How to make CAD tools more useful to designers through re- representation

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ABSTRACT: This paper describes research that explores computational approaches to automatically developing multiple representations of objects, with the aim of overcoming the limitation of fixed representations. The claim is that if CAD tools used a more fluid system of representation they would be more useful to designers by preventing fixation and by providing a means of resolving the ambiguity in internal representations. A method for producing multiple representations has been developed and implemented to demonstrate that simple sketches can be re-represented automically. The method uses a neural network to find features in an arbitrary canonical representation and to restructure a sketch based upon groupings of similar features. The results demonstrate the feasibility of automated computer-based re-representation. This research provides the foundations for support for multiple representations in CAD tools that would make CAD tools more useful to designers.

Conference theme: Digital
Keywords: CAD, design representation, concept formation

INTRODUCTION

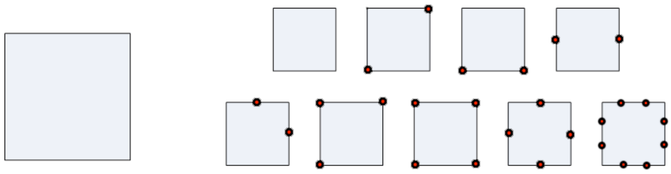
Current CAD tools are built using fixed representations of the objects that they utilise or that are constructed by the user. The effect of this is that the user cannot connect the computational representation with the image seen on the screen; there is ambiguity about the internal representation of the image when looking at it. The internal representation in CAD programs is fixed based upon the choices of the program implementer and the designer during designing and drawing. Designers in the visual domain regularly re-interpret what they have drawn and this is one basis for the progression of designs and is often claimed to be the basis of the difference between designing and problem solving (Schön and Wiggins, 1992). The makeup of the sub-components remains as the designer originally intended, regardless of any new interpretation that the designer has of the representation. This operates in opposition to the idea that it is desirable for designers to be able to create new interpretations of what is seen. New interpretations are desirable because they facilitate the revision of design ideas and prevent fixation (Suwa and Tversky, 2002).

This paper presents research that lays the foundations for a fluid system of representation in CAD tools to allow designers to make the internal representation of an image match their current interpretation more easily. Further, designers could be presented with alternate representations of the structure to aid them in constructing new design ideas. In this way it is claimed that CAD tools would become more useful to designers, allowing them to re-interpret the graphical image and act upon it, and stimulate them to revise their ideas.

1. REPRESENTATION

The distinction between a representation and the interpretation of that representation can be made with reference to the ideas of situatedness (Clancey, 1997). A designer interacts with a representation through the ability to sense (e.g. sight, touch). In order to gain knowledge from the representation, the designer must perceive this sense data. Situatedness recognises that the act of perception is necessarily an act of interpretation, because the ability to make use of sense data is a function of the current knowledge of the designer. For example, a bricklayer looks at the same building plans as a student of classical architecture. The student perceives many lines of symmetry and repeated forms, while the bricklayer perceives only the need for another delivery of bricks. The initial representation is the same, but the knowledge gained differs due to interpretation.

When using CAD tools the image on the screen is a visual representation of the structure represented inside the computer. The image is the input for the designer's interpretation of that structure. Designers receive feedback from their actions in a visual way, yet must first interpret what is seen before further design actions are carried out. For example, when considering a CAD representation of a pen, a designer might interpret this as the sum of two elements, a shaft and a cap. Alternatively, it could be interpreted as a single pen-shaped object. When perceiving visual forms there is often ambiguity concerning the way that the structure is internally represented. Many representations of the image of the square shown in Figure 1(a) are possible, some of which are indicated in Figure 1(b). Each one of these representations offers different opportunities to change the shape and different shapes can result, many of which cannot be produced with an alternate representation.

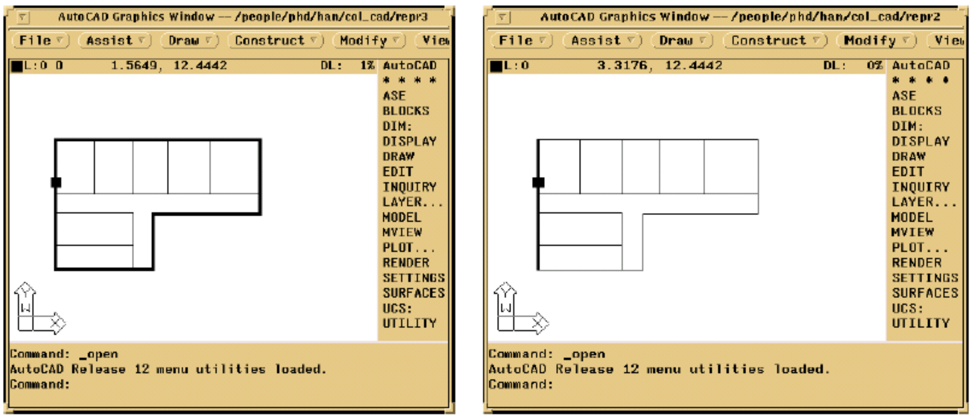


(a) (b)

Source: (Gero, 1997)

Figure 1 Multiple representations of the image of a square: (a) original square; (b) different representations of the original square.

When a designer perceives the internal structure one way and the CAD program has a fixed representation that differs from the designer's perception, the designer is restricted. Figure 2 shows two representations that are identical visually. In each image the same line has been selected for manipulation. The visual feedback in each image makes it clear that the internal compositions of the representations differ. The representation of the perimeter line in Figure 2(a) is a polyline, whilst that of Figure 2(b) is composed of line segments.



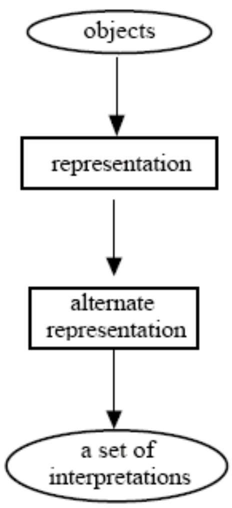
(a) (b)

Source: (Jun and Gero, 1997)

Figure 2 Different representations of the same drawing in a computer-aided design system; the selected parts are represented by thicker lines; (a) shows that the perimeter line is a single element, while (b) shows that it is composed of segments.

1.2. Re-representation

Fixation upon a single interpretation of a design structure can be avoided through the use of multiple representations. Multiple representations are created through the process of re-representation: the act of creating a new representation from an existing representation (Jun and Gero, 1997). This process is shown in Figure 3, where a set of interpretations is developed through the use of re-representation.



Source: (Jun and Gero, 1997)

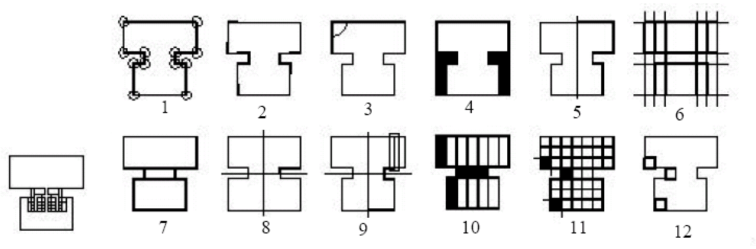
Figure 3: Process model of re-representation

Multiple representations support the creation of a set of alternate interpretations, and also allow for the selection of the representation that is best suited for further design actions. Figure 4 is used to demonstrate this through multiple representations of the same floor plan, where the representations numbered 1 to 12 use features based on:

1. nodes and orientations
2. relative line units and orientation
3. angles and lengths
4. figure and ground
5. transformations
6. sub-shapes among boundary lines
7. decomposition
8. reflection
9. reflection and stretch
10. arrays of rectangle units
11. arrays of square units, and
12. addition and subtraction

respectively (Gero and Reffat, 1997). It can be seen that different representations offer different design knowledge about structure, by comparing any two representations in this figure. For example, representation number 11 with an array of rectangle units, gives the viewer instant access to a great deal of spatial information about the floor plan, whilst representation number 7 gives the viewer explicit knowledge of the basic geometric shapes composing the plan. This relationship between a representation and the information it contains is often only tacit knowledge for the designer. Whilst this paper does not touch further on it, connecting spatial knowledge to representation provides opportunities to select representation for purposes rather than finding what a representation can be used for.

In addition to spatial information, each representation offers manipulation opportunities that are sometimes unique to that representation. If the representations shown in Figure 4 were being manipulated inside a CAD program, each representation would lend itself to certain actions whilst restricting others. For example, representation number 1 is based on nodes, which would facilitate the movement of a corner of the floor plan whilst leaving other corners unaffected. Representation number 8 involves reflection in the floor plan, which lends itself to the duplication of actions to maintain symmetry.



Source: (Gero and Reffat, 1997)

Figure 4 Multiple representations of shape: (a) floor plan and (b) multiple representations

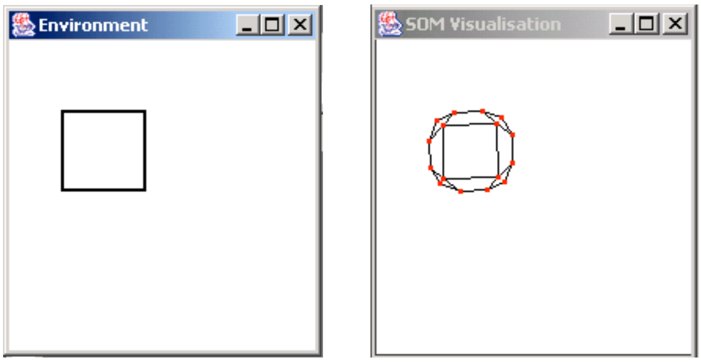
Multiple representations give the designer a range of representations to work with and allow for the selection of a representation that is most useful to them with respect to predicted design actions. Revisiting the earlier example of the potential internal representations of a pen; consider a designer revising the pen to make it easier to grip. One possible design action is to make the entire pen larger, in which case a single pen object may best suited for this action. If the designer wanted to achieve this goal by making the shaft more conical then a pen internally represented by more than one component would be easier to manipulate. If the designer wanted to use a different material in the grip another representation would be more useful. A designer with access to multiple representations would have a range of choices to facilitate more fluid designing.

2 TOWARDS MORE USEFUL CAD TOOLS

A method for producing multiple representations has been developed and implemented to show that simple sketches can be re-represented by a computational process. The method uses a neural network to find features in an arbitrary canonical representation and to restructure a sketch based upon groupings of similar features. The results demonstrate the feasibility of automated computer-based re-representation.

2.1. Computational re-representation using Self Organising Maps

The canonical representation is the set of pixels that can be viewed on the screen. The re-representation method uses a self-organising map (SOM) neural network (Kohonen, 1995) to organise the pixels in a representation into groups based upon the position of each pixel within the image. Another SOM is then used to cluster these initial groups based upon group dimensions. An SOM is a type of neural network made up of interconnected neurons that is capable of re-organising itself based upon the inputs presented to it with no supervision – this is a form of learning. No supervision implies without human intervention and without human guidance. The architecture of the SOM is defined by the number of neurons and the number of inputs and learning in an SOM occurs competitively. An *n*-dimensional SOM is made up of interconnected neurons, where each neuron has *n* features to match *n* inputs. The SOM implemented in this example has two features, one for each of the two dimensions (X and Y locations in a grid of pixels) in the image. When the network is presented with each pixel it finds the best matching neuron in the network based upon a comparison of the net weight of the features. This can be described in a visual way as finding the neuron with a position closest to the pixel. Learning occurs through the shifting of neuron weights to make the best matching neuron more similar to the input. The amount that the best matching neuron changes, and the effect upon its neighbourhood of neurons, is determined by learning variables. Figure 5 shows the visualisation of a SOM resulting from the input of the image of a square.



(a) (b)

Figure 5: (a) Initial representation in the form of pixels making up the image of a square independent of its internal representation; and (b) resulting SOM shown visually.

Pixels are clustered into groups with the same best matching neuron. Another SOM is then used to cluster these groups of pixels. The process is identical to that described above, but instead of using the location of each pixel as inputs for the network the dimensions of the group is used. Figure 6 shows the clusters of pixel groups resulting from this process. Contiguous elements within these clusters are joined, and the resulting elements make up the new representation. The process is then repeated, but with different numbers of neurons in the SOM. This facilitates the creation of multiple representations from a single initial representation through re-representation. Figures 6(a), 6(b) and 6(c) each have a different element learned from the initial unstructured representation.

(a) (b) (c)

Figure 6: Groups of (a) corners; (b) vertical lines and (c) horizontal lines resulting from the application of the SOM to the input pixels. Each one these groups forms the basis of a concept.

Figure 7 presents the flow between the processes required to produce an alternate representation. The restructuring process involves the combining of clusters into a single representation. Markers are used to delineate cluster boundaries to make the structure of the representation explicit, Figure 8. In a CAD implementation of the re-representation system, the initial representation would appear unchanged, but the internal structure of the representation would differ, broken down into the elements marked.

2.2. Alternate representations

Figure 8 shows two alternate representations resulting from an initial shape of a square. The representation in Figure 8(a) shows the result from restructuring the groups described in Figure 6. The representation in Figure 8(b) demonstrates the effect of increasing the number of neurons in the SOM, resulting in a greater number of groups and a breakdown into smaller features. This process can be extended to create a potentially infinite number of representations, restricted only by the pixel resolution of the image.

The system was presented with a number of initial representations to demonstrate its capacity to re-represent in a flexible way, unrelated to the initial environment. One example is a simplified floor plan of Frank Lloyd Wright's Unity Temple, Figure 9(a). Figure 9(b) is one alternate representation. Although not described in this paper, the example representation produced can be used to show a way that re-representation helps prevent fixation. Symmetry in the representation can be found and used by the designer for further design acts that are now based on symmetry. Alternate representations may have other properties such as repetition that can be used by the used in a manner similar to symmetry.

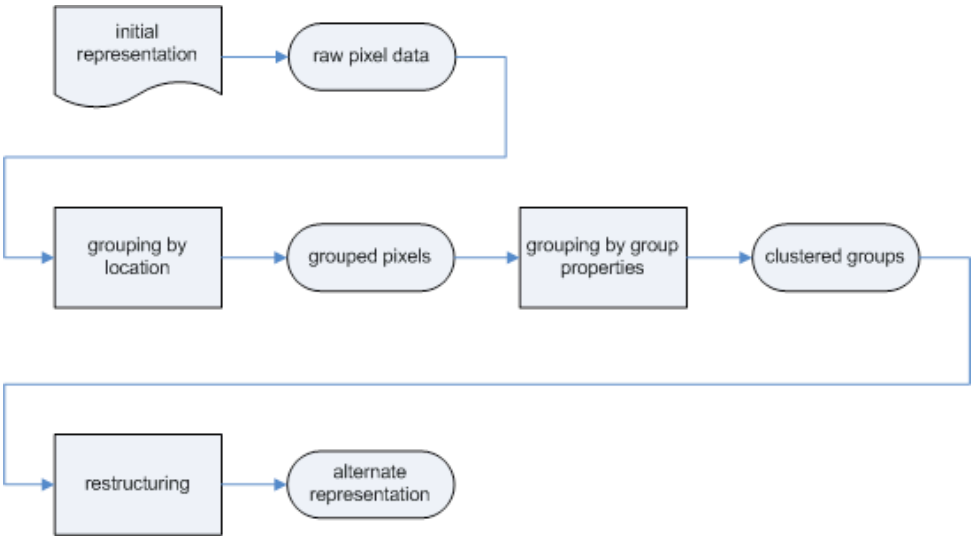


Figure 7: Re-representation processes and the flow between them

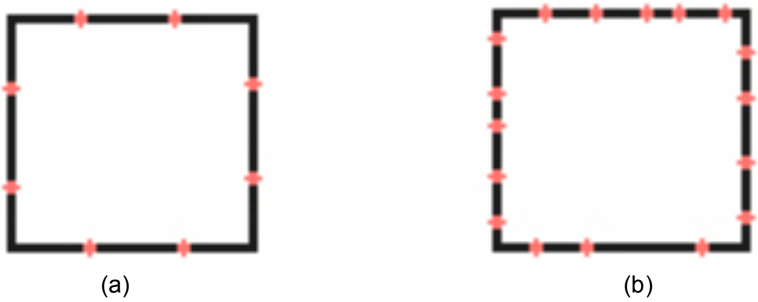


Figure 8: Representations resulting from the linking together contiguous elements within the clusters found for the initial image of a square: (a) with 8 groups and (b) with 17 groups

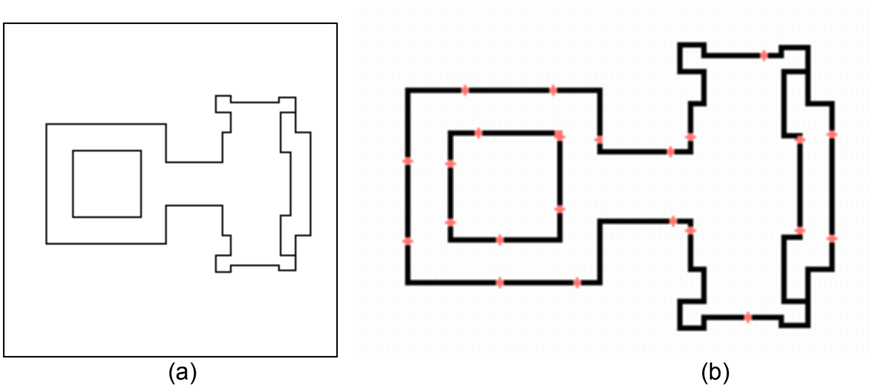


Figure 9: (a) Initial representation in the form of an image (Frank Lloyd Wright's Unity Church) based on lines composed of pixels, and (b) one resulting representation composed of a number of clusters of different types.

3 DISCUSSION

This paper has presented the basis of a computationally tractable approach that is the foundation of a fluid system of representation in CAD tools. It has briefly discussed the ways that this could aid designers by connecting their interpretation to the internal representation within the computational system. It has also raised the idea of assisting designers in preventing fixation through the presentation of new design representations and shown one way in which alternate representations could be created automatically.

The technique proved successful in automating the creation of alternate representations through the definition of the internal structure, facilitating the creation of multiple representations. The use of a SOM means that any two-dimensional image can be used as the input to the process. The use of SOMs also means that the process can be easily adapted to three-dimensional representations through the addition of a third feature for the z-axis.

It is expected that not all representations will be equally valuable to a designer at a particular time in the design development. Within the large number of possible representations able to be created automatically using re-

representation, it is likely that there will be some that closely match a designer's interpretation of the internal structure. There is a strong chance of there being a representation that is sufficiently different to the designer's current interpretation to stimulate the revision of design ideas.

Future work in making this research useful to designers can proceed in two directions. One direction would be to focus on ways of altering CAD tools so that designers are better able to alter the representation to bring it into line with their current interpretation. The other direction is to create design tools that could make suggestions of alternate representations, stimulating designers to revise their design ideas. Research needs to address how to make multiple representations available to designers. One method being investigated is the notion of a representation system that gives the designer access to a limited number of alternate representations that are dynamically generated during the design process. This may give the designer the ability to change the representation in a fluid way based upon the current interpretation as well as providing stimulus for re-interpretation to avoid fixation. This claim could be assessed through the implementation of such a system, and subsequent cognitive studies to determine the influence upon design actions.

Further research is required to develop higher level concepts from different re-representations. Concepts such as symmetry, repetition, rotation, translation and scaling may all be able to be automatically determined and made available as part of the representation.

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