INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED11
15 - 18 AUGUST 2011, TECHNICAL UNIVERSITY OF DENMARK

DESIGN EXPLORATION WITH USELESS RULES AND EYE TRACKING

Iestyn Jowers[1], Miquel Prats[2], Alison McKay[1] and Steve Garner[2]
(1) University of Leeds, UK (2) The Open University, UK

ABSTRACT

Shape reinterpretation is an essential component in design generation and exploration. However, computational design tools, such as computer-aided design systems, offer poor support for shape reinterpretation and, as a result, do not provide effective support for design ideation. A key difficulty in realising systems that support shape reinterpretation is the issue of interface – how can a user guide a system with respect to their interpretations of a shape? In this paper, research is presented that explores this question through the development of a software prototype. The prototype uses identity shape rules (so-called ‘useless rules’) and eye tracking to support the creation and manipulation of shapes. The paper presents theoretical developments that have informed development of the prototype, including outcomes of a series of eye tracking studies. The software prototype builds on the results from these studies and uses gaze data in combination with traditional mouse-based input to restructure designed shapes based on the visual attention of the users, so that manipulation according to the users’ interpretations is afforded.

Keywords: shape grammars, eye tracking, shape interpretation, computer-aided design

1 INTRODUCTION

Shape reinterpretation is central to the processes of design generation and exploration, and as such has been linked to creativity [1]. For example, in many creative professions, including industrial design and architecture, conceptual design involves the creation, exploration, and development of design shape alternatives. These processes are typically supported using freehand sketching because the ambiguity of sketches enhances the cognitive processes of shape reinterpretation which are essential in effective shape exploration and development [2]. Commercially available computational design tools, such as computer-aided design systems, offer poor support for shape reinterpretation because the data structures on which they are built assume that a given shape has a unique interpretation [3]. As such, current tools do not support the flexible interaction that designers need during design exploration.

The research presented here explores how a computational design tool might support multiple interpretations of a shape and how designers might guide such a system with respect to their current interpretation. The research builds on the shape grammar formalism [4], which has previously been implemented in computational design tools where shape reinterpretation is supported e.g. [5], [6], [7]. A unique strength of shape grammars over other methods of design generation lies in their ability to support reinterpretation of designed shapes, to the extent of recognising and transforming parts of shapes that have emerged from a generative process [8]. Past research has explored how shape grammars can be used to formalise [9] and support [7] ideation processes, however an inherent difficulty in using them in conceptual design lies in the distance created between the designer and the design representation. When using shape grammars, a designer does not directly control the ideation process. Instead, shapes are manipulated indirectly via the definition and application of shape rules. Therefore, although shape grammars enable designers to visually reinterpret designed shapes according to recognised parts or structures, they do so at the cost of interrupting the reflective conversation between the designer and the design representation [2].

This paper presents a software prototype intended to support interpretation of designed shapes in the ideation processes in conceptual design. As illustrated in Figure 1, three areas of literature were brought together to inform this research. The prototype addresses the need for shape interpretation emphasised in the creative design literature, as discussed in Section 2, and builds on the shape grammar formalism, as reviewed in Section 3. Consideration of these two areas resulted in a prototype that uses identity shape rules (so called ‘useless rules’ [10]) as a mechanism for supporting the visual shape interpretation afforded by shape grammars whilst retaining a direct contact between the designer and the design representation. This prototype is presented in Section 4, with an example showing how a user is able to manipulate subshapes of interest in a designed shape.

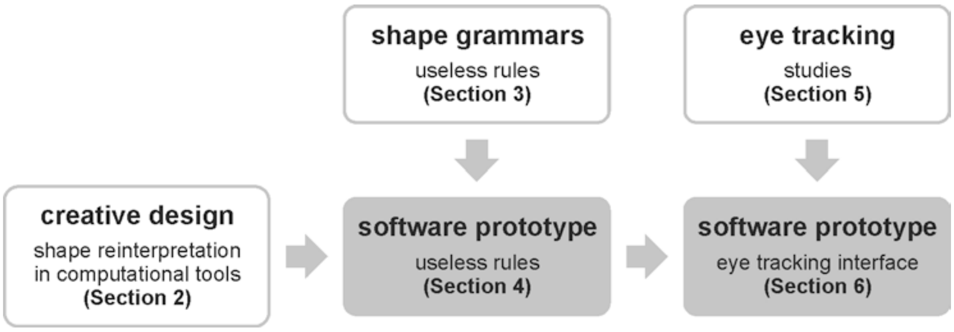

Figure 1.Methodology

The interaction between the designer and the representation is further enhanced through consideration of the outcomes of a series of eye tracking studies, an overview of which is presented in Section 5. In these studies, the visual strategies of participants were analysed in order to determine whether eye tracking data can be used to support shape reinterpretation in the software prototype. Based on findings from the studies, an eye tracking interface was developed that automates application of identity shape rules. The eye tracking interface uses gaze data to determine in real-time a users' interpretation of a designed shape with respect to the subshapes embedded in the shape. Based on this data, identity shape rules are used to restructure the shape accordingly and hence afford manipulation of the shape according to recognised parts or structures. This interface is presented in Section 6, with an example showing how a user is able to manipulate subshapes of interest in a designed shape.

2 BACKGROUND

2.1 Interpretation in Design

Design, as a creative activity, adheres to a constructivist philosophy with designers constructing their knowledge of a design problem as they explore potential solutions [11]. Central to this process are gestalts – coherent wholes that are defined by designers' interpretations of the geometric elements that compose design representations. Gestalts enable designers to reason about design problems, and are not fixed. The same set of geometric elements can be reconstructed as many different coherent wholes, and a designer often shifts gestalt during a design exploration process. The use of gestalts is apparent from studies of designers as they undertake creative design tasks. For example, Schön and Wiggins [2] observed that designers employ a 'seeing-moving-seeing' process, in which sketched design alternatives are explored visually in a search for patterns and associations that lead to new avenues of exploration. Seeing a sketch can result in its reinterpretation according to different gestalts, and this in turn informs the development of future sketches. This visually explorative process typically involves the recognition and transformation of shapes in sketches, such as overall outline shapes or the embedded parts of shapes, referred to as subshapes [9]. Reinterpretation of sketches according to alternative gestalts, defined with respect to subshapes, is a vital element in design exploration and is believed to be a decisive component of creative design [1]. To this end, Schön [11] emphasises that computational design tools should be capable of supporting such cognitive shifts by designers.

2.2 Interpretation in Computational Design Tools

Goel [12] and Stones and Cassidy [13] report studies of reinterpretation in design tools where designers undertook conceptual design tasks using either sketching or commercial computational tools. They found that participants readily use reinterpretation of geometric elements in their design exploration if sketching, but not when using the computational tools. Stones and Cassidy observe reinterpretation did take place cognitively when computational tools were used, but there was no evidence of these interpretations in the creation of new solutions. They suggest the reason for this is that, when participants were using computational tools, they were looking for accuracy in their design concepts and until a form closely resembled their mental picture they were unable to progress to alternative interpretations. Lawson and Loke [14] propose a more pragmatic reason and suggest that development of computational design tools has placed too much emphasis on graphical representation techniques. As such, the resulting tools are unable to support processes essential to creative design, including the process of shape reinterpretation as a means for supporting gestalt shifts. Traditionally, computational design tools adhere to an objectivist philosophy assuming that information, including design representation, is independent of the user. For this reason, a given representation is assumed to have a unique interpretation and significant changes to this interpretation are not readily supported [3].

2.3 Supporting Reinterpretation of Shapes

A key difficulty in computationally supporting shape reinterpretation is the problem of developing an interface that allows the user to specify their current interpretation of a designed shape out of the countless possibilities. Conventional selection techniques such as pointing, clicking or encircling shapes with a mouse are not always practical because of ambiguity that arises due to overlapping interpretations. Research into this problem has resulted in approaches that enable the manipulation of designed shapes according to recognised structures. For example, Jowers et al. [7] present an approach based on the shape grammar formalism [4], in which shape replacement rules are applied to identify and manipulate recognised subshapes in a design. The resulting system enables designers to manipulate designed shapes according to different interpretations, but it does so at the expense of imposing a distance between the designer and the design representation. When using shape grammars to explore design concepts a designer does not directly manipulate design representations but instead manipulates the representations indirectly via shape rules that specify which subshapes a designer is interested in and how those subshapes are to be manipulated or replaced. Consequently, the process of seeing-moving-seeing is drawn out, necessitating the designer to define and apply shape rules in response to changes in interpretation and intention. This distance has the potential to interrupt ideation processes and reduce creativity since, as emphasised by Goldschmidt [15], the speed at which shape transformations and manipulations take place is an important factor in creative design exploration. Despite these limitations, the reinterpretation mechanism afforded by shape grammars is powerful and its application in a more direct manner deserves consideration. The research reported in this paper explored the use of identity shape rules in a prototype drawing system. These are a specific type of shape rule explored by Stiny [10], and can be applied to restructure a designed shape according to recognised subshapes, but without manipulation. Such rules can be applied so that recognised subshapes are available for direct manipulation according to the different interpretations of the user, as discussed in the next section.

2.4 Supporting Direct Manipulation of Interpreted Shapes

Other methods for supporting direct manipulation of designed shapes, according to different interpretations, have been explored in the sketched-based interface literature. For example, Saund and Moran [16] present a WYPIWYG (What You Perceive Is What You Get) drawing system that supports perceptual interpretations of digitally sketched shapes. In the system, different interpretations are specified and manipulated according to simple pen-based gestures. Similarly, Gross [17] presents the ‘Back of an Envelope’ system, a drawing program that uses standard pattern recognition techniques to automate the recognition of emergent subshapes in a digital sketch, based on a library of shapes defined by the user. Although both systems support direct manipulation, users have to specify their interpretation of a drawn shape via additional pen strokes – either through learned gestures [16], or by tracing over subshapes of interest [17]. Such gestures have the potential to interrupt the creative flow of the user, and a more intuitive, dynamic system, one that better supports a cognitive process of seeing-moving-seeing, would offer real benefits in avoiding the need for users to explicitly define their interpretation of designed shapes. To this end, eye tracking technology presents itself as a potential interface for computational design tools.

2.5 Eye Tracking Interfaces

Previous research has explored the application of eye tracking as an alternative drawing interface, to replace traditional mouse and keyboard input, e.g. EyeDraw [18]. In the research reported in this paper eye tracking is used as an additional interface, augmenting traditional input by identifying areas that are of interest to the user, in a manner similar to that described by Sibert and Jacob [19]. This is coupled with identity shape rules to allow new structural elements to be identified, by using gaze data in combination with mouse input to reveal areas of a designed shape that are of interest to a designer at a particular moment in time. The system uses identity shape rules to allow these new structural elements to be referenced, an important prerequisite to their subsequent manipulation. This interface is based on eye tracking studies, which are described in Section 4.

3 USING USELESS RULES

3.1 Shape Grammars

Shape grammars [4] are formal production systems that are defined according to shapes and shape rules, as illustrated in Figure 2a. The rules are of the form $A \rightarrow B$, where A and B are both shapes, and are used to recognise and replace subshapes embedded in a given shape, under a specified set of transformations, e.g. the Euclidean transformations. Formally, application of a rule $A \rightarrow B$ to a shape S, under a transformation t, results in the shape $(S - t(A)) + t(B)$.

Shape grammars are typically applied as a method of computational generation, with rules applied repeatedly to generate networks of new shapes, as illustrated in Figure 2b. A key differentiation between shape grammars and other methods of computational generation lies in their visual nature, and this makes them particularly suitable for consideration in design research. Shape rules can be used to identify and replace any subshape that is recognised to be embedded in a shape, including those that emerge throughout a generative process [8]. Consequently, during such a process, a shape is not defined according to a fixed structure but is structured as a result of shape rule applications. This is illustrated in Figure 2b where rules are applied to recognise and replace squares that have emerged as a result of previous rule applications.

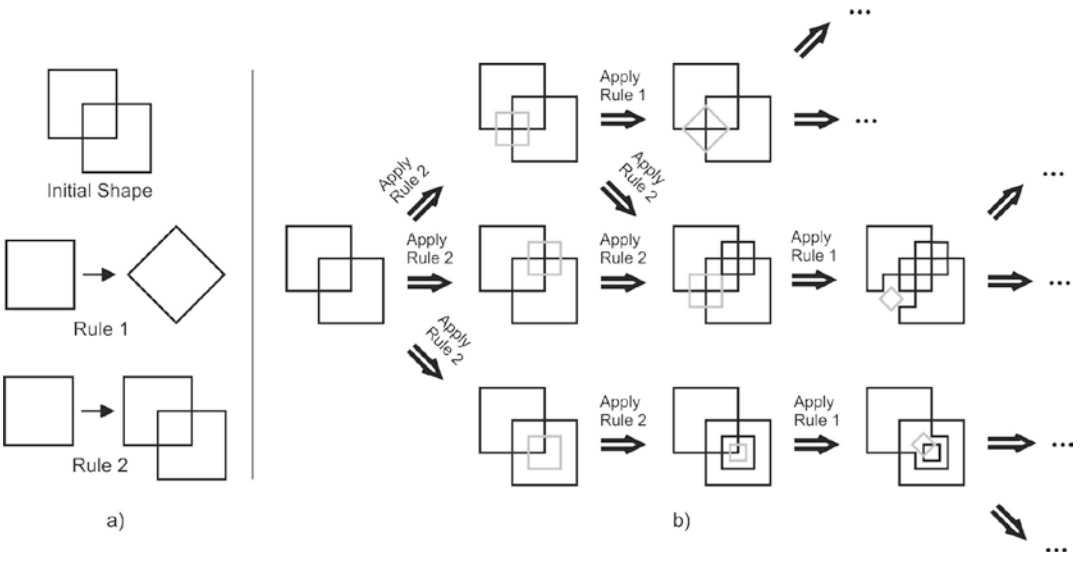

Figure 2. An example shape grammar and its application

3.2 Applications of Shape Grammars

In design research, shape grammars have traditionally been applied to the problem of formalising specific styles or brands, e.g. [20], [21], and generating existing or new designs in the style or brand. Research has also explored problems inherent in implementing shape grammar interpreters, computational systems intended to support the application of shape grammars, e.g. [5], [6], [7]. Such systems have the potential to be powerful tools in the explorative stages of design. For example, Prats et al. [9] explore the use of shape rules as a method for formalising the ideation processes employed by designers when sketching in design. In their studies, designers' explorative actions of seeing and moving were formalised and analysed according to shape rules that recognise and replace parts of shapes. Conversely, shape rules can also be used to computationally afford the process of seeing-moving-seeing, and hence support shape reinterpretation in computational design tools, as explored by Jowers et al. [7]. Within such systems, designers can use shape rules to recognise and replace subshapes according to their current interpretation of designed shapes, without adherence to any predefined structure. This is potentially a great advantage over traditional computational design tools, such as computer-aided designs systems, where reinterpretation is made difficult due to the fixed structure of shape representations [3].

3.3 Reinterpretation with Shape Grammars

The reinterpretation mechanism afforded by shape rules is fully captured by identity shape rules, so-called ‘useless rules’ [10]. These are shape rules of the form $A \rightarrow A$, where a shape A is recognised and replaced by itself, as illustrated by the rule in Figure 3a. Application of an identity shape rule to a shape S, results in the shape $(S - t(A)) + t(A)$, where t is the transformation under which the rule is applied. The resulting shape is visually identical to the shape S, and in a generative process such a rule is useless because it does not modify a shape in any way. But, in an explorative process it is an important observational device that supports reinterpretation of the structure of the shape according to recognised subshapes. Identity rules allow designers to specify how a shape is viewed by making recognised subshapes defined parts of the shape, as illustrated in Figure 3b. Here, the identity rule in Figure 3a is applied repeatedly to recognise the different squares embedded in the initial shape in Figure 2a, and after each application of the rule the structure of the shape is redefined so that the recognised square is part of the shape.

Identity shape rules support the reinterpretation mechanism afforded by shape grammars, but do so without applying any manipulations. As such they can be used in a computational design tool to support an explorative process where the designer is free to interpret a designed shape according to recognised subshapes, and also to have direct interaction with the designed shape, thereby encouraging what Schön and Wiggins [2] refer to as the ‘reflective conversation’ between the designer and the design representation.

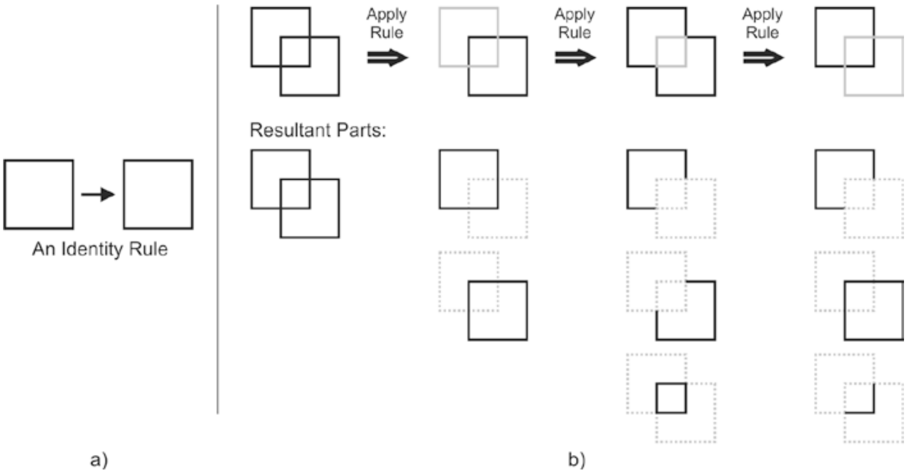

Figure 3. An example identity rule and its application

4 A SOFTWARE PROTOTYPE

In order to explore the potential for using identity shape rules to support reinterpretation in a computational design tool a software prototype was developed, the user-interface of which is illustrated in Figure 4. This user-interface consists of a large drawing area, on the left hand side, and a library of identity shape rules, on the right hand side. Shapes are defined as sets of line segments, and subshapes are defined according to subsets of these. Users can manipulate constructed shapes by translating the end points of individual line segments, or by selecting and translating defined subshapes.

Identity shape rules of the form $A \rightarrow A$ are represented by the shape A, and are defined by the user according to shapes that they find interesting. The rules can be defined in two ways: firstly, any shape that the user explicitly draws can be used to define a rule; secondly, the user can trace over any interesting emergent subshapes and use them to define a rule. For example the shape in Figure 4, was initially constructed as two squares, and the corresponding shape rule was added to the library. Also, the user has identified that the emergent ‘L’ shapes are of interest and has consequently added an appropriate identity rule to the library, by tracing over an ‘L’ subshape.

In the prototype, the structure of a shape is initially defined according to how the shape is constructed. But, as shape exploration proceeds identity shape rules are defined and these can be applied by the user to reinterpret the designed shape according to recognised subshapes, which can then be selected and manipulated. Application of a shape rule uses a method of subshape detection to recognise embedded parts of a designed shape, as described by Trescak et al. [5]. For example, an exploration of the shape in Figure 4 is illustrated in Figure 5. In Figure 5a, the shape is initially constructed as two squares, one of which is translated by the user so that they overlap in Figure 5b. In Figure 5c, the user applies an identity rule to recognise an emergent ‘L’ shape, and in Figure 5d this is translated so that the two Ls form a cross. In Figure 5e, the user applies another identity rule to recognise the emergent square in the centre of the cross, and in Figure 5f this square is translated.

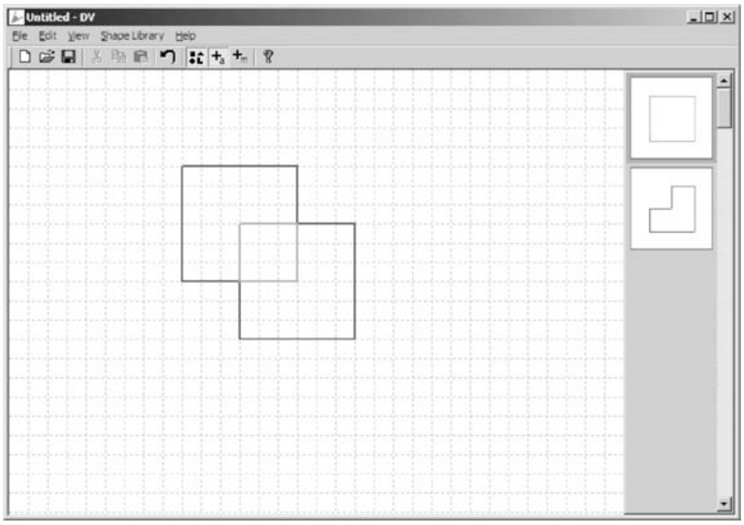

Figure 4. The software prototype

This simple demonstration illustrates the potential for identity shape rules to be implemented in computational design tools that support shape interpretation, and consequently design generation and exploration. However, the approach is potentially disruptive to the creative flow of the user, requiring the selection of appropriate identity shape rules in order to restructure a designed shape according to recognised subshapes. Accordingly, the remainder of this paper explores the use of eye tracking as an interface to support this process of shape reinterpretation without the need for a user to explicitly specify which identity shape rules to use.

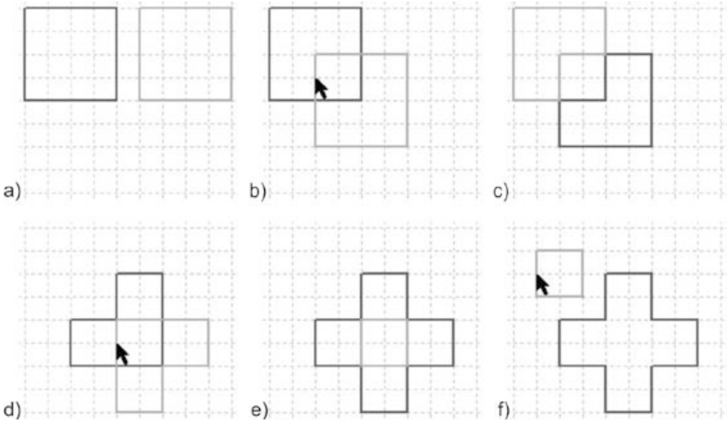

Figure 5. Supporting design exploration with identity rules

5 USING EYE TRACKING

In order to inform development of the eye tracking interface, a series of three studies was conducted with the aim to build an understanding of how gaze data can be used to support shape reinterpretation in a computational design tool. Gaze data, consisting of scan paths and points of visual fixation, can reveal much about how shapes are viewed and interpreted. The studies attempted to identify gaze patterns that distinguish between shapes that are attended to and those that are simply looked at. In particular, they sought to identify gaze patterns that indicate whether a particular shape is being attended to in a cluttered image or whether a particular subshape is being attended to in an ambiguous shape. Attention to a shape is a necessary process that precedes interpretation [22], and is identified by focus on one particular shape in an image, whilst ignoring others that are also present. This act of attending is linked to the act of selective looking but not necessarily to the act of recognising, which requires cognitive awareness of the visual stimulus [23].

5.1 Participants and Technologies

The participants were a mixture of students and university staff, both male and female, with varied research interests, and ages ranging from early 30s to late 40s. Different participants took part in the different studies, and the outcomes of each study were analysed independently. All the participants were unpaid volunteers, naive to the purpose of the studies, and had normal or corrected-to-normal vision. There was one exception in the third study, where a project member was included as a participant. This was to explore the extent to which familiarity with the theory and purpose of the research would influence the resulting gaze data.

During the studies gaze data was collected using a Tobii X120 eye tracker (accuracy 0.5°, drift < 0.3°, binocular tracking, data rate 120 Hz). This equipment is nonintrusive and includes a head-motion compensation mechanism that allows for a freedom of movement of 0 × 22 × 30cm. Despite this, participants were asked to keep as steady as possible in order to ensure gaze data was consistently captured. A dual VDU arrangement allowed the facilitator to monitor the participants in order to ensure that gaze data was captured at all times.

5.2 Shape Search

The first study involved search tasks in which seven participants were asked to search cluttered images, composed of shape primitives, for specified shapes. One of the images presented to the participants is given in Figure 6, along with an example of the gaze data collected. Before each image was presented, the participants were given instructions regarding which shape they were to search for. They were also instructed to vocalise when they had found the target shape, and to focus on it for a few seconds before proceeding to the next image. In the example illustrated in Figure 6 the participant was asked to find the arrow shape, highlighted in Figure 6a, a task that is made more difficult due to the necessity to undertake a figure-ground reversal.

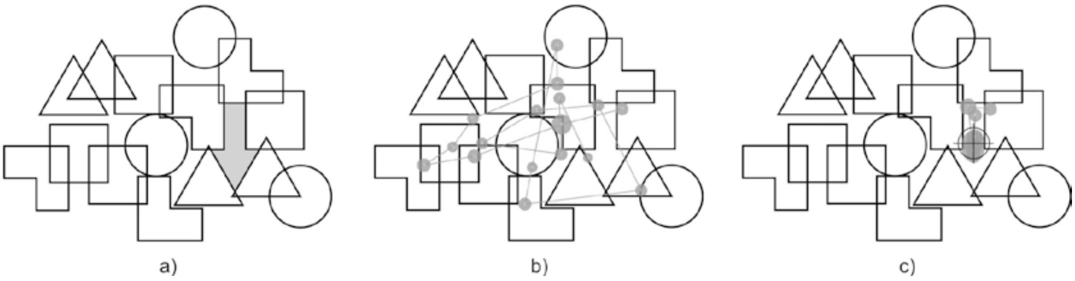

Figure 6. Stimuli and corresponding data from a shape search task

During the study, verbal and gaze data were collected and analysed with the aim to identify patterns that indicate participants were attending to shapes. It was found that, when participants were searching for the target shape, scan paths followed no pattern of note but were loosely concentrated around the centre of the image and the majority of visual fixations took place inside the individual shape primitives, as illustrated in Figure 6b. After finding a target shape, it was found that scan paths and fixations were concentrated around the centre of gravity (or centroid) of the target shape, as illustrated in Figure 6c. Analysis of all the data gathered revealed that during the search for a target shape only 27% of visual fixations were near the centres of gravity of shape primitives, i.e. within a radius of 50 pixels from the centres. After the target shape was found 69% of visual fixations were near to the centre of gravity of the attended target shape. This confirms the findings of Vishwanath and Kowler [24] who report that participants attending to simple shapes naturally fixate on their centres of gravity.

5.3 Shape Transformation

The second study involved tasks in which four participants were asked to construct different target shapes (e.g. squares or triangles) by translating given shape primitives, and using Boolean operations of union, difference, intersection, or complement (i.e. figure-ground reversal). The study consisted of sixteen tasks divided into four sections of four tasks each. Each section started with a short training session introducing a particular Boolean operation. This was followed by the tasks in which the participants were instructed to use the specified operations to construct the target shapes. In each task, the participants were given a period of 3 seconds to analyse the given set of shape primitives before they were instructed with respect to the target shape that was to be constructed from them. They were also instructed to vocalise when they had completed the task, and to focus on the constructed shape for a few seconds before proceeding to the next image. One of the tasks is illustrated in Figure 7, along with an example of the gaze data collected. In this example, the participants were asked to translate the two shape primitives, *A* and *B*, so that their Boolean difference, *A* – *B*, formed a square, as illustrated in Figure 7a.

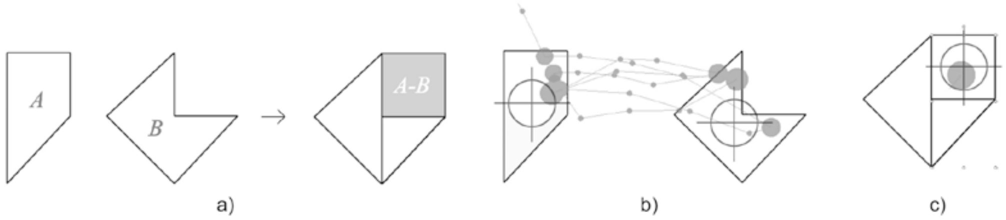

Figure 7. Stimuli and corresponding data from a shape transformation task

Analysis of the verbal and gaze data collected during the study concentrated on two particular periods of time – the first 3 seconds of free-viewing and the moments when the participants verbalised that they had completed the task by constructing the target shape. In the periods of free-viewing, there was no pattern of note in the gaze data, as illustrated in Figure 7b. In the moments when participants verbalised they had completed the task, it was found that scan paths and fixations were concentrated around the centre of gravity of the target shape, as illustrated in Figure 7c. Analysis of all the data gathered revealed that during the period of free-viewing only 20% of the visual fixations were near to the centres of gravity of the given shape primitives, i.e. within a radius of 50 pixels from the centres. Once the target shape was constructed, however, 75% of visual fixations took place near to its centre of gravity. This suggests that the findings from the shape search study, described in the previous section, also apply to shape transformation tasks.

5.4 Shape Interpretation

The third study involved series of trials in which four participants were asked to fixate on specified subshapes of the pentagram in Figure 8. In the trials, participants were shown images of the pentagram with particular subshapes highlighted in bold, two examples of which are illustrated in Figure 8a. In each trial they were asked to fixate on the specified subshape whilst ignoring all others for a period of 3 seconds. The study consisted of 136 trials and these were divided into eight sessions, with periods of rest between each session.

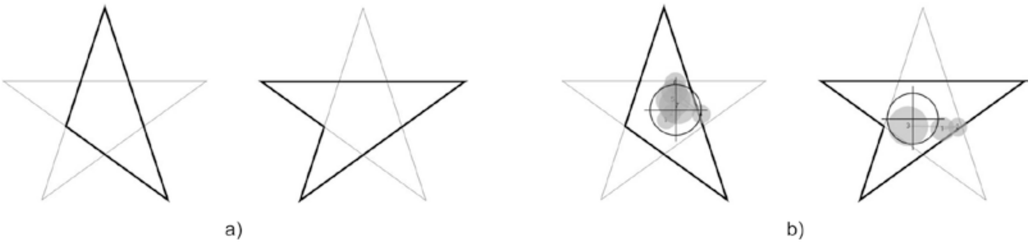

Figure 8. Stimuli and corresponding data from a shape interpretation task

The aim of this study was to determine whether it is possible to infer a viewer’s interpretation of an ambiguous shape by comparing their visual fixations with the positions of the centres of gravity of potential subshapes of the shape. As with the shape primitives in the previous studies, it was found that when participants were seeing a shape without attending to any particular subshape the gaze data had no pattern of note. However, a dominant pattern emerged when subshapes were attended to, with a majority of scan paths and fixations concentrated around the centre of gravity of the attended subshape, as illustrated in Figure 8b. Analysis of the data revealed that, when participants were attending to the target subshapes specified in each trial, 72% of the visual fixations were near to the centres of gravity of the subshapes, i.e. within a radius of 50 pixels from the centres. One of the participants in the study was a project member with familiarity of the purpose of the research, but analysis of the data provided no evidence to suggest that this knowledge influenced the outcome of the study, and the project member tended to fixate on the centres of gravity in a manner similar to the other participants.

5.5 Summary of Findings

Although the number of participants in each of the three studies was too small to suggest statistically significant results, the analysed data does suggest that the visual strategy of attending to specific shapes or subshapes gives rise to different gaze patterns than free-viewing or shape search. In particular, attention to individual shapes or subshapes can be identified by visual fixations of long durations, exceeding 500ms, and these fixations can be used to identify when a viewer is attending to rather than free-viewing or searching a shape or subshape.

The studies also revealed that when participants were attending to an individual shape or subshape their visual fixations tended to take place near the centre of gravity of the attended shape/subshape. Here, a visual fixation is said to be near to a centre of gravity if it is within a radius of 50 pixels of the centre. This corresponds with the accuracy of visual fixations which consist of random micro-saccades and are inherently noisy to within an accuracy of a 5^{o} visual angle [25].

These results suggest that the distance between visual fixations and the centres of gravity of subshapes of an ambiguous shape can be indicative of a viewer's interpretation of the shape, with respect to recognised subshapes. However, if a shape is composed of subshapes that have centres of gravity that are close together (within a distance of 50 pixels), then it is not possible to unambiguously determine which of the subshapes is being attended to based purely on gaze data. For example, the gaze data illustrated in Figure 8b could not conclusively identify which of the two subshapes the participant was attending to because their centres of gravity were too close. Instead, it was only possible to identify subshapes that were *potentially* attended to.

6 SOFTWARE PROTOTYPE REVISITED

The results of the eye tracking studies were used to inform development of an eye tracking interface for the software prototype introduced in Section 4. The interface was implemented using the Tobii Software Development Kit[1], and key to implementation was a need to understand users' interpretation of designed shapes based on potentially ambiguous gaze data and mouse-based input.

As discussed in Section 2, when manipulating recognised subshapes in a designed shape, mouse-based methods of selection are not always practical, especially if different interpretations of the shape overlap. This is because the geometric elements that are used to construct shapes can be shared by different interpretations, as illustrated in Figure 9a. Here, the user is selecting an edge shared by a square and a triangle, and mouse-based selection cannot unambiguously determine which of the subshapes the user is selecting.

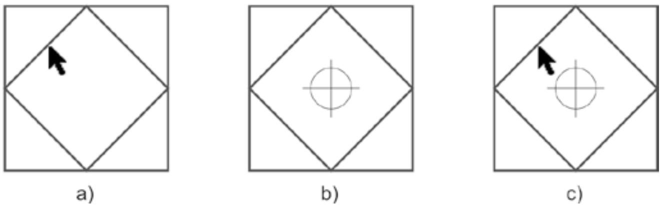

Figure 9. Resolving ambiguity in subshape selection

Given a list of potential subshapes of a shape, gaze data can be used to determine which of these a user is attending to, by comparing the centres of gravity of the subshapes with the visual fixations of the user, as described in the previous section. However, if potential subshapes have centres of gravity that are close to each other then it is not possible to unambiguously determine which specific subshape is being attended to. This is illustrated in Figure 9b, where gaze data cannot unambiguously determine whether the user is attending to the outer or the inner square, because they share a centre of gravity.

A combination of mouse-based input with gaze data can serve to cancel out these two types of ambiguity in subshape selection. Gaze data can be used to resolve the ambiguity that can arise in

---

[1] http://www.tobii.com/landingpads/analysis_sdk.aspx

mouse-based input, and mouse-based input can resolve the ambiguity that can arise in data from an eye tracker. This is illustrated in Figure 9c where the combination of the two methods of input means that the user can unambiguously select the subshape that is of interest. Here, the gaze data suggests that the user is attending to one of the two squares, while the mouse-based input suggests that the user is selecting either the inner square or the triangle. Therefore, a combination of the two methods of input means the user can unambiguously select and manipulate the inner square.

This method of identifying attended subshapes was implemented in the software prototype, along with various eye tracking tools, such as a dialog that reports the current status of the gaze data being recorded, as illustrated in the bottom right corner of Figure 10. In the prototype, the library of identity shape rules is used to specify subshapes that are potentially of interest in shape exploration. Given a designed shape, the rules in the rule library are used to create a list of subshapes that are potentially of interest to the user. This list is populated by using subshape detection [5] to calculate all subshapes embedded in a design that are similar to the shapes in the identity rules. For example, in Figure 10, the user has specified an interest in squares and right-angled triangles by creating appropriate identity shape rules.

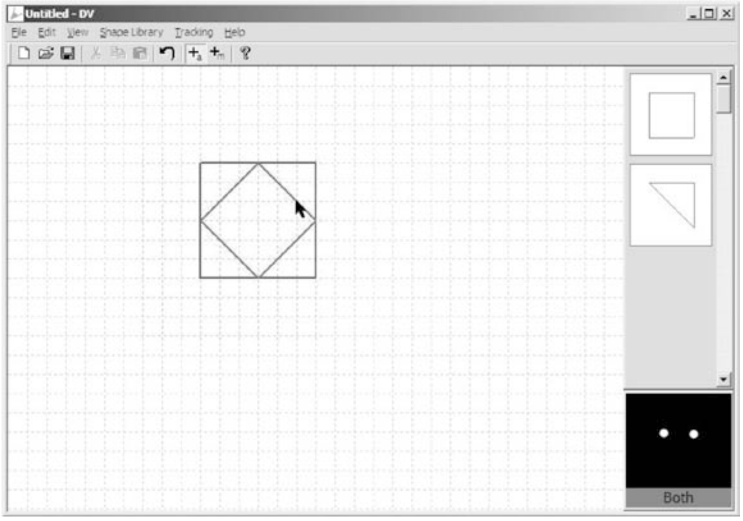

Figure 10.The software prototype revisited

Using a combination of the mouse-based input and gaze data of the user, at each stage of an explorative process all the square and right-angled triangle subshapes of a designed shape will be available for manipulation, as illustrated in Figure 11. In Figure 11a, the shape is initially constructed as two squares, one of which is selected and translated by the user in Figure 11b. In Figure 11c, the user changes interpretation and attends to the emergent triangle which is selected, and in Figure 11d it is translated. In Figure 11e, the user changes interpretation and attends to a second emergent triangle, and in Figure 11f this triangle is translated.

Note that, throughout this example, the user’s mouse-based input is consistent and the same line segment is always selected. However, because the user is attending to different subshapes according to different perceptions of the designed shape, it is possible to manipulate different interpretations of the shape. This is clearly illustrated by comparing Figures 11d and 11e, where the user attends to different triangles and consequently is able to select and manipulate those triangles in turn. At each stage of the explorative process the centres of gravity of the detected subshapes are used in combination with mouse-input and gaze data to determine the current interpretation of the designed shape – if a user is attending to a subshape that is similar to a shape in the rule library, and if that subshape is selected using mouse-based input, then the designed shape is made available for manipulation via automatic application of the appropriate identity shape rule. There is no additional cognitive effort required, and instead a reflective conversation can be conducted between the designer and the design representation.

7 CONCLUDING REMARKS

In this paper a software prototype has been presented that is intended to support what Schön and Wiggins refer to as the reflective conversation between the designer and the design representation. In the prototype, identity shape rules are used to support dynamic reinterpretation of the geometric elements used to construct shapes, whilst also allowing direct manipulation of the shapes. The application of these rules is automated according to an eye tracking interface that uses a combination of gaze data and mouse-based input to determine a user's interpretation of a designed shape with respect to recognised subshapes.

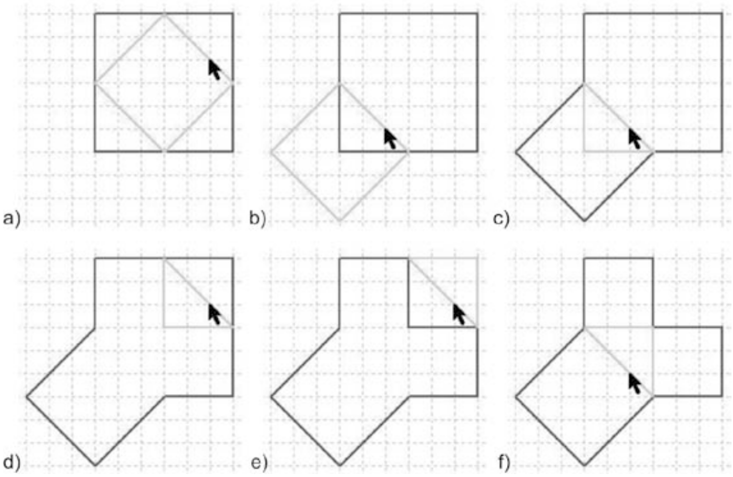

Figure 11. Supporting design exploration with identity rules and eye tracking

Not all design concerns the transformation of shape but a significant number of design disciplines do fundamentally engage with shape - ranging from graphic and communication design to architecture. Computational tools for design exploration require support for shape transformation and idea generation. Supporting these with computational tools is difficult because the technology must mesh with human cognitive processes that are frequently messy, unpredictable and fast. Furthermore there are difficulties in integrating external representations into what is traditionally an internalised process. However, the potential benefits to professional, commercial and recreational sectors, drives the search for systems that can genuinely contribute to generative computing. This research has demonstrated the potential of eye tracking technology as a means by which users can select shapes and subshapes without the cognitive overload that can so easily interrupt creative flow and so stifle creative thinking. Paradoxically, the use of useless rules in this work has synergies with the cognitive strategies of human creative thinking. What may appear obvious actually has a complex, generative functionality. The future for this work is to develop such synergies and to integrate this with a capacity to create meaningful representations to create generative systems that synthesise, rather than just support, human creative activity.

ACKNOWLEDGEMENTS

The research reported in this paper was carried out as part of the Designing with Vision project[2], funded by The Leverhulme Trust.

REFERENCES

[1] Suwa M. Constructive perception: Coordinating perception and conception toward acts of problem-finding in a creative experience. *Japanese Psychological Research*, 2003, 45(4), 221-234.

[2] Schön D. A. and Wiggins G. Kinds of seeing and their functions in designing. *Design Studies*, 1992, 13(2), 135-156.

[3] Gero J. Situated Design Computing: Principles. In B. H. V. Topping, (ed), *Civil Engineering Computations: Tools and Techniques*. 2007 (Saxe-Coburg Publications, Stirlingshire), 25-35.

[4] Stiny G. *Shape: Talking about Seeing and Doing*, 2006 (MIT Press, Cambridge).

[5] Trescak T., Rodriguez I. and Esteva M. General Shape Grammar Interpreter for Intelligent Designs Generation. In *Proceedings of Sixth International Conference on Computer Graphics, Imaging and Visualization*, 2009, Tianjin, China, 235-240.

[6] Keles H. Y., Özkar M. and Tari S. Embedding shapes without predefined parts. *Environment and*

---

[2] http://design.open.ac.uk/DV

Planning B-Planning and Design, 2010, 37(4), 664-681.
[7] Jowers I., Hogg D., McKay A., Chau H. H. and de Pennington A. Shape Detection with Vision: Implementing Shape Grammars in Conceptual Design. *Research in Engineering Design*, 2010, 21(4), 235-247.
[8] Knight T. Computing with Emergence. *Environment and Planning B-Planning and Design*, 2003, 30(1), 125-155.
[9] Prats M., Lim S., Jowers I., Garner S. and Chase S. Transforming shape in design: Observations from studies of sketching. *Design Studies*, 2009, 30(5), 503-520.
[10] Stiny G. Useless rules. *Environment and Planning B-Planning and Design*, 1996, 23(2), 235-237.
[11] Schön,D. A. Designing: Rules, types and worlds. *Design Studies*, 1988, 9(3), 181-190.
[12] Goel V. *Sketches of thought*, 1995 (MIT Press, Cambridge).
[13] Stones C. and Cassidy T. Seeing and discovering: how do student designers reinterpret sketches and digital marks during graphical design ideation? *Design Studies*, 2010, 31(5), 439-460.
[14] Lawson B. and Loke S. M. Computers words and pictures. *Design Studies*, 1997, 18(2), 171-183.
[15] Goldschmidt G. On visual design thinking: the vis kids of architecture. *Design Studies*, 1994, 15(2), 158-174
[16] Saund E. and Moran T. A perceptually supported sketch editor. In *Proceedings of ACM Symposium on User Interface Software and Technology*, 1994, Marina del Rey, CA, 175-184.
[17] Gross M. D. Emergence in a recognition based drawing interface. In *Proceedings of Visual and Spatial Reasoning in Design II*, 2001, Sydney, Australia, 51–65.
[18] Hornof A. J., Cavender A., and Hoselton R. EyeDraw: A system for drawing pictures with eye movements. In *Proceedings of the 6th international ACM SIGACCESS conference on Computers and accessibility*, 2004, Atlanta, GA, 86-93.
[19] Sibert L. E. and Jacob R. J. K. Evaluation of eye gaze interaction. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2002, The Hague, The Netherlands, 281-288.
[20] Koning H. and Eizenberg J. The language of the prairie – Frank Lloyd Wright's Prairie houses. *Environment and Planning B-Planning and Design*, 1981, 8 (3), 295-323.
[21] McCormack J. P., Cagan J. and Vogel C. M. Speaking the Buick language: capturing, understanding, and exploring brand identity with shape grammars. *Design Studies*, 2004, 25 (1), 1-29.
[22] Fua H., Chi Z. and Feng D. Attention-driven image interpretation with application to image retrieval. *Pattern Recognition*, 2006, 39 (9), 1604-1621.
[23] Rees G. Seeing is not Perceiving, *Nature Neuroscience*, 2001, 4(7), 678-680.
[24] Vishwanath D. and Kowler E. Localization of shapes: eye movements and perception compared. *Vision Research*, 2003, 43(15), 1637-1653.
[25] Carpenter R H S, *Movements of the Eyes*, 1977 (Pion, London).

Contact:
Iestyn Jowers
School of Mechanical Engineering
University of Leeds
Leeds, LS2 9JT
UK
Phone: +44 (0) 113 3432215
E-mail: i.jowers@leeds.ac.uk

Iestyn Jowers is a Research Fellow in the School of Mechanical Engineering, University of Leeds. His research is concerned with investigating computational methods for supporting designers' visual interactions with design representations.