A Framework for the Description and Representation of Emergent Shapes

Bassel Soufi
Ernest Edmonds

LUTCHI Research Centre
Department of Computer Studies
Loughborough University of Technology
Loughborough, Leicestershire LE11 3TU
UK

This paper is concerned with the computational modelling of emergent shapes in design. The categorisation of emergent shapes, and the development of a framework capable of modelling different types of emergent shapes are of particular interest. A scheme is proposed for the description of emergent shapes. Four different types of emergent shapes are described. A framework based on multiple shape representations is then presented. The operation of the framework is illustrated using a worked example.

Keywords: creative design, emergence, categorisation of emergent shapes, multiple shape representations, description-representation framework.

1 Introduction

Drawing and sketching play an important role in design reasoning. This reasoning is facilitated by the interaction between the designer and visual representations of the design. Drawing provides a mechanism for externalising the ideas of the designer and subsequently for analysis and reconsideration of these ideas. This may lead to novel elements or directions in the design process as a result of the modified conceptualisation of the design space. Fish & Scrivener (1990) argue that an important feature of sketches is that they contain uncertainties important to their function and play the role of preserving alternatives. These uncertainties can arise because of ambiguity in the sketch or as a result of new interpretations. New interpretations allow shapes or patterns that were not intentionally represented, to be discovered as result of perceptual or reflective acts. Shapes brought to the designers attention in this manner are defined as emergent shapes. Mitchell (1993) argues that interpretation and reinterpretation of emergent shapes plays a crucial role in directing design exploration: *"Designers ... frequently recognise emergent subshapes, and subsequently structure their understanding of the design and their reasoning about it in terms of emergent entities and relationships"* (Mitchell, ibid).

2 Emergent shapes and CAAD support for creative design

At present there are a variety of methods for representing shapes in computer aided design/ computer aided drafting systems. All of these, however, do not provide sufficient support for flexible and creative visualisation of shapes not conceived of in the original construction of a pattern.

Object oriented drafting. systems impose a certain structure on the drawing according to the shapes originaly used in its construction. The interpretation of the pattern, therefore, is usually frozen to this structure. Traditionally, according to the object oriented paradigm, objects are atomic and indivisible. Hence, this approach does not lend itself to arriving at multiple interpretations of a pattern.

In the case of shape algebras which form the basis of many CAD systems, shapes are represented in terms of their geometric primitives. A two-dimensional shape is described in terms of the line segments that constitute the shape and the coordinates of their end points. A shape therefore is a set of line segments that have particular geometric relationships to each other. Line segments can be added by defining and associating end points and removed by dissociating end points. A CAD system may be used to provide various interpretations of shapes based on subsets of the primitives. The system recognises shapes by finding lines in the set that have appropriate relationships. Although it is possible that different interpretations are produced by finding meaningful groupings of lines, these interpretations are limited and the approach remains unsatisfactory. Designers, by comparison, are capable of perceiving shapes in a variety of ways and simple regroupings of lines will not adequately resolve the problem.

At the other extreme, raster based systems allow designers freedom in editing the bitmap. However this is not a convenient level for a designer to work at. The freedom gained by the ability to change the bitmap is counterbalanced by the impoverished communication between the user and the system as users are unable to describe structures seen in the image. Bitmaps in themselves are unstructured and therefore do not contribute to the maintenance of a particular interpretation. On the contrary, transforming a drawing from an object-oriented (structured) representation to a bitmap representation is a means of unstructuring the drawing. This is seen as a useful step in removing the constraints associated with imposing a certain structure.

By maintaining the original structure used in the construction of an image, computer-aided design systems do not respond to the designer's needs for restructuring and reinterpreting images in creative ways. This has been the cause of reduced take up of CAD systems in the early conceptual stages of design. These systems have replaced hand-drawing techniques only in the more detailed and routine aspects of design. Users are not capable of communicating with CAD systems in terms of perceived structures because of the constraints imposed by the technology. Human thinking however is free from such constraints. In order for CAD systems to support the creative process of the designer they need to respond to their users in reinterpreting the image according to emergent shapes that are perceived.

3 A closer examination of emergent shapes

There is support for the idea that images give rise to emergent shapes beyond observations of designers and studies of design. It comes from studies in perception and mental imagery. Mufti-stability and ambiguity are important perceptual characteristics that lead to competing interpretations of a given pattern (Pomerantz & Kubovy, 1986). The notion that an image may be represented in the mind as a set of structural descriptions has arisen from experiments by Reed (1974). The possibility that emergent shapes arise is a corollary of a particular image having alternate sets of structural descriptions.

Although it is understood that there are different types of emergent shapes, distinctions between the different types have not often been clearly stated. In many cases different categories have been used by design researchers to include the same types of emergent shapes. For example categories such as explicit! implicit shapes (Liu, 1994),subshapes, visual emergent shapes, shapes that have boundaries present in the original shape, and those that have boundaries not present in the original shape (Gero & Yan, 1994) etc. have been used to describe emergent shapes. However closer examination suggests that explicit shapes match those whose boundaries exist in the original pattern. This highlights the need to develop a clear scheme for the description of emergent shapes. it is proposed that distinctions between emergent shapes are made along two dimensions.

The knowledge-based dimension distinguishes between emergent shapes that are domain-knowledge driven and those that are not. The emergence of shapes that represent known entities is considered under this category (e.g. the emergence of a square shape in an architectural plan where such a shape represents a room). The psychologically-based dimension distinguishes between four different types of emergent shapes:

(a) Embedded shapes.

These are shapes all of whose boundaries exist in the original pattern. Usually, the pattern is composed of overlapping shapes and because of perceptual ambiguity various interpretations can arise. Figure 1, therefore, will lead to embedded emergent shapes such as four small triangles. Figure 2 gives further examples of shapes that emerge from Figure 1.

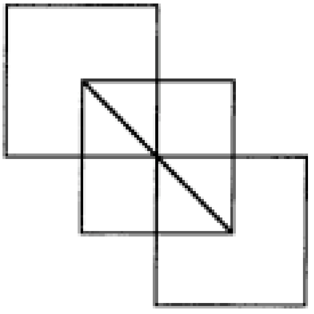

Figure 1 - Original shape

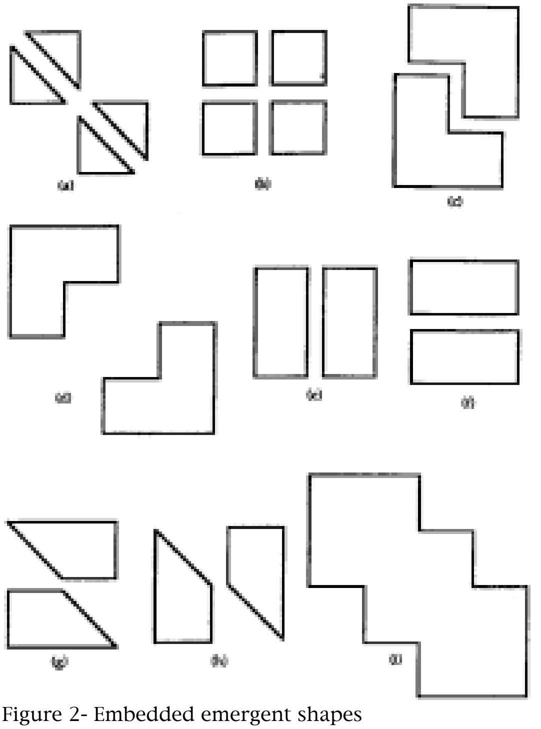

Figure 2- Embedded emergent shapes

(b) Spatially completed shapes.

Unlike embedded shapes, spatially completed shapes may have boundaries that do not exist in the original pattern. They are obtained by a process of shape completion that is associated with occlusion. Spatially completed emergent shapes therefore represent shapes that are partially or totally occluded in the original pattern. The pattern shown in Figure 1 does not lead to any spatially completed shapes because it does not exhibit occlusion properties. By contrast, the pattern of Figure 3 below gives rise to various emergent shapes of this category such as 2 outer squares, 2 central squares, and 4 small triangles. These emergent shapes are shown in Figure 4.

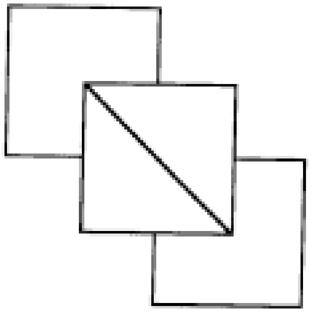

Figure 3 - Original shape which shows occlusion properties

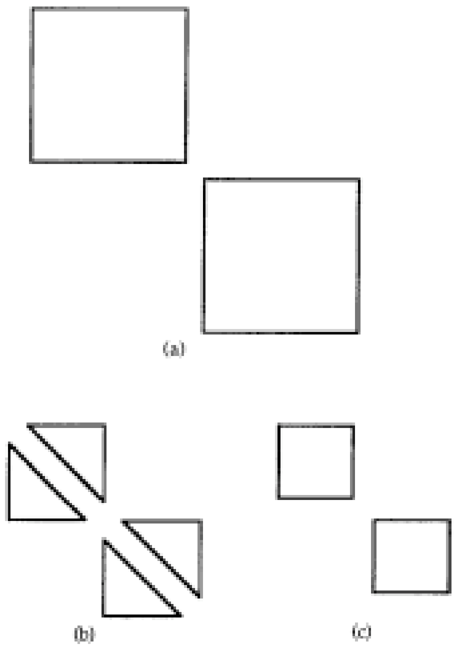

Figure 4 - Spatially completed emergent shapes

(c) Spatially extended shapes.

These share with completed shapes the property of having boundaries that are not present in the original pattern. In the scheme proposed here, spatially extending the shape means extending its boundaries. This is distinguished from completion since completion is taken to be a process that deals with occluded shapes. Spatially extended shapes do not therefore include partially or totally occluded shapes. Examples of spatially extended shapes which can be obtained from Figure 1 are two large squares, and a larger square that encloses the whole pattern (see Figure 5).

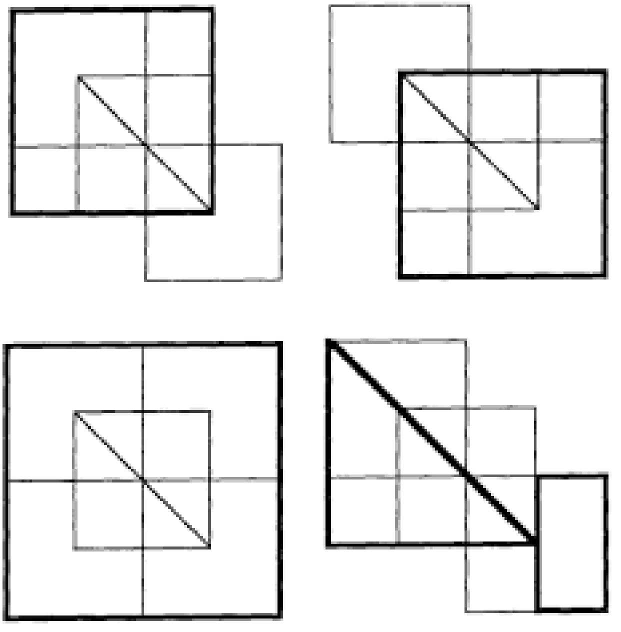

Figure 5 - Spatially extended emergent shapes (Emergent shapes are drawn in bold)

(d) Illusory shapes.

Illusory shapes are defined by psychologists as those arising from interpolation or subjective contours. Kellman & Shipley (1991), proposed a theory to explain the perception of visually interpolated and illusory shapes. Here, illusory shapes are defined as those that arise because of subjective contours that cannot be accounted for by previous descriptions i.e. the processes of completion and boundary extension are not sufficient to account for illusory shapes. An example is shown in Figure 6.

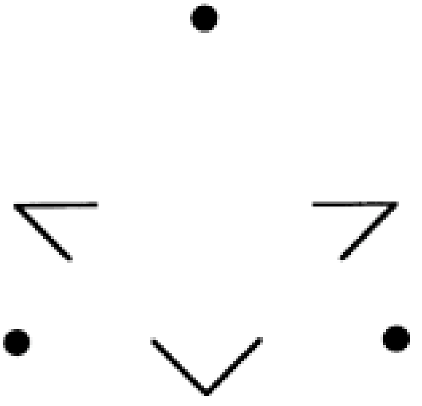

Figure 6 - Cognitive or illusory contours give rise to illusory shapes. The triangle which joins the three dots is an illusory emergent shapes. Based on Kanizsa (1979).

4 The Computational Modelling of Emergent Shapes

4.1 A Proposed framework

In the previous section a scheme has been proposed for distinguishing between different types of emergent shapes. The computational modelling of emergent shapes has recently received considerable attention in design research. Edmonds & Soufi (1992) proposed a computational approach concerned with the creative perception of drawings in early design. Based on the three-stage process of action-perception-reflection, a computational model of the perception of drawings can be used to generate emergent shapes. Gero & Yan (1994) described a symbolic computational model of shape emergence based on infinite maximal lines. Using this representation, and by removing/ replacing constraints, emergent shapes can be discovered using both hypothesis-driven and data-driven searches. Liu (1994) proposed a connectionist approach to the encoding of shapes. Other approaches, more concerned with the representation of shape and shape algebras than emergence, are those of Stiny (1980, 1993), and Krishnamurti & Stouffs (1993).

Several approaches concerned with shape emergence use a scheme based on the decomposition of the original shape into some primitives (e.g. lines, points etc.) followed by reconstruction of these into new shapes. A key feature of these is the use of an intermediate representation which enables new shapes to be discovered. The intermediate representation is a richer representation in the sense that it leads to more structures being pattern and removes the constraints that describe the initial structure. The computational model of Gero and Yan (1994) uses a representation based on infinite maximal lines. The computational Model of Edmonds and Souffi (1992) uses a representation based on regions. Regions are primitive elements grown from pixels using 4 or 8 connectedness (Rosenfeld, 1970). Soufi & Edmonds (1994) argued for the use of multiple representations in the computational modelling of emergent shapes. Given that there are different types of emergent shapes, it is suggested that no one reconstruction mechanism will be sufficient to account for all emergent phenomena, and no one approach to emergence can deal with all of these types. There must be different and parallel deconstruction /reconstruction mechanisms. A framework is proposed that shows how these mechanisms can be integrated. The framework is based on the use of multiple representations followed by the operation of computational mechanisms that generate emergent structures at two levels of processing. 'Primary Emergent Structures are generated by computational mechanisms which operate on the representations: 'Line Segments', 'Regions', 'End Points', and Pixels. The 'Representation Agent' is responsible for creating these representations and enabling transformations between them, given the original shape. The primary emergent structures are the overall set of emergent shapes that can be captured by the model depicted in Figure 7.

Secondary Emergent Structures result from the application of selection processes to first-level structures. The selection processes utilise both domain independent knowledge about human perception and domain specific knowledge of the application domain. This achieves the important function of guiding the computational mechanisms to generate structures that would appear intuitive to the designer because they reflect cognitively valid aspects of emergence. Selection based on knowledge of human perception assigns higher weights to structures that can be considered to have more validity from a perception viewpoint. Simplicity and likelihood are considered the two main alternative accounts for this selection (Pomerantz & Kubovy, 1986). Selection based on knowledge of the application domain assigns higher weights to shapes indicative of entities that exist in domain. For this, it is necessary to have knowledge of what a shape may represent in particular domain and a shape vocabulary in reference to which shapes can be classified. Therefore, the framework leads to emergent structures having different rankings.

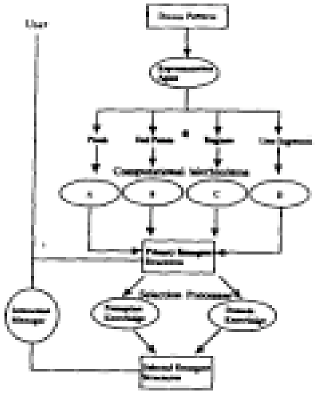

Figure 7 - A multiple representation framework for the computational modelling of emergent shapes.

4.2 *An illustration of the operation of the framework to arrive at emergent shapes*

In this section, the operation of the framework is explained. The illustrations given focus on the region, and line segment based representations. Taking the example of Figure 1, the representation agent constructs two types of representations:

(a) A region-based representation shown in Figure 8 where regions are the areas enclosed by the bounded shapes shown in the figure.

(b) A line-segment based representation shown in Figure 9 where each segment is a straight line that has a uniform orientation and extends until it is intersected by another line segment.

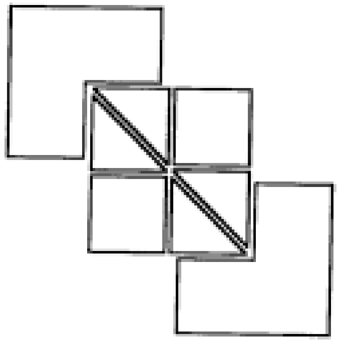

Figure 8 - The region based representation

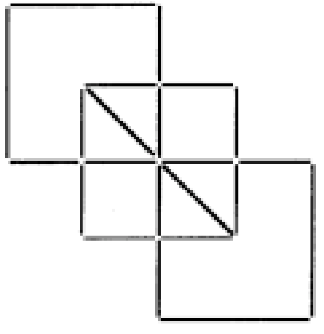

Figure 9 - The line segment based representation

The representation of Figure 9 becomes a basis for generating the extended segment representation shown in Figure 10.

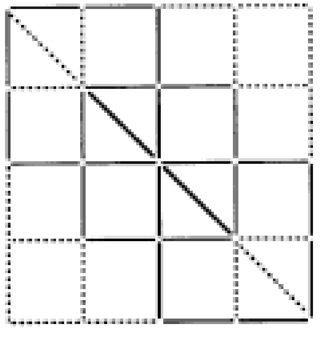

Figure 10 - Extended line segment representation

Different computational mechanisms operate on the different types of representations. Edmonds & Soufi (1992) describe the operations that can be applied to the region based representation. In essence they are grouping processes that generate a multiplicity of structures based on Gestalt psychology (Ellis, 1938). Grouping on the basis of size similarity is shown in Figure 11.

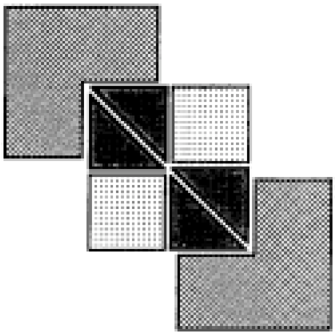

Figure 11 - Emergent structures derived from the region based representation by processes which model size similarity

The operations that are applied to the line segment representations achieve grouping of segments to generate closed shapes. Working from the segment based representation, shapes are extracted with reference to an n-segment shape (where n= 3,4,5 etc.). Figure 12 shows the shapes that are generated from the representation of Figure 9.

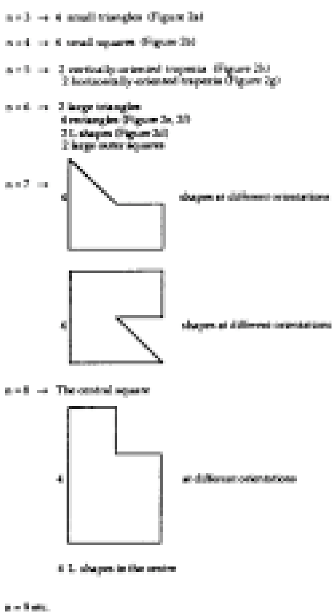

Figure 12 - Emergent shapes derived from the line segment representation

A larger number of shapes can be derived from the extended segment representation. In addition, some new shapes are discovered (see Figure 13).

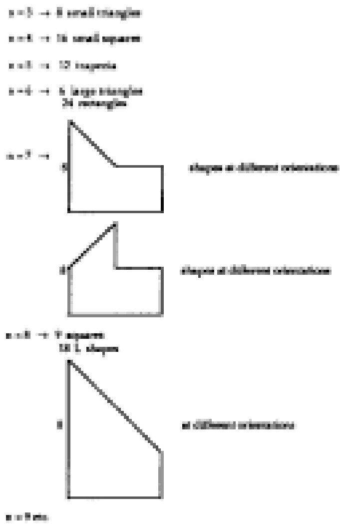

Figure 13 - Emergent shapes derived from the extended line segment representation

5 Discussion

A scheme has been proposed for making distinctions between different types of emergent shapes. The scheme separates the roles of perception and domain knowledge in the description of different types of shapes. Four main categories of emergent shapes have been defined and a framework has been presented for the computational modelling of emergent shapes. The framework is based on different computational mechanisms operating on multiple representations. The multiplicity of structures that can be generated by the framework raises interesting questions regarding the potential interaction between the designer and the system with respect to these shapes. This issue is discussed in detail by Soufi & Edmonds (to appear). They describe two different approaches to this interaction which exploits the 2 level architecture of the framework.

The use of multiple representations has been advocated in order to deal with the different types of emergent shapes that can arise. The pixel-based representation is the bottom-level decomposition in terms of which other representations can be expressed. End points, line segments, and regions are higher level representations. Although processing is required to arrive at these representations, less processing is required to arrive at emergent structures when operating on these higher level representations.

Illusory shapes, as defined according to the scheme, are the most difficult ones to capture by the framework. A mapping between representation and category of emergent shapes is shown in Figure 14. This shows that the line segment and end point representations are capable of modelling more categories of emergent shapes than the region based representation. However, the latter is capable of handling drawings with curved lines.

	Regions	Line segments*	End points*
Embedded shapes	√	√	√
Spatially completed shapes	×	√	√
Spatially extended shapes	×	√	√
Illusory shapes	×	×	Some

* For drawings with straight lines

Figure 14 - A mapping between representation and category of emergent shapes

6 References

Edmonds, E. A. & Soufi, B.: (1992) The computational modelling of emergent shape in design, in Gero &Sudweeks (Eds.), Computational Models of Creative Design, University of Sydney, Sydney, Australia, pp. 173-190, December 1992.

Ellis, W. D. (ed.): (1938) A Source Book of Gestalt Psychology. Routledge & Kagen Paul, Kloisterberg.

Fish, J. & Scrivener, S.: (1990) Amplifying the Mind's Eye: Sketching and Visual Cognition, LEONARDO, Vol. 23, No. 1, pp. 117-126.

Gero, J. S. & Yan, M.: (1994) Shape emergence by symbolic reasoning, Environment and Planning B: Planning and Design, Vol. 21, No 2, pp. 191-212.

Kanizsa, G.: (1979) Organisation in vision. New York: Praeger, 1979.

Kellman, P. J. & Shipley, T. F.: (1991) A Theory of Visual Interpolation in Object Perception. Cognitive Psychology, Vol. 23, pp. 141-221.

Krishnamurti, R. & Stouffs, R: (1993) Spatial Grammars: Motivation, Comparison, and New Results, in Flemming, U. & Van Wyk S. (eds.), CAAD Futures 93, Elsevier, Amsterdam, pp. 57-74.

Liu, Y. T.: (1994) Encoding explicit and implicit emergent subshapes based on empirical findings about human vision, in Gero, J. S. & Sudweeks F. (eds.) Artificial Intelligence in Design 94, pp 401-418, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Mitchell, W. J.: (1993) A computational view of design creativity, in J. S. Gero & M. L. Maher (eds.) Modelling Creativity and Knowledge-based Creative Design. Lawrence Erlbaum, Hillsdale, NJ. pp. 25-42.

Pomerantz J. R. & Kubovy M.: (1986) Theoretical approaches to perceptual organisation, in Boff K. R. (ed.), Handbook of Perception and Human Performance, Vol. 11, Wiley, New York.

Reed, S. K.: (1974) Structural descriptions and the limitations of visual images. Memory and Cognition, Vol. 2, No. 2, pp 329-336.

Rosenfeld, A.: (1970) Connectivity in digital pictures. J. Assoc. for Computer Machinery, Vol. 17, pp 146-156.

Soufi, B. & Edmonds, E. A.: (1994) Perceptual interpretation and representation of emergent shapes, Reasoning with Shapes in Design, Workshop Notes, Artificial Intelligence in Design 94, Lausanne, Switzerland, August 1994, pp 39-45.

Soufi, B. & Edmonds, E. A.: (to appear) Cognitive issues of emergence and interaction: Implications for computational models. Third International Round-Table Conference on Computational Models of Creative Design. Heron Island, Australia, December 95.

Stiny, G.: (1980) Introduction to shape and shape grammars. Environment & Planning B, Vol. 7, pp. 343-351.

Stiny, G.: (1993) Emergence and continuity in shape grammars, in Flemming, U. and Van Wyk S. (eds.), CAAD Futures 93, Elsevier, Amsterdam, pp. 37-54.

7 Acknowledgements

This research was supported by a grant from Loughborough University. The authors would like to acknowledge this assistance.