Reint-Ops: A Tool Supporting Conceptual Design

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Reasoning is influenced by our perception of the environment. New aspects of our environment help to provoke new thoughts. Thus, changes of what is perceived can be assumed to stimulate the generation of new ideas, as well. In CAD, computerized three-dimensional models of physical entities are produced. Their representation on the monitor is determined by our viewing position and by the rendering method used. Especially the wire-frame representations of views lend themselves to a variety of readings, due to coincident and intersecting lines. Methods by which wire-frame views can be processed to extract the shapes that they contain have been investigated and developed. The extracted shapes can be used as a base for the generation of derived entities through various operations that are called Reinterpretation Operations. They have been implemented as a prototypical extension (named Reint-Ops) to an existing modeling shell. Reint-Ops is a highly interactive exploratory CAD tool, which allows the user to customize criteria and factors which are used in the reinterpretation process. This tool can be regarded as having a potential to support conceptual design investigations.

Keywords: CAD, three-dimensional model, wire-frame representation, shape extraction, generation of derived entities, reinterpretation, conceptual design

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Historic aspects of computers in architecture

Computers were developed as tools for the solution of complex calculations in an efficient and expedient manner. Therefore, their use in the engineering profession was evident (LeMessurier, 1964). Other applications supported visualizations (Fetter, 1964). While in civil engineering computers were readily accepted as tools the architectural profession seemed to shun them. Justposed to that general attitude of architects were great efforts and high aspirations of a few researchers who aimed at an architecturally specific utilization of computers (Nicholas Negroponte 1970, 1975a). The researchers' goal was to furnish machines that can act like human beings and that can develop into architectural design partners (Negroponte 1970) and eventually substitute for architects (Negroponte 1975a). Computers became sentient machines embedded in the environment directly interacting with the users of architecture and concurrently adjusting the built environment to the users' needs. A third book (Negroponte, 1975b) conveys an attitude subdued by the realization of how far out of reach the initial goals had been.

The impossibility of directly controlling the environment guided the development towards the control of what is perceived of the environment. Multi-media technologies are trying to put the control of the influx of information at the hand of the consumers through automated filters. Information that is suppressed by these filters needs not to be seen at all. A totally controlled percept of the environment thus emulates total control of the environment. Cyberspace then is a next step toward control of the environment. Information that is artificially generated—ideally in photorealistic quality—can substitute for the information that the consumers do not want to perceive. However, most architects still want to change the environment and not just what is perceived of it.

Though the aspirations of research have been high, what computers can do for architects and what has been perfected to date still is limited.
Design as part of the human action process

An understanding of the design process can be mediated by an examination of the human action process in general. The human action process can be viewed as following a circular method which through its application over time is a linear process with recurring elements (figure 1). The main elements of the human action process are perception, reasoning, and action. This action cycle model explains problem-solving processes, as well. A perceived situation poses a problem for the observer if the situation does not conform with his or her goals. If the observer can conceive actions adjusting the situation as needed, the problem is solved. Such actions are called problem-solving. Successful actions contribute to the accumulating knowledge as well as unsuccessful actions. This is also known as learning by trial and error.

Each individual human being has an idiosyncratic way of understanding reality by constructing plausible systems of inter-relationships between events, actions, or reactions. All these constructs and concepts can be considered to be mental models of reality (Schweizer, 1979, pp. 26-27). Physical models can be considered materialized representations of mental models. A subset of all possible physical models is used in support of the architectural design process. This support is necessary because architectural problems tend to be ill-defined or "wicked" problems (Mitchell, 1979, pp. 60-61; Rowe, 1987, p. 41). Design states as steps of the problem-solving process are accordingly complex. This complexity demands for an external storage of the design state's information content. Such externalizations serve the communication with oneself as well as other people.

The process of externalization can be promoted by additionally externalizing human actions. The success of the externalization depends on the understanding that we have of these actions. Designing as an action is not well understood. In the progress of the design process, designers generally reduce ill-defined design problems that they capture in equally ill-defined sketches into well-defined design solutions documented by
highly standardized drawings (deVries and Wagner, 1989). Once construction drawings are developed, their production is a straightforward action. Therefore, this part of the design practice has been implemented on computers.

There are several ways to go in order to further externalize the design process. Apparently tools for conceptual design should be conceived according to a general model of human reasoning to achieve intuitivity and familiarity to the designer. The major obstacle to doing this is the lack of understanding of human reasoning processes. So far attempts to model human reasoning have been limited to probabilistic interpolation of past experience and presently known data. However, additionally to the use of existing knowledge, design needs creativity, and what creativity is in terms of human reasoning is less known and understood than human reasoning in general. Another approach, the delegation of the tasks the designers do not like to perform to the computer, is exemplified in most CAD systems. The third approach, the utilization of the computers' strengths and capabilities different than human capabilities, is used in recent research exploring new design tools. The goal is not to mimic human design behavior; rather, the goal is to complement human design behavior with tools based on the capabilities that are inherent to computers.

A model of memory and creativity

For the brevity of argument, the following discourse about the structure of human memory and reasoning is limited to visual perception as well as to memory for and reasoning about forms and shapes. A basic assumption is that memory accumulates experience. The storage of perceptions in connection with actions and consequences can be modeled by a complex associative network. The network consists of nodes containing memory entities linked by connections that can be considered to have different connectivity. If a node is stimulated the connected nodes will be stimulated depending on the connectivity. New nodes are created or vacant nodes are filled when necessary to accommodate yet not contained memory entities. New links can be created, connecting yet unconnected knowledge. Existing links can be strengthened or weakened.

In distinction to the intellectual act of classification, which starts with the individual elements and tries to group them into a hierarchical system of classes and subclasses (Eco, 1984, pp. 46-86), memory, in combination with perception, works from the most general concept to the specific (Arneheim, 1969, pp. 153-187; Bruce & Green, 1985, pp. 52-60, figure 2). The structuring of the stored experience is empirical by nature and highly contextual because of its associativity. The process of perception includes the immediate knowledge of what is perceived without the intellectual effort of classification. Perception inherently is thinking. It provides for substitution of missing knowledge by more general concepts and for inferences by association of unknown percepts with known concepts.

![Perception vs. reasoning in the network model](image)

Within this model, reasoning can be reconsidered the task of matching or complementing a pattern of associated nodes with another pattern. Both patterns as a whole are the solution. In distinction to perception, reasoning uses the associative network in a traversal perpendicular to the direction of its generation and use by perception (figure 2). Nevertheless, the same holds true for
reasoning as for perception, it affords substitution of missing detail by more general concepts and inference.

This model of memory also provides for a plausible explanation of creativity. Creativity can be considered to be the ability to find connections between nodes which so far only were weakly or remotely connected. Creativity creates patterns which are new in configuration. Creativity is equivalent to the reorganization of existing knowledge.

The design process is partially externalized in its resorting to representations. Creativity in architectural design is partially externalized as well. Looking at the representations which have been created with a certain pattern of knowledge in mind, the perceptive thinking is not bound to the same paths that would recreate the generating pattern. Perceptive thinking thus can arrive at associations that differ from the initial connotations. This represents a creative leap.

Recent developments in CAAD research

Corresponding to the dichotomy between computational methods and the complementing of non-computational design methods by computer operations, two major branches of research can be distinguished—and among others. One approach explores the integration of computational methods for design and building evaluation, in order to form a comprehensive computational support for the design process (Kalay, 1990). The second approach explores algorithms that generate designs or design alternatives in support of the creative phase of the design process.

In this discussion, the second branch of research is of special interest. The major approaches within this branch of research are the use of fractals (Yessios, 1987), the consideration of shape grammars (Flammang, 1987; 1989; March & Stiny, 1985), replacement operations (Bonn, 1989), and transformations or reformations (Terzidis, 1989).

These approaches describe processes that take graphic data as a base and modify these data. With regard to the previously described model of creativity, it is obvious that these changes in the formal composition of representations can instigate new insights by the designer. Clearly these approaches serve the design process by modifying the design state representation to which they are applied.

Considering that each designer has a different approach and different predilections and biases, design systems will have to be designed in a way that they can include all approaches that prove of value for the design process, in order that each designer can find his or her personal method of design generation.

Reint-Ops

Even in a computer aided design process with the ideal postulation of three-dimensional modeling, the designer primarily interacts with two-dimensional screen images or printer/plotter output. Stiny (1989), Mitchell (1990), and Tan (1990) describe the potentials of ambiguity in two-dimensional representations with the inherent opportunity for interpretation—or the necessity of reduction of ambiguity for clearer communication (figure 3). It seems to be possible to utilize these ambiguities for the rearrangement of the information contained on the screen.

![Different interpretations of a wire-frame image](image)

In the traditional design practice a similar process occurs when the designer detects and traces an appealing shape out of a sketch or drawing and develops it into an element with a meaning different from the one it was intended to convey. This is a creative act by the assignment of a new meaning to this shape. If there is no sufficient distance to the intended meaning the designer will perceive the sketch or drawing unable to reinterpret it.
The computer can provide for a tool, the Reinterpretation Operations (Reint-Ops), which analyzes a given screen image for shapes which are contained in it. Reint-Ops evaluates an image representing three-dimensional objects as a composition of two-dimensional, topologically equal elements. These elements are detached from their original meaning as parts of the objects and are put into a new context as parts of two-dimensional shapes (figure 4). Because of the new context the elements acquire new meanings. Because of the capabilities of computers, Reint-Ops is likely to detect shapes which remain undetected even by the designer who engages in this kind of investigation. Consequently Reint-Ops provides the designer with additional alternatives which are opportunities for creative leaps.

In a three-dimensional modeling environment the two-dimensional shapes can be used to inform the representation in which they have been found to generate three-dimensional models. This means an additional distancing from the original representation that was used as a point of departure for the investigation. Each of these steps of distancing from the original meaning of a design representation is understood as an opportunity to reinterpret and re-evaluate the represented design state, in turn informing the designer about alternatives implicit to the examined design state.

Reint-Ops can be applied in a range from high user control to little user control. Thus the user can assume the role of an investigator using very selective and possibly biased criteria to scrutinize the design representation, or the user assumes the role of a distanced spectator watching the system work. These extreme positions support the acquisition of knowledge about form and the instigation of creativity.

**Objects, their parts, and aspects**

Reint-Ops is applied to viewing projections of solids. In the prototypical modeling application a boundary representation is used to describe solids. Topological entities are solids, faces, curves, segments and points. Resulting from the condition of closure, in the used model each edge of a solid is comprised of exactly one pair of reversely oriented and coincident segments.

Screen images are projections of the three-dimensional model of the world onto a virtual image plane. This two-dimensional image plane is displayed on the screen. If types of projections and display methods are considered in conjunction, it suggests itself that the image that is most readily understood is a perspective projection displayed as a surface rendering with shades. Reint-Ops draws upon the ambiguity of parallel projections displayed as wire-frame images.

**Breaking, minimal lines, and shapes**

The rendered edges of a wire-frame projection are split into equal two-dimensional elements at each intersection with other edges in the image. This process is called breaking. The result of the breaking is a line set which consists of coplanar lines. All edges are broken at all intersection points, therefore, lines do not intersect each other. Such lines can be considered minimal lines (as opposed to Stiny's "maximal lines"; Stiny, 1989, pp. 4-8). The lines are collected into curves. If a curve is closed it forms a shape. If a shape does not enclose lines it is called a contiguous shape (figure 5). A collection of shapes derived from a line set is a shape set.

**Reint-Ops as search process**

The line set needs to be properly traced to derive the shapes that it contains. A method for solving this problem is search (Mitchell, 1977, pp. 453-468). Starting with a first line segment the next line segment can be chosen from several
alternatives. Each of these alternative line segments, in turn, can be complemented by several other line segments. In a finite line set that means that line segments can be reused. Curves can contain line segments multiple times. The process can be terminated when a shape has been found or when the process reaches a state in which it is impossible to successfully find a shape. In any case the search ends when all alternatives have been exhausted. The search resembles a tree search with the starting line segment as root (figure 6). The criteria for success and failure can be applied throughout the search process. With searching a tree that means that the branches of the tree already obey the specified criteria. Therefore, the search consists of many local successful and unsuccessful terminations without being entirely finished. The search terminates when all possible branches of the tree have been traced to either successful or unsuccessful terminations.

Search criteria

Criteria for finding shapes in the set of minimal lines can be determined by the geometry of the line set and by the structure of the search tree. The criteria that are inherent to the geometry of the line set can be expected to be intuitively understandable by the user (figure 7). Those criteria that are inherent to the search tree are not obvious, because the method of constructing the search tree is hidden to the user. Therefore they
are not necessarily intuitive, but their consistent nature makes them understandable by use.

Criteria inherent to the geometry of the line set can be subdivided into three categories according to the considered elements. The first group of criteria is applied to a single line. The second group looks at the relations between two consecutive lines. The third group of criteria is applied to the found shape as an entity in its relation either to the line set or to the shape set. Criteria that are inherent to the search process essentially determine the selection of the next continuing line segment, out of a number of alternative possibilities. The tree-structural criteria can depend on geometrical criteria, in that—if geometric criteria are applied—they cause a sorting of the available alternatives.

The application of a set of criteria can cause a line segment to have no eligible continuation. In that case, there is the choice to release constraints. A release can be formulated in the set of geometric criteria by specifying a criterion range and not just a specific value. Beyond that the search can select the alternative which is the close miss to the applied criterion.

**Three-dimensional model generation**

The evaluation of the derived set of shapes as three-dimensional objects can be performed by interpreting the found set of shapes as an information complementary to the line set, or by interpreting shapes as images of parts of three-dimensional objects. In the former case the entire line set is used to derive a new volume and the third dimension depends on the found shape set. In the latter case the shapes of the shape set are taken as bases for the derivation of volumes. The third dimension of these volumes can be made dependent on qualities of the generating shape or on the relationship of that shape to the line set.

These processes are an inversion of the previously described process of reducing the ambiguity of a screen image into the line set. There may be more than one way to interpret the image as a representation of a volume, but for each image there is only one way to interpret it as a line set. Consequently, reversing this interpretation means that there is more than one way to interpret a line set and any derived set of shapes as volumes (figure 8).

In any case, the height for the volume derivation has to be specified as additional information. The height can be dependent on user determination of the height for a shape, on characteristics of the shape itself, or random choice.

**The implementation of Reint-Ops**

The major determinant for the feasibility of Reint-Ops as tool for conceptual design and form investigations is the degree of freedom the user can attribute to the system. The system’s freedom is complemented by the degree of control the user wants to retain. The amount of possible criteria necessitates a paradigmatic selection of criteria for the implementation for both the shape search as well as the three-dimensional model generation. The selection of the criteria for the shape search is based on considerations of the intuitive understanding of those criteria by the user, as well as on their value for the demonstration of possible criteria categories. The volume derivation methods are selected with respect to their applicability for architectural investigations.

Selected as geometric search criteria were line length, the angle between two consecutive lines, the number of vertices in a shape, the area of a
shape, contiguity and orientation of a shape, and the frequency of a line segment’s use, most of these criteria offering a range option. As tree-dependent selection criteria were chosen the first/smallest, or the last/largest, or a random choice of possible continuations (figure 9). The search for a shape terminates unsuccessfully —without adding a shape to the shape set— when one of the following cases is encountered: a curve intersects itself, a curve is not closed when another termination criterion is met, or a similar shape has been included in the active shape set (figure 10). A successful termination occurs when a curve is closed to a shape meeting all specified criteria, and that shape does not exist in the shape set, yet. The entire process terminates when all possible branches of the search tree have been traversed.

The choices for the derivation of volumes are oriented towards architectural applications. This applies to the derivation methods and to the determination of heights. Due to the orientation towards conceptual design phases the available three derivation methods are purely volumetric: single volume derivation, stacked volume derivation, and composite volume derivation (figure 11). Heights for the shapes are limited within a range that is user controlled. The options for the determination of heights are dependent on the relationship between the line set and the shape set, geometric qualities of the shape, they are randomly assigned, or determined by the user (figure 12).
Reint-Ops applications

Form investigations

The way of employing Reint-Ops suggested in this section, form investigations, is an attempt to use the operations to gain knowledge about form manipulations. Two objects, an extruded solid with triangular base and an extruded solid with rectangular base, are repeatedly subjected to the same manipulation.

Starting with one of the base objects the line set is derived and the search for contiguous shapes is performed. The exterior shape gets a height assigned, all other volumes are deleted. This derived object is now, in turn, subjected to an identical process. After several repetitions it becomes obvious that, in spite of the topological difference between the two initial shapes, the results of the repeated application of a very restricted reinterpretation operation are increasingly similar in appearance (figure 13).

The reason for this result is evident. After a sufficient number of repeat operations the emergent shape is detected to witness the rules of the two dominant determinants of the operation, the projection and the extrusion. The result of the investigation suggests further exploration with alternative outlets. In figure 14 the results are shown which are obtained with a converged object. Even though the investigation is not carried through to the same degree as is the previous investigation, the results confirm the supposition that the emergent shape witnesses the rules of the manipulation. The use of another projection shows the influence of the projection angle on the emergent shape (figure 14).

![Repeet manipulation of a triangular and a rectangular prism](image)

The extrusion can be conceived as an orthogonal projection of the base shape onto a plane that is located in the distance of the height from the reference plane. The octagon thus obtains a new meaning as the result of an iterative process of projections onto the reference plane and then back up onto a plane parallel to the reference plane. Therefore, form investigations can be conceived as leading to a new understanding of forms that are supposedly well understood.

Conceptual design

Reint-Ops can be used for conceptual design as systematic generators of alternative objects. The user can abstain from interferences with the generation of alternatives, but he or she can also control the entire process from the shape finding to the volume derivation. Even if the first alternative is chosen and the user leans back and examines the suggestions the system offers, the user still must evaluate the results and draw his or her own conclusions.

An example of different degrees of control is given in the following discussion. The base shape for reinterpretation is a rectangular prism. The shape search is restricted to find shapes with five corners. However, with the fixed setting to the derivation of composite volumes with fixed minimum height and maximum heights and height increments, the other options are systematically altered. Thus alternative mass models that could inform a more controlled generation of another model study are generated (figures 15 and 16).
The examples for the systematic studies are complemented by a few variations on a line set derived from two cubic objects (figures 17 and 18).

**Modifications and extensions**

The proximity of the line set to a two-dimensional void model suggests a combination of these two model types. Information contained in the line set is valuable for a void model. Void model information could facilitate editing functions on the line set. Conclusions drawn out of investigations could make changes of the line set necessary for the further pursuit of a design idea. Enhanced editing capabilities also add to the possibilities of investigating a line set by modifying it and examining the effects of these modifications in the progress of form investigations. Additional editing capabilities mean that either the restrictive definition of what constitutes a shape have to be enforced throughout the editing or the definition of shapes has to be modified. A viable implementation of a new definition of shapes could leave the choice between the more restrictive and the less restrictive shape definition to the user.
The result of the merger of a two-dimensional void model and the line set would be advantageous for the performance and versatility of the Reint-Ops. The scope of shape finding criteria could be increased; the line set data could directly relate to a building model via a void model; the derivation of volumes could be enriched with a variety of alternative types of void models/building models. This modification alone could make the line set data a versatile two-dimensional data base for the conceptual design phase (figures 19 and 20).

**Conclusion**

Reint-Ops aims at the utilization of specific capabilities of the computer for conceptual design. The abilities considered here are the exhaustiveness of searches and the consistency in the application of rules. Both abilities differ from the human tendency to compromise by association or inference. That way computers support Reint-Ops in the indication of alternatives to the designer which he or she would not have considered otherwise.

Offering a scope from high control to high degrees of delegating control to the system in both the search process and the volume derivation the user has the opportunity to investigate a line drawing in a multitude of alternative ways. Individual preferences can be accommodated though the user might have to experiment with the offered options before he or she is able to establish a specific design approach.

Reint-Ops —especially under consideration of the suggested modifications and extensions— seems to be able to support both the investigation of design alternatives as well as the investigation of form as a design approach. With the indicated modifications and extensions Reint-Ops can be considered as a viable addition to CAAD systems for further experimentation and evaluation in the design practice.

**Remarks**

1. The cyclical nature of the design process with a certain development through time has been described by deVries and Wagter (1989, pp. 9-13).
2. Simulation is characterized by its repeatability, reversibility, and non-destructive nature (Zeigler, B. P., 1976, pp. 3-6). The important aspect of simulation is that time, as the independent variable in the process, can be set and reset to any desired time, and that the dependent variables can be changed at will.
4. Enforcement of knowledge and forgetting, respectively.
5 The term “line” is used to describe a finite element, which usually is called “line segment.” However, in this chapter the term “line segment” is used with a meaning distinct from the redefinition of the term “line.”

6 In this chapter all lines are minimal lines, consequently the terms “line” and “minimal line” are used indiscriminately.

References


