ROLE OF VISUAL EMERGENCE IN COLLABORATIVE DESIGN

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In searching for a new solution, Leonardo projected new meanings into the forms he saw in his old discarded sketches (Gombrich, 1966).

INTRODUCTION

There are two fundamental approaches to the use of computers to support collaborative design:

(i) to use the computer as a device which increases the efficiency of what designers could do previously, and

(ii) to use the computer as an active device which allows designers to do what they could not readily do previously.

This paper is concerned with the latter approach by introducing the concept of visual or graphical emergence as one form of collaboration at a distance that can not readily be carried out without the aid of the computer.

Shapes play an important role in at least three domains. Drawn shapes are used to represent ideas, concepts, and possible physical worlds. Perceived shapes are the way we begin to understand the world our visual sense brings to us (Marr, 1982). Computer generated shapes play a critical role in computer-aided design systems and in many areas of artificial intelligence generally. Drawn shapes specifically play a dominant role in various design domains and particularly in architectural, engineering and industrial design where they are used not simply as the representation of an idea but also as a representation open to reinterpretation. In the conceptual and creative aspects of designing this reinterpretation of what has been drawn appears to play a critical role in the design process (Schön, 1983). It provides opportunities for designers to conceptualise what has been drawn differently from what was intended when it was drawn. This process of restructuring and reinterpreting an existing drawing can be said to result in the recognition of a shape that is present but unrecognised or implicit in the initial drawn shape. The shape that is made explicit in this way can be regarded as an emergent shape and the process of reinterpretation and restructuring forms the basis of emergence.

A feature that is not represented explicitly is said to be an emergent feature if it can be made explicit. There are three views of emergence: computational emergence; thermodynamic emergence; and emergence relative to a model (Cariani, 1992). Computational emergence is the view that novel behaviours can emerge as a result of local computational interactions (Forrest, 1991; Langton, 1991). This is one of the approaches to the field of artificial life. Thermodynamic emergence is the view that thermodynamic theory may be used to describe how new, stable behaviours and structures can arise at loci removed from equilibrium. Emergence relative to a model sees emergence as a deviation of the behaviour of a system from an observer's model of it. This latter view is the one that is used in this work.

While perceived shapes are associated with the building blocks of visual experience and there has been extensive research in this area (Kanizsa, 1979; Marr, 1982), there are also what appear to be parallel phenomena to the emergent shapes discussed in the literature on the design process (see, for example, Reed, 1974; Kellman and Shipley, 1991; Shipley and Kellman, 1990). The phenomena initially discussed by the Gestalt psychologists, where particular relationships between sets of shape elements, such as the proximity or similarity of the elements, result in the appearance of shapes through the grouping of sub-sets of the shape elements, would appear to be a case of emergence similar to that discussed in the design literature. Similarly the phenomena of subjective or illusory figures, where the contours defining a shape are perceived even though no contours are physically present would seem to be related to emergence. Perhaps the direct relevance of these phenomena concern the work done on the identification of a shape when it is embedded within a more complex shape. Here an existing, complex shape contains within it initially unrecognised shapes which only become explicit through a process of emergence which would appear very similar to that found in the design process. It is this type of perceived shape emergence which is of particular interest here as it provides the theoretical and methodological link between shape emergence in design and the possibility of shape emergence in a graphical computer environment.

There is currently however no parallel to emergent shapes in the commercial CAD area. Current CAD systems have not been used extensively during conceptual design for a variety of reasons, one of which is that they freeze the shape being represented and do not allow any other interpretations - that is, the possibility of emergence is removed from the situation. Since emergence plays an increasingly important role during design collaboration it is important that CAD systems have the capability to deal with emergent shapes. Most CAD systems use geometric representations of shape based on line segments and their endpoints. Line segments are grouped together to form a shape. Given this approach to shape definition it is not possible for such systems to produce or identify emergent shapes. Some symbolic models related to shapes and to a lesser extent to shape emergence have been presented extensively by Stiny (1980; 1981; 1986), and by Krishnamurti (1980; 1981).

In the specific area of shape emergence, Tan (1990) presents a limited approach to shape emergence as do Edmonds and Soufi (1992). Recently Gero and Yan (1993; 1994) have presented a computational model of shape formation which also allows for the explicit identification of all explicitly represented and implicitly present shapes - that is the model allows graphical emergence. The basis for this model of shape formation lies in identifying the boundaries of shapes as segments of infinite maximal lines and placing a set of constraints on the behaviour of these lines. This is the first directly implementable model of computational graphical emergence and provides the possibility of allowing designers to inspect both the shapes they have generated and all the implicit emergent shapes which are present within the particular shapes produced by them. However, the benefit of this capacity will only occur if either the computer or a collaborating designer can draw the other designer's attention to potentially emergent shapes which that designer would either not recognise at all or where it would take prolonged periods of inspection of the existing shapes before the emergent shapes were found. In order to allow such forms of collaboration to occur the database representing the shapes would need to change so that the emergent shapes could now be worked with.

This paper proceeds by presenting an outline of a computational model of visual emergence, then presents examples of visual emergence before concluding with a discussion of the role of visual emergence in collaborative design.

COMPUTATIONAL MODEL OF VISUAL EMERGENCE

Gero and Yan (1993; 1994) have presented a computational model of graphical emergence. A brief introduction to the model is presented here.

Psychologists have reported that, when perceiving a picture visually, a person attaches a certain organization to it (Granovskaya et al, 1987). This organization involves dividing everything in the visual field into a figure and background, and grouping elements in the figure into recognizable structures. Thus, shape recognition involves two steps:

(i) isolating a figure from its background; and

(ii) structuring the elements of the figure.

However, shape recognition involving the above two steps is not appropriate for emergent shape recognition which commences from a structured figure rather than an unstructured background. Emergent shape recognition restuctures an already structured figure. It is more difficult to build a new structure for an already structured figure than from an unstructured background, because the existing structure results in fixation (Purcell and Gero, 1991) that encumbers the establishment of a new structure. Thus, a precursor step is required to unstructure the existing figure so that it becomes part of the background. Figure 1 shows a generic process model of shape emergence which includes the fundamental steps of shape hiding and shape emergence.

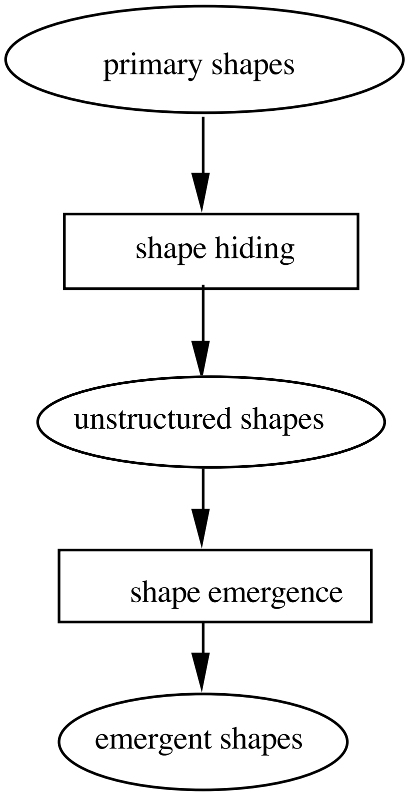

Figure 1. A generic process model of shape emergence.

In order to hide shapes another form of representation of shapes is required which facilitates this activity. A conventional way to represent shapes is to use point coordinates as primitives (Stiny, 1980). In this way a line segment is described by the coordinates of its two endpoints. A shape as a set of line segments is represented through a set of point coordinates. Shape recognition based upon this coordinate representation is coordinate computation in which geometric properties of shapes are not explicitly used and the results are dependent upon calculating accuracy (Tan, 1990). A new representation, called the infinite maximal line, has been developed (Gero and Yan, 1993; 1994).

A *line segment,* is defined as a part of a line between two points. A *maximal line* is defined as a line segment which embeds at least one line segment (Stiny, 1980). An *extended maximal line* is a line segment within which at least one maximal line is embedded. An *infinite maximal line* is the infinite line in which an extended maximal line is embedded. Figure 2 illustrates the concepts of line segment, maximal line, extended maximal line and infinite maximal line. Using infinite maximal lines as the primitives a shape can now be represented symbolically without geometry based entirely on the number of infinite maximal lines it contains plus constraints on the way those infinite maximal lines interact.

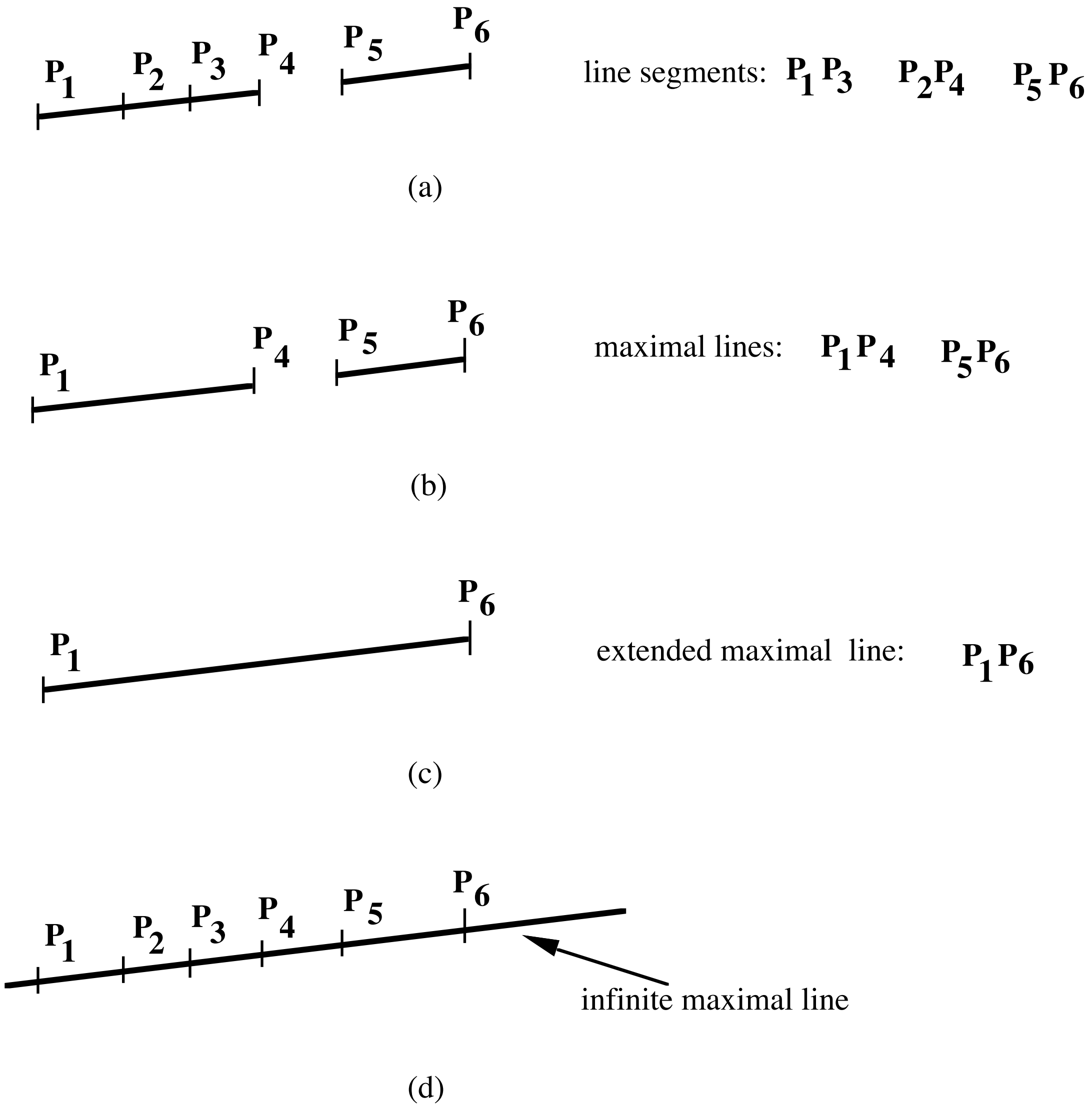

Figure. 2. (a) Line segment; (b) maximal line; (c) extended maximal line; and (d) infinite maximal line; Pi is an endpoint of a line segment.

Shape hiding makes shapes which are explicitly represented become implicit. When a shape is explicitly represented the behaviours which define are constrained. When these constraints are relaxed or destroyed an explicitly represented shape becomes implicit and becomes hidden in the background. Shape hiding transfers structured representations of shapes into unstructured representations.

Shape emergence is the process of discovering possible shapes in the background of unstructured representations. It consists of two steps: constraint derivation and shape discovery. Constraint derivation produces constraints which define shapes by generating constraints which do not exist in that representation. Shape discovery maps the symbolic representations which now include constraints onto known shapes.

These two processes form the basis of the computable process model of shape emergence. Of particular interest here is the requirement for the representation of the shapes under consideration to change. This has far-reaching implications for CAD systems which currently do not have the capacity to alter the representations of their objects. Figure 3 shows how the database of a CAD system can be changed to accommodate newly emerged figures.

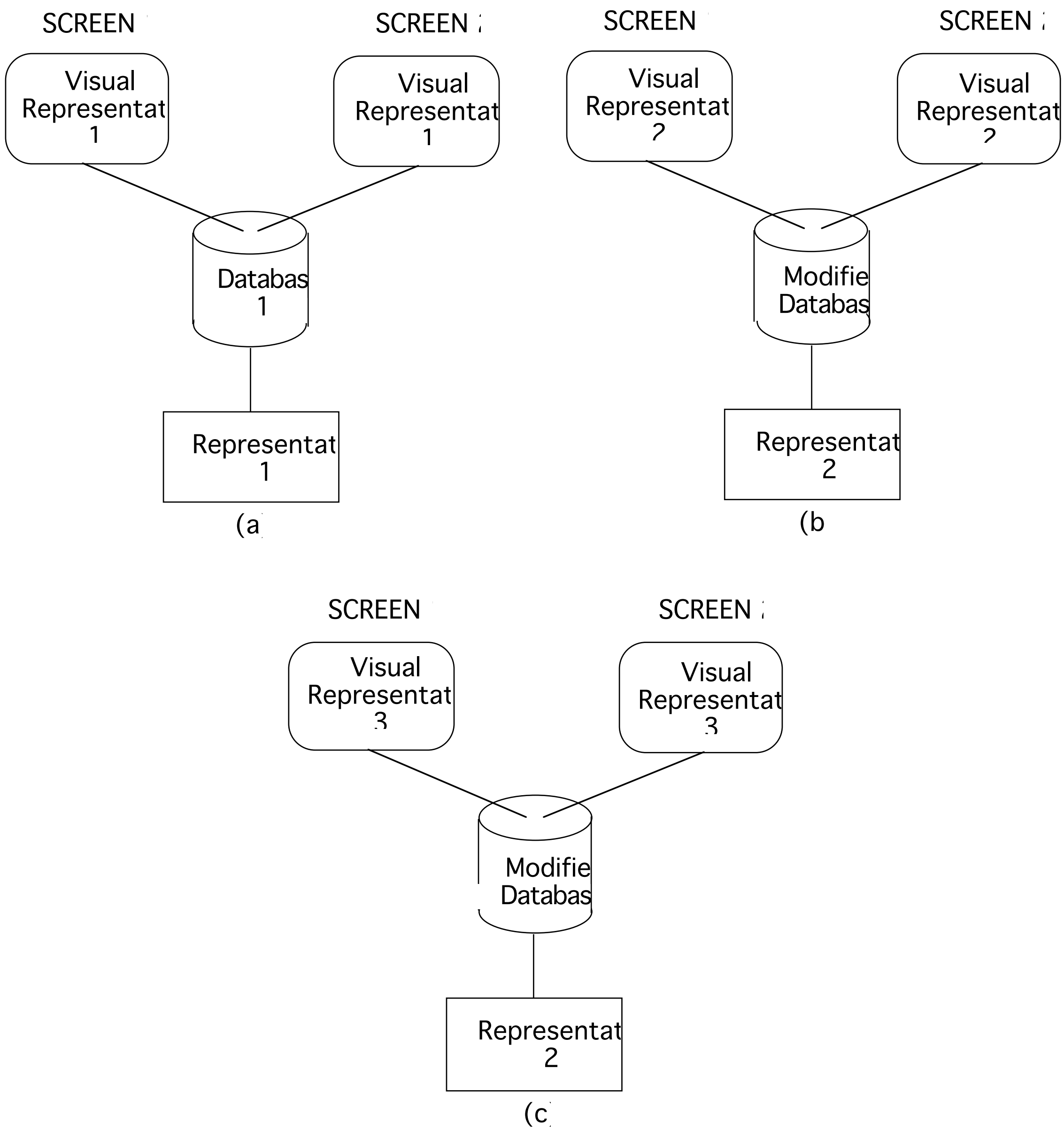

Figure 3. Model of database changes to accommodate visual emergence.
(a) The two screens of the collaborating designers with their visual forms, database and underlying representation at some stage in the design.
(b) The two screens showing the emergent visual forms, the database modified by the emergence process and the underlying representation.
(c) The two screens showing manual changes to the emerged visual forms with the database and underlying representation.

EXAMPLES OF VISUAL EMERGENCE

Visual emergence can be categorised into a number of class:

(i) shape emergence

(ii) relationship emergence

(iii) form emergence.

Examples from each class will be presented.

Shape emergence is concerned with the emergence of individual or multiple shapes. Figures 4, 5 and 6 are examples of shape emergence. In each case, the computer model above is capable of representing and if needed finding these emergent shapes.

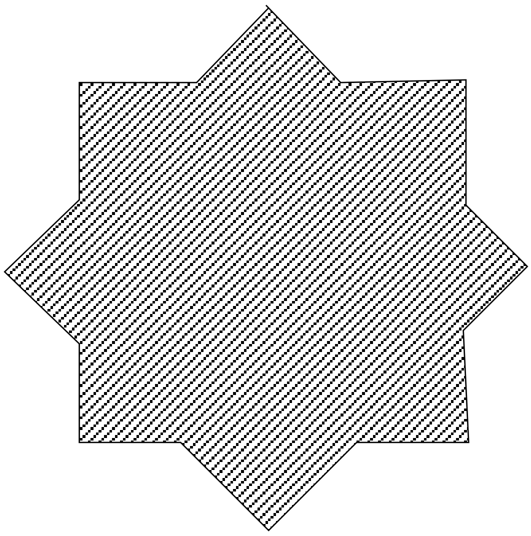

Figure 4. The shape as drawn

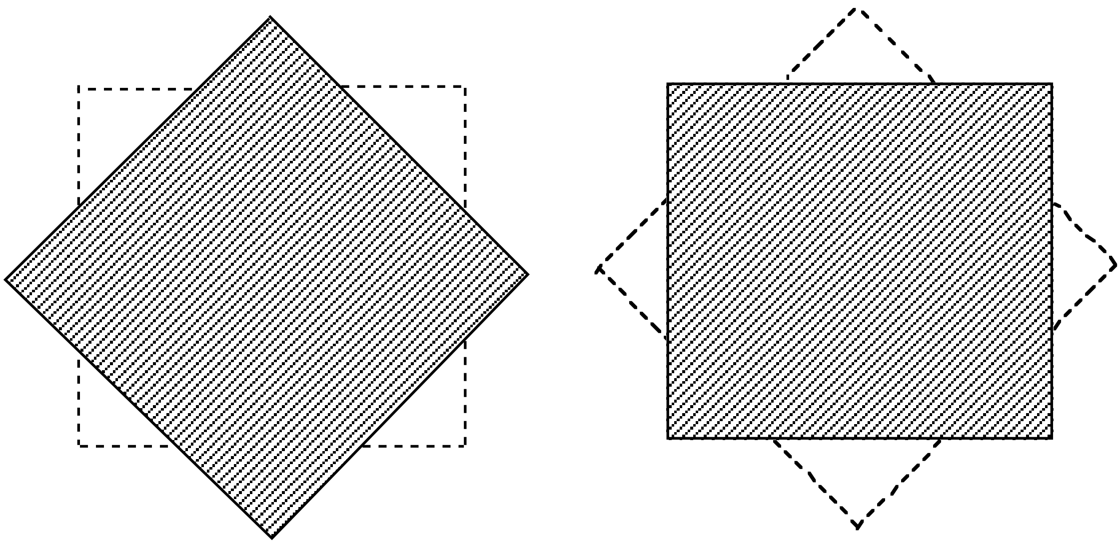

Figure 5. Two emergent shapes derived from the as-drawn shape.

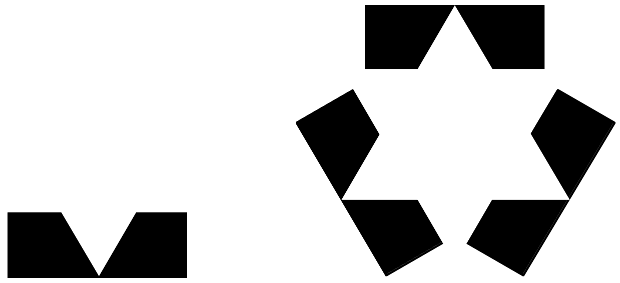

Figure 6. (a) Single shape. (b) Configuration of three copies of the single shape resulting in a number of emergent shapes including triangles and a star.

Relationship emergence is concerned with representing and finding emergent relationships between elements in a drawing. Typical emergent relationships are the various kinds of symmetry; an example is given in Figure 7.

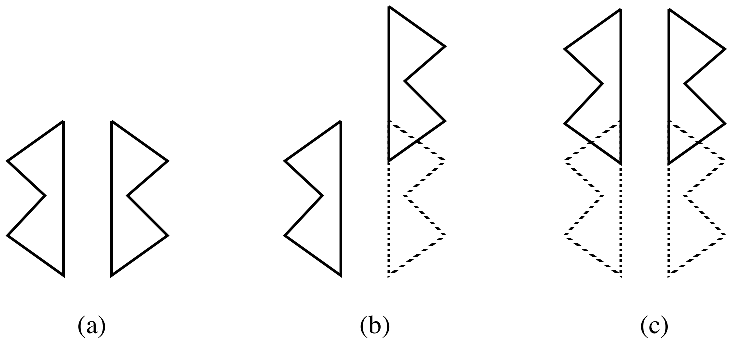

Figure 7. (a) Original form. (b) Form without emergent symmetry after one part has been moved. (c) Form with emergent symmetry after one part has been moved.

Form emergence is concerned with representing and finding forms which were not explicitly described. Form emergence is a domain specific issue, ie it require knowledge about the specific design domain in order for it to occur. Figures 8, 9 and 10 show an example of form emergence in the domain of structural engineering.

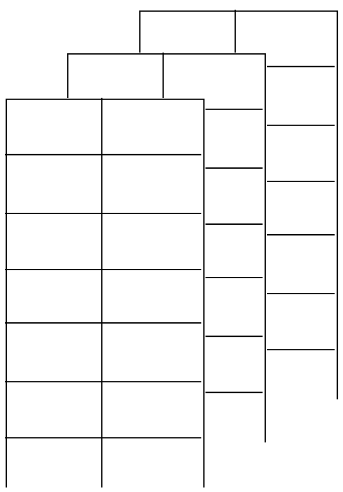

Figure 8. Building structure as a set of parallel load resisting frames.

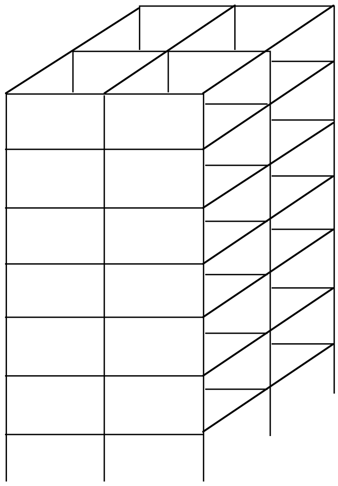

Figure 9. Building structure with horizontal lateral bracing added.

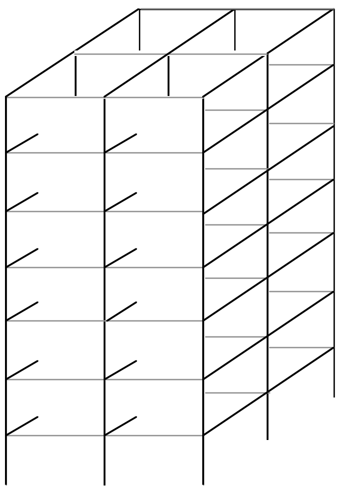

Figure 10. Building structure with emergent frames highlighted.

ROLE OF VISUAL EMERGENCE IN COLLABORATIVE DESIGN

Given that it is becoming possible to capture and make available visual emergence in a computational environment what might be its role in collaborative design? Synchronous design collaboration at a distance involves two or more designers working on the same drawing surface at the same time. Shared whiteboards provide a technology for sharing drawing surfaces across a network and there is research currently underway to allow the sharing of the underlying representation of the drawing in a CAD database across the network synchronously (Maher et al, 1993). It is thus possible to develop an architecture which includes emergence in synchronous design collaboration, Figure 11.

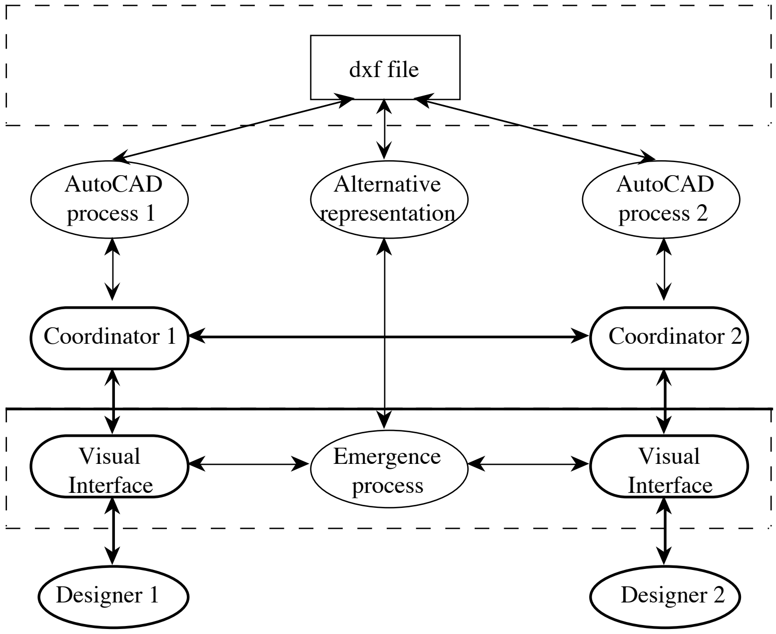

Figure 11. An architecture which provides for synchronous design collaboration based on emergence (Maher et al, 1993).

A system based on this architecture could be used by collaborating designers at the conceptual stages of designing when the meanings of the sketches and drawings have not yet been frozen. Designer A could draw an idea in which designer B sees something other than what designer A intended. This new emergent concept is negotiated between designers A and B and if agreed upon the database of the system is then automatically updated to represent that concept even though the drawing on the screen still looks the same as before. With the same looking drawing but a new interpretation the designers have now begun to travel down a new path *thus exploring rather than searching*. This notion of exploration plays an important part in the early stages of designing when not all the concepts have been sorted out and a fixed set of ideas, which have then to be developed, arrived at. Current CAD systems only become useful in the design process after all the ideas have been agreed upon and fixed. Their utility is thus limited to documentation of design ideas not their development. Emergence is opportunistic, ie it cannot be predicted beforehand, it is an important process in exploring design ideas. Emergence appears to play one of the fundamental roles in design and is brought to the fore in collaborative design. Computer supported collaborative design requires that emergence be supported.

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