REPRESENTATION, RE-REPRESENTATION AND EMERGENCE IN COLLABORATIVE COMPUTER-AIDED DESIGN

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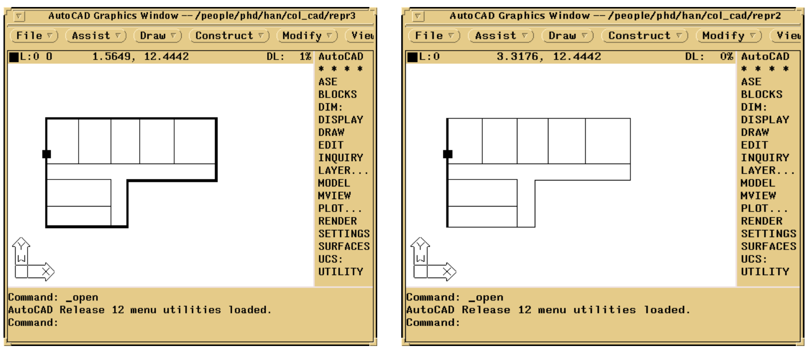
Abstract. Representation of drawings in CAD systems can cause problems during design collaboration. The notion of re-representation is proposed as one way of addressing these problems. Furthermore, re-representation is one way of allowing emergence to occur; emergence is an important aspect of collaborative computer-mediated design. Based on the concept of re-representation a model for collaborative CAD supporting emergence is presented and an example is demonstrated.

1. Introduction

Ways of representing drawings in computer-aided design system vary from designer to designer. What you see is not what you get in a computer-aided design system because of the way what you see is represented. For example, two drawings are seen as the same architectural plan but when a designer selects the same position in each drawing respectively Figure 1(a) shows that the whole of perimeter line is selected (shown by thicker lines) while Figure 1(b) shows only one side of perimeter line is selected (shown by a thicker line). This is exacerbated when collaborating because the collaborators are not exposed to the way the designs are represented in the drawing database. To allow different players to interact they need to have either a canonical representation of drawings and models or the system should support the ability to translate between an individual's representation and some canonical re-representation or the ability to support different views which can interact with each other.

There is the further issue of different collaborators seeing different things in the same drawing: *emergence*. In collaborative designing, emergence plays a supportive role in conceptual design because collaborators may see different things in the design drawn by one of them. However, current CAD systems are unable to assist the collaborators in the perception of emergent structures because existing representations do not readily allow interpretations other than the one intended. Therefore, collaborative computer-aided design requires that these issues be addressed. This paper describes re-representation and emergence in more detail and puts forward proposals to handle them.



(a) (b)

Figure 1: Different representations of the same drawing in a computer-aided design system. The selected parts are represented by thicker lines.

2. Collaborative CAD

Collaborative CAD means that synchronous collaboration is accommodated through a multi-user interface in a more comprehensive computer-aided design environment (Maher et al, 1993). Synchronous collaboration in computer-aided design occurs through shared workspaces. Shared workspaces have been regarded as a distinct subarea within computer supported cooperative work (CSCW) (Greenberg, 1991). A shared workspace, identified by Wilbur (1990), is a feature of most CSCW systems. It is a mechanism whereby all of the users in the group have access to the same piece of data. The variables of a shared workspace are (Winnett et al, 1994) :

• *Group membership:* some method is required for specifying which particular users on the network are participating in the CSCW session. Each of these users has to have access to the shared workspace.

• *Shared workspace contents:* a mechanism is required for transferring data into the shared workspace and distributing it to all members of the group.

• *Floor control:* floor control policy determines which member or members of the group have control of the shared workspace at any particular time. A mechanism is required whereby control can be given to one participant or to a subset of participants or all members of the group can have equal control.

In this paper, we focus on the second of these; ie what collaborators communicate via a computer-aided design system when designing. A large proportion of the research work on shared workspaces has to do with the understanding and construction of shared drawings spaces (Peng, 1994). Work on shared drawing systems is currently exploring such dimensions, as human-computer interactions situated in a group context and the structures of distributed graphics, which are not normally seen in traditional CAD systems. These drawings contain only unstructured graphic entities such as lines, text and symbols. The drawings can be interpreted in a multitude of ways because the graphic entities are essentially unstructured and different kinds of interpretation knowledge exist. There are two cases to be considered when collaborators deal with drawings. Firstly, collaboration between designers in different disciplines such as in the AEC domain occurs. CAD modelling in this collaborative environment has been suggested by Rosenman and Gero (1996). Multiple views from collaborators were represented by functional contexts. Secondly, collaboration between designers in the same discipline occurs. The remainder of this paper describes processes for re-representation and emergence within a collaborative computer-aided design environment

3. Re-representation and Emergence

Re-representation is the process of using an alternate representation for already represented objects. Re-representation allows for a consistent interpretation between collaborating designers as is required at various points during the design process.

3.1. RE-REPRESENTATION AND INTERPRETATION

Alternate representation makes new interpretations possible, interpretations which are only implicit in an existing representation (Damski and Gero, 1994). Interpretation is the process of inferring results from a given object in a particular representation. Therefore, re-representation allows implicit properties in one representation to become explicit in an other representation, ie as a result of re-representation, a new set of interpretations can be derived, Figure 2.

Two types of interpretations are considered here: visual semantic interpretation and structure interpretation. Visual semantics are interpreted when visually recognized patterns are discovered. Given objects, visual semantic interpretation varies from designer to designer because although the same visual pattern may be discovered the description of it is different. From a computational view, visual semantic interpretation is directly possible when types of visual semantics are predefined such as: visual symmetry, visual rhythm, visual balance and visual movement (Gero and Jun, 1995). Structure interpretation concerns changing the original shapes into new ones by modifying their structure. Structure is concerned with the components of objects and their relationships.

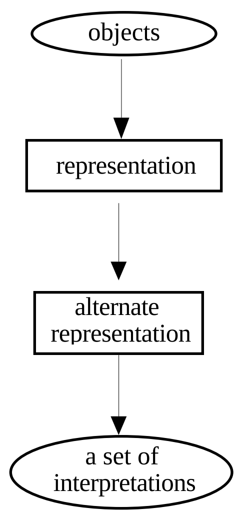


Figure 2: Process model of re-representation.

3.2. EMERGENCE IN DESIGN

Emergence is the process of making properties which were not explicitly represented at the outset become represented explicitly. Emergence in design occurs when a new property that was not explicitly represented or intended is discovered in a design description. Emergence in design can occur as function emergence, where a new function emerges from an existing design description; as behaviour emergence, where an unintended behaviour is recognized; and visual emergence, where some aspect of the shape of a design that was nor originally intended or drawn becomes a focus for manipulation. Visual emergence is of concern in this paper because of its special role during collaborative design. Two types of visual emergence have been developed: shape emergence and shape semantics emergence. Shape emergence is the process for discovering possible new shapes that were not explicitly represented in the given shapes. Gero and Yan (1993) and Liu (1993) have developed process models of shape emergence. Shape semantics emergence is the process for discovering visual patterns in groups of shapes or in a single shape. A process model of shape semantics emergence has been developed by Gero and Jun (1995).

Interpretation through alternate representations is regarded as one basis of the emergence process. An application of visual semantic interpretation of shapes is shape semantics emergence. Given a set of shapes, various types of shape semantics are discoverable through this process. On the other hand, an application of structure interpretation of shapes is shape emergence. Structure interpretation allows emergent shapes to be discovered. Therefore the process model of re-representation shown in Figure 1 becomes a visual emergence process model when alternate representations allow new interpretations, such as shape emergence and shape semantics emergence, to be possible as shown in Figure 3.

4. A Model for Collaborative CAD Supporting Emergence

In this proposed model five types of drawings are considered:

(i) *initial drawing:* the drawing of a designer's initial visual presentation using that designer’s given representation without any collaboration,

(ii) *re-represented drawing:* the drawing re-represented as consistent drawing primitives,

(ii) *modified drawing:* the drawing modified by other collaborators,

(iii) *emergent drawing:* the drawing emerged through emergence process and adopted, and
(iv) *new drawing:* the drawing considered as a new initial drawing.

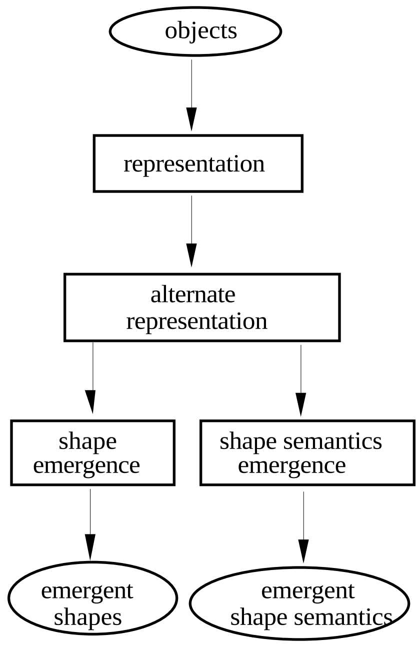


Figure 3: A visual emergence process model through alternate representation.

Each designer may propose their own initial drawing and the initial drawings are shared in the shared workspace simultaneously. If a collaborator finds an interesting drawing for further development, modification of the drawing commences through re-representation. Re-representation plays the role of producing the equivalent of a canonical representation so that all collaborators share the same representation without having to necessarily work in that representation. In this proposed model, Figure 4, initial drawings and new drawings are visually shared and given representations, re-representations and emergence processes are invisibly shared through the shared workspace. Re-represented drawings, modified drawings and emergent drawings are available privately in private workspaces until the drawings are considered as new drawings or as shared drawings.

4.1. GIVEN REPRESENTATION

Initial drawings are seen in the shared workspace by all the collaborating designers thus allowing the sharing of visual information. The initial drawing represented by its given representation from each collaborator is shared initially in this workspace.

Current CAD systems represent visual data as files stored in persistent memory. For example, AutoCAD stores the visual data in a Drawing Exchange Format (DXF) file. This representation stores the geometric data according to the primitives used to create the visual image, for instance same shape visually can be stored either as a set of lines or as a polyline. Therefore in this model the given representation only plays the role of representing initial drawings in the shared workspace.

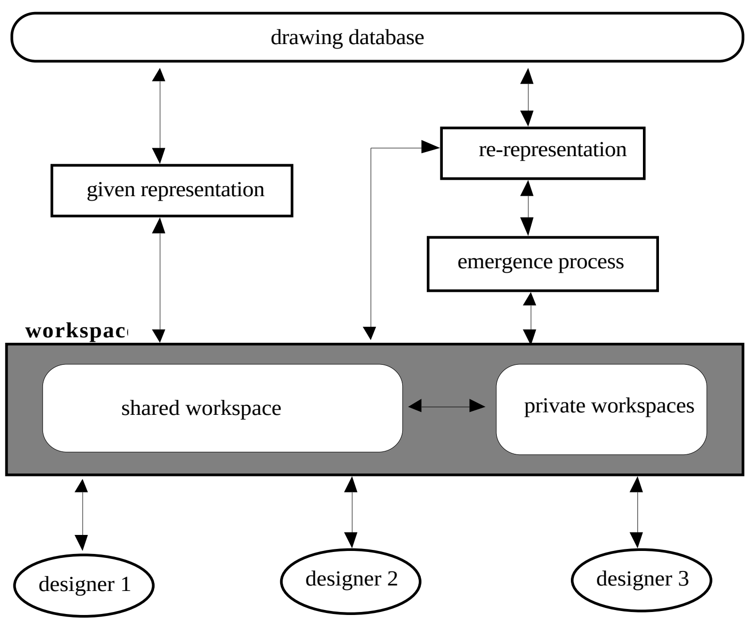


Figure 4: A model for collaborative computer-aided design supporting re-representation and emergence (after Maher et al, 1993).

4.2. RE-REPRESENTATION AND EMERGENCE PROCESS

A process model for re-representation and emergence process is illustrated in Figure 5. This process model consists of four steps:

(i) re-representation,
(ii) emergence,
(iii) modification, and
(iv) adoption.

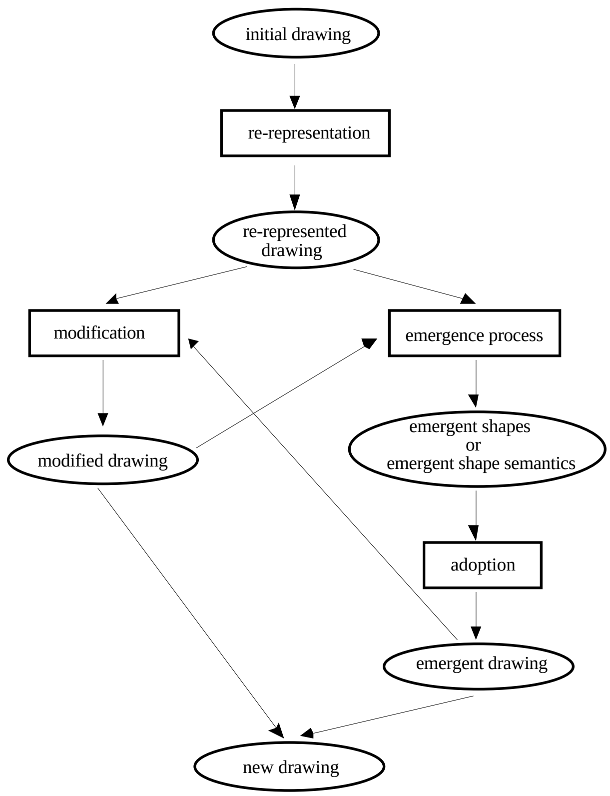
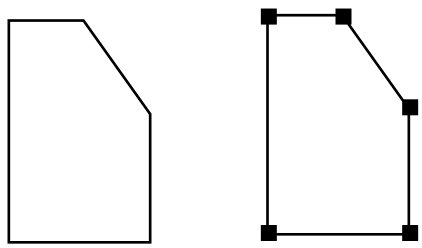


Figure 5: A process model for re-representation and emergence.

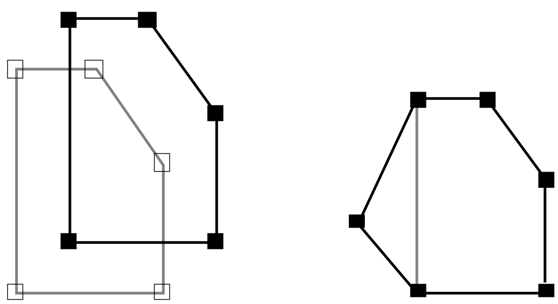
4.2.1. Re-representation

Re-representation may be executed on the fly as a designer signals an intention. For example, consider the drawing in Figure 6(a). This drawing, irrespective how it was drawn, might be re-represented as shown in Figure 6(b) by a series of line segments and vertices. One designer may wish to manipulate the whole object which results in a grouping-style re-representation, Figure 7(a), whilst another designer may wish to change the topology of the object resulting in the introduction of a new vertex, Figure 7(b). Therefore, this allows one designer to modify an initial drawing done by another designer without worrying about how it was initially represented. Visual emergence is supported as another major role of re-representation. One way of re-representing initial drawings is adapted here so that new structures emerge visually and computationally (Gero and Yan, 1994; Damski and Gero, 1996).



(a) (b)

Figure 6: (a) Initial drawing and (b) re-represented drawing.



(a) (b)

Figure 7: Possible manipulations of re-represented drawing: (a) grouping-style manipulation and (b) topological manipulation.

4.2.2. Emergence process

Re-represented drawings allow the emergence processes to take place. Two types of emergence processes are considered here:

(i) shape emergence and

(ii) shape semantics emergence.

Figure 8(a) illustrates a process model of shape emergence and Figure 8(b) of shape semantics emergence. These process models are based on the concept of re-representation. Primary or initial shapes which are represented in a predefined structured manner are subjected to a process in which the explicitly represented shapes become implicit. Thus, the structured shapes lose their structure when re-represented from which shape emergence becomes possible. A process model of shape emergence has been developed by Gero and Yan (1993) as shown in Figure 8(a). In this model, both explicit structures and emerged structures are found through re-representation of primary shapes. Corresponding structures are searched and grouped according to their behaviours in their re-represented forms. If groups satisfy constraints on various types of shape semantics, then these shape semantics are emerged in the process of shape semantics emergence as shown in Figure 8(b) (Gero and Jun, 1995).

4.2.3. Adoption

Emergent shapes or emergent shape semantics are discovered through emergence processes. Collaborating designers can adopt emergent shapes or both emergent shapes and shape semantics. There are two possible forms of adoption. One form is user-driven adoption in which one designer can select an interesting emergent shape manually and search for shape semantics based on the selected shape otherwise only emergent shapes are adopted. Another form is system-driven adoption in which a system displays possible emergent shapes in the shared workspace and collaborating designers choose interesting ones for further development or for discovering shape semantics. The use of various heuristics to limit the number of selected shapes and emergences is necessary.

4.2.4. Modification

Modification of drawings can occur at two different stages in this model. In the first stage a designer modifies an existing (re-represented) drawing. Since it has been re-represented there is no difficulty associated with not having direct access to its original representation. In the second stage, modification of an emergent drawing can occur. Emergent drawings are then considered as new drawings. New drawings are available in the shared workspace as developed designs.

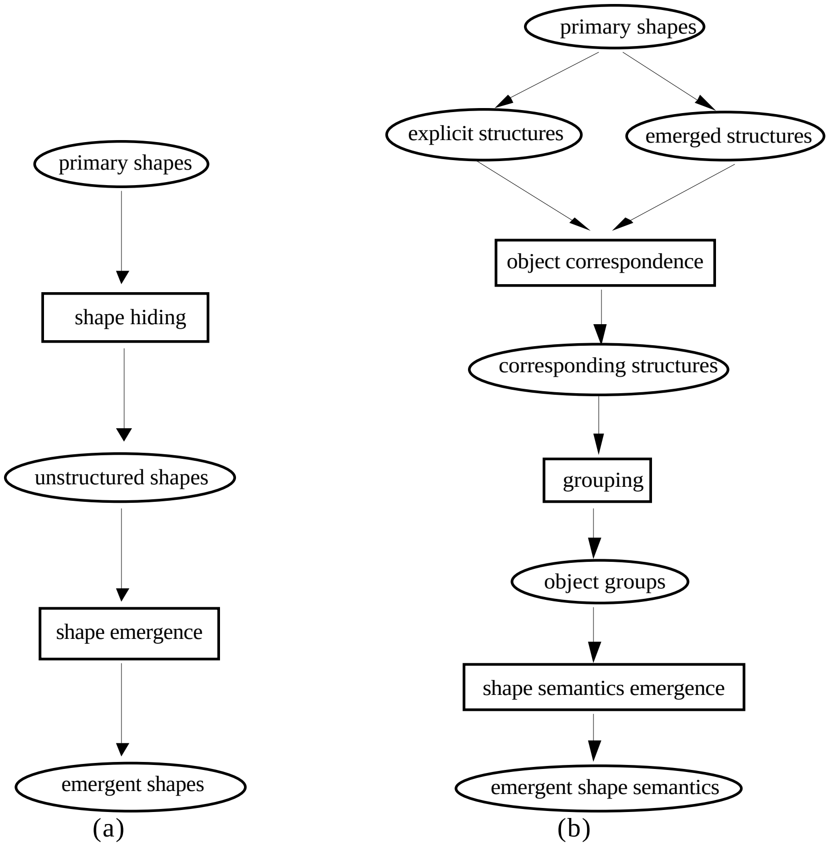


Figure 8: Process model of emergence: (a) shape emergence and (b) shape semantics emergence.

5. Examples

Three designers are assumed to be collaborating: designers labelled A, B, and C. Designer A proposes an initial drawing and then the other designers collaborate in developing the design further based on this initial drawing.

Let the representation of a drawing be:

Drawing = {number of primitives; type of primitives}.

Initial drawings are represented in various ways depending on the designer's use of the CAD system. Let us assume that designer A represents his initial drawing as three polylines as shown in Figure 9. Thus the representation of the initial drawing is:

D_i = {3; polylines}

D_i: initial drawing in given representation.

5.1. RE-REPRESENTATION

Different types of representation of initial drawings become one consistent type through re-representation. In this example only n-sided shapes are considered. N-sided shapes are re-represented as a number of line segments. So the general representation of re-represented drawing becomes:

D_r = {number of line segments; line segments}.

D_r: re-represented drawing by re-representation of D_i.

When collaboration occurs the system applies a re-representation process to the initial drawing. As a consequence, the representation of the re-represented drawing in this example becomes:

D_r = {12; line segments}.

D_i and D_r produce identical images as shown in Figure 9, although their representations are different.

5.2. EMERGENCE PROCESS

When designers B and C want to apply an emergence process to the re-represented drawing, D_r allows another re-representation for visual emergence. In this example the concept of infinite maximal lines (Gero and Yan, 1993) is used. D_r becomes a set of infinite maximal lines as shown in Figure 10. All lines are extended to a frame which is defined as an encompassing rectangle. Representation of D_r becomes

$D_{r'}$ = {12; infinite maximal lines}

$D_{r'}$: re-represented drawing of D_r .

5.2.1. Shape emergence

Through the infinite maximal line representation emergent intersections and line segments are discovered. An emergent shape is decided by one of the designers as a closed set of line segments or more than two adjacent closed sets of line segments. Two emergent shapes are discovered by designer B and designer C respectively as shown in Figures 11(a) and (b). The emergent shapes are shared through the shared workspace for collaboration.

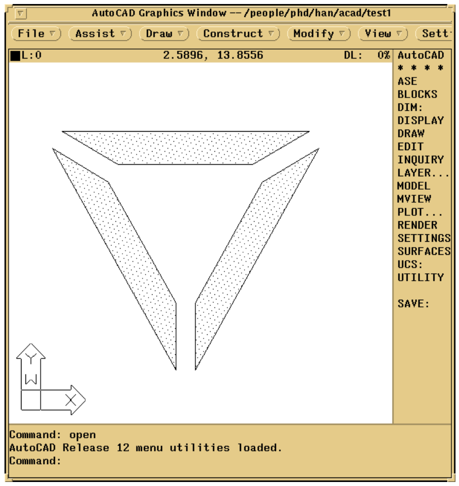


Figure 9: Initial drawing from designer A in the initial representation. This initial drawing is re-represented and still appears the same as the initial drawing.

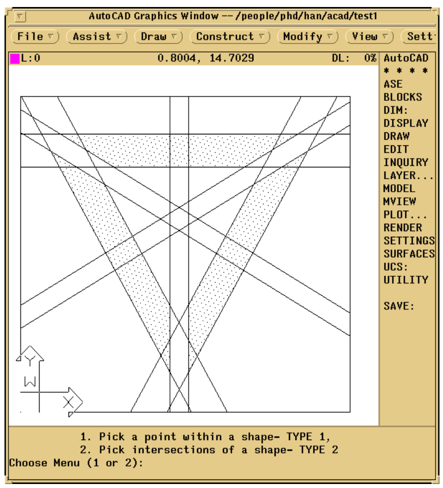
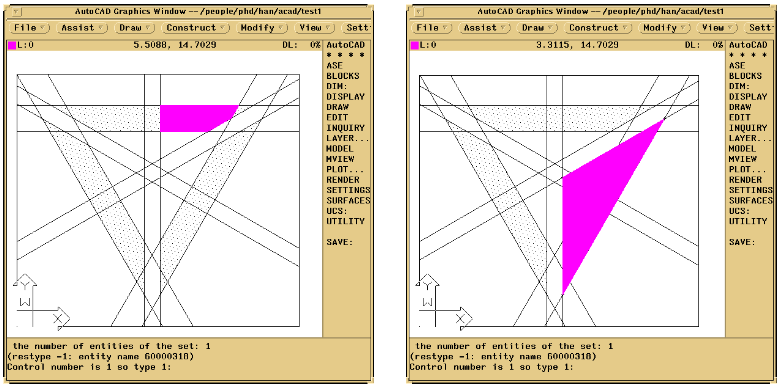


Figure 10: Re-represented drawing using infinite maximal lines.



(a) (b)

Figure 11: Discovering emergent shapes by different designers: (a) a five sided shape is discovered by designer B and (b) a triangle is discovered by designer C.

5.2.2. Shape semantics emergence

Shape semantics are searched through a shape semantics emergence process based on a selected shape. Designer A searches for visual symmetry based on one of the discovered emergent shapes as shown in Figure 11(b). In this example designer A selects the triangular emergent shape discovered by designer C. As a consequence of shape semantics emergence process several types of visual symmetries are emerged as shown in Figure 12.

5.3. ADOPTION

After designer A discovers several types of visual symmetry, the emergent shape semantics are shared with collaborators which provides the opportunity for adoption by them. In this example, one of emergent reflectional symmetries is adopted by designer A as shown in Figure 13(a) and another emergent reflectional symmetry is adopted by designer C as shown in Figure 13(b). Therefore, the notion of reflectional symmetry is considered as an important concept of this design and reflectional symmetry remains in a new design irrespective of other modifications.

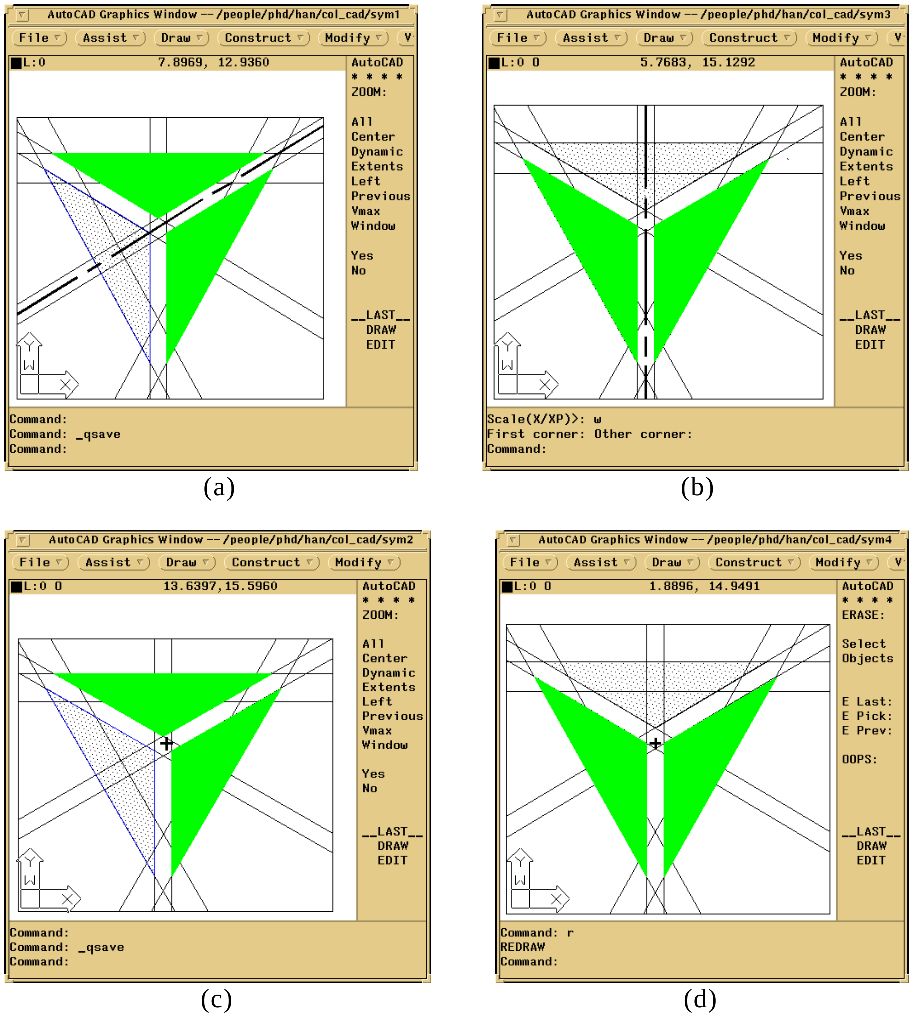
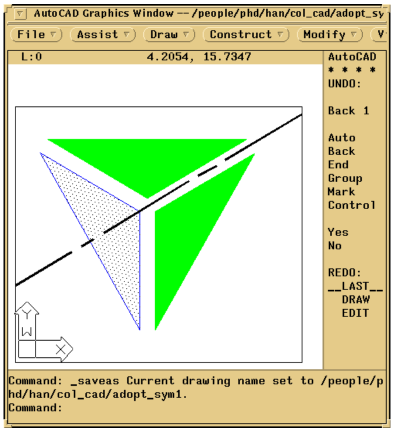
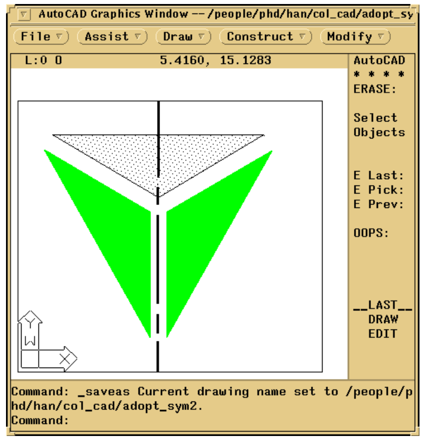


Figure 12: Designer A searches for emergent visual symmetry. Two types of symmetries are discovered from the selected shape in Figure 11(b) : reflectional symmetries shown in (a) and (b) where ▬ ▪ ▬ defines axis of reflection; and rotational symmetries shown in (c) and (d) where + defines centre of rotation.



(a)



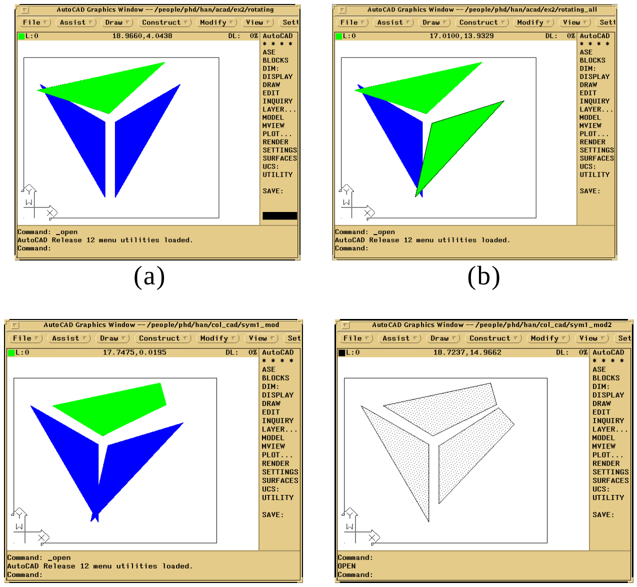
(b)

Figure 13: (a) Adopted emergent shape semantics by designer A and (b) adopted emergent shape semantics by designer C.

5.4. MODIFICATION

Modification of the adopted shape semantics occurs in such a manner as to maintain the shape semantics whatever operations are applied, such as reshaping, rotating, moving and so on. A possible modification is described resulting from adopting a particular emergent shape semantics. Designers A and B collaborate to modify the adopted emergent reflectional symmetry in Figure 13(a) by rotating and reshaping. Figure 14(a) shows a new drawing generated by designer A rotating one part of the reflectional symmetry from Figure 13(a). The reflected part is rotated in order to maintain reflectional symmetry as shown in Figure 14(b). At this moment, designer B develops the design by reshaping a symmetrical part in Figure 14(c) and a new drawing is generated as shown in Figure 14(d).

Designer C modifies his/her adopted emergent reflectional symmetry in Figure 13(b) by rotating and cutting the reflected part. Figure 15 shows the modification and a new design resulting from this modification.

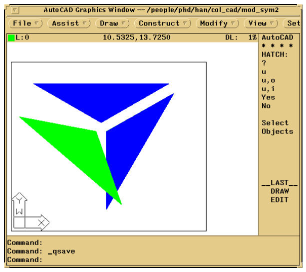


(a) (b) (c) (d)

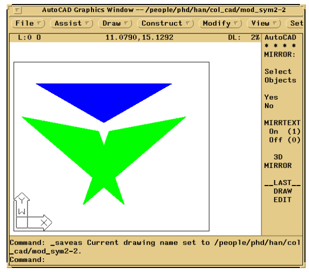
Figure 14: Modified drawings by designers A and B after adoption of reflectional symmetry from Figure 13 (a): (a) designer A rotates one part of the reflectional symmetry and (b) the reflected part is rotated; and (c) designer B reshapes one part of the reflectional symmetry and (d) a new drawing is generated.

5.5. SUMMARY

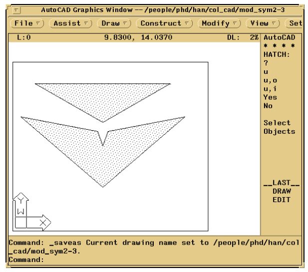
As a result of collaboration through the proposed model, two different new drawings are generated as shown in Figure 14(d) and Figure 15(c) respectively. Two types of collaboration can take place through this model: synchronous collaboration and asynchronous collaboration. This example shows one of possible synchronous collaboration. Three designers work together simultaneously to generate new designs. All drawings from each designer in each step are shared in the shared workspace. One designer discovers emergent shapes or shape semantics through re-representation and then other designers adopt some of them and develop them further by themselves or with others. On the other hand, each designer works individually to generate his/her own design from initial designs. All drawings generated by each designer during designing are not necessarily shared with collaborators in this case. This type of work is one of possible asynchronous collaboration.



(a)



(b)



(c)

Figure 15: Modified drawing by designer C after adoption of reflectional symmetry from Figure 13 (b): (a) rotating one part of the reflectional symmetry and (b) the reflected part is rotated and (c) a new drawing is generated after cutting some parts.

6. Discussion

The importance of representation of visual objects, drawings in this case, in computer-mediated collaboration has been demonstrated. Progress towards the resolution of this issue has been the focus of this paper and the concept of re-representation has been proposed for tackling this problem in collaborative computer-aided design. This paper has described a model for collaborative CAD supporting emergence based on the notion of re-representation. The concept of re-representing already represented drawings plays an important role not only for developing a canonical representation but also for allowing visual emergence when collaboration occurs.

Collaboration, whether synchronous or asynchronous when using a human-to-computer-to-human design system introduces special problems not evident in human-to-human collaboration. This is exacerbated when using a computer-aided design system which needs to have a structured representation of the objects being described. Unstructured representations such as pixel-level descriptions do not suffer from the problems described in this paper but do not have sufficient functionality to make them useful in a design environment. Re-representation has many roles to play in the act of designing with the aid of a computer, here we have described just two of them.

Acknowledgements

This work has been supported by a grant from the Australian Research Council. Computing resources have been provided by the Key Centre of Design Computing.

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This paper is a copy of: Jun, H. and Gero, J. S. (1997). Representation, re-representation and emergence in collaborative computer-aided design, *in* Maher, M. L., Gero, J. S. and Sudweeks, F. (eds), *Preprints Formal Aspects of Collaborative Computer-Aided Design*, Key Centre of Design Computing, University of Sydney, Sydney, pp. 303-320