particles could cause a deformity in the armature.
Virtual spray

Value contrast or color could be used to build three dimensional form by spraying on a flat, two dimensional screen. This tool may utilize a shading convention where recognition is made of lighter values as being furthest forward and darker values being furthest back. It may be used in a mode that detects atmospheric perspective and recognizes strongest value contrast as furthest forward. This could be demonstrated by spraying those portions of the surface white that need more depth. If however, the surface has too much depth, then it could be sprayed darker. These methods are metaphors of drawing and airbrushing.

Virtual carving

This system initiates an octree decomposition of a cube based on the control points assigned by the artist. For visual feedback, the object is viewed as the decomposition occurs. The object can be recomposed through the return of portions of the cube as the process continues.

In another form of virtual carving, objects are specially created to be used as polygonal chisels that leave an imprint on the surface of an object or leave material in the shape of the tool on the object. This represents a stitching of the object's surface data in such a way that the new shape is woven into the original surface data. Curves should be used to control the amount of pressure that the wand leaves and might include a heuristic for the intersection of the impression or bump left by the wand and the surface.
Virtual smoothing

At the intersection of two objects the flavor of the transition at the intersection should be controllable by the artist. In Metabols (Blinn, 1982), a radius is placed in the space between to web across the intersection. This tool creates a span across two objects at the intersection. The softness of the object is controlled by the characterization of this junction. The junction, therefore, needs to be controlled and not just have a radii applied. The form of the web should follow a curve and should be controlled interactively.

Rules of thumb about the flavor of these intersections might be guided by the metaphor of the object's semantics. The variety imposed might be a transitional blend between two attractors or a contrasting sharp corner using two different colors and materials. An example demonstrating this could be in comparing the soft geometry of the bicycle seat on one hand to the end of a tube at the other extreme.

Virtual attractors

Weaving object surfaces about a series of attractors in virtual space would provide a flexible tool. The attractors have a mass that is visualized through a sphere that is placed in the virtual world. The object or objects are then formed about the attractors. It is as if Amkraut's flocking birds (1989) had vapor trails and the vapor trails were spun into the surface of objects.
APPENDIX D

USING GEOMETRIC OBJECTS TO ORGANIZE ASPECTS OF DISPLAY PROCEDURES
A SIMPLE CUBIC MATRIX FOR DEMONSTRATING THE CONCEPT OF USING A THREE-DIMENSIONAL GEOMETRIC OBJECT'S VERTICES FOR THE ORGANIZATION OF INFORMATION FOR SPATIAL BROWSING AND SELECTION

Cube grid matrix representing the procedural scaling of a cube.
AN EXAMPLE OF A FRAME FROM BROWSING THROUGH THE DISPLAY
LIST OF REFERENCES


Hillier, W., Musgrove, J. and O'Sullivan, P. (1972). Knowledge and design. In W.J. Mitchell (Ed.), Environmental Design: Research and Practice (pp. 29-3-1 to 29-3-14). University of California


Liefer, L. (1985). Presentation at The Ohio State University, Columbus, Ohio, Spring.


Seidman, A. (1986). *The Blue Chair*. The Ohio State University, Advanced Computing Center for the Arts and Design.


