Shape based reminding as an aid to creative design

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Abstract

This paper describes "Drawing Analogies," a shape based reminding program that uses freehand sketches to index and retrieve visual references for creative designing. Architects often employ reference images from books, magazines, and other visual collections to find forms they can adopt and adapt into their designs. We give examples of how designers use drawing and analogies and describe our approach to finding similar drawings. We argue that a graphical reminding scheme based on sketching can help designers find interesting references from various domains.

1. Introduction: Supporting creative design with visual references

We aim to develop computer based design environments that can support creativity in design. We believe that contemporary CAD programs serve this goal poorly for two major reasons. First, freehand drawing with pencil and paper offers considerable advantages for creative design; yet CAD programs do not support freehand drawing. Second, creative design often engages references drawn from various domains; but CAD programs isolate designers from sources of inspiration. Therefore, we approach computational support for creative design with freehand drawing and an integrated scheme for finding references. In this paper we describe "Drawing Analogies," a prototype visual referencing system based on drawing.

Many stories suggest that human creativity can be inspired by incorporating ideas from foreign domains. Architects, in particular, like to draw visual analogies from diverse sources of ideas into their designs. For example, Le Corbusier suggested that to increase one's creative power, one should study the natural, by drawing "a plant, a leaf, the spirit of a tree, the harmony of a sea shell, formations of clouds, the complex play of waves spreading out on a beach...." [1] (p 83). Likewise, the sketchbooks of Leonardo da Vinci are filled with study drawings of the structure of plants, human anatomy, and other natural forms; and many of his designs reflect the spatial structure of these references [2]. Architects have drawn on visual references as diverse as musical scores, scientific diagrams, human organs, paintings, and letter forms as sources for the spatial and physical form of buildings [3].

A well known example from the work of Le Corbusier lends weight to the idea that designers draw on references as inspiration for their architecture. Le Corbusier says of the design for his Chapel at Ronchamp, "the shell of a crab picked up on Long Island in 1946 is lying on my drawing board. It will become the roof of the chapel...." [4] (p 89). Iain Fraser and

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Rod Henmi point out that the pages of Le Corbusier's sketchbook on Ronchamp also contain other references, including an airplane wing, a ski jump, and building forms from North Africa [5] (p 5, 6). Geoffrey Broadbent describes the design process of Ronchamp as a sequence of direct analogies [6]. He suggests that after the shell shape became the roof of the chapel, Le Corbusier applied a bell-shape to the floor plan to express "visual acoustics." Then, images collected through sketches during previous years of travel were added to strengthen the "phenomenon of visual acoustics" and so the deep window he had seen in Arab housing and ventilation "funnels" were built in to the chapel. Also, Broadbent relates that Le Corbusier was struck by a drawings of Boulbon's reredos, so he traced the drawing and made the shape into the basic 'armature' of his chapel doors [6] (p 343). Other design examples are Calatrava's bull heads and bird wings for the Merida and Austerlitz bridges [7], Utzon's yacht shapes for the Sydney Opera House [8], and Wright's clasped praying hands for the Unitarian meeting house in Madison, Wisconsin [9].

In architectural design, the very act of drawing seems to play an instrumental role in the adopting and adapting of references. Although designers do not usually adopt a reference exactly and in full detail, often its essential spatial qualities are worked into the fabric of a design. Many designers keep a sketchbook to record visual impressions during travel, in daily life, or while browsing books and visual collections, later returning to review their sketchbooks when designing. Following this lead, in our Shape Based Reminding / Drawing Analogies project the sketchbook is the primary instrument for indexing and recall.

The remainder of the paper is organized as follows. Section 2 discusses the need to integrate references in computational design environments. Section 3 presents Drawing Analogies, a program that a designer can use to index and retrieve images in a visual database by freehand drawing. Section 4 describes our framework for judging the similarity of drawings Finally, section 5 reviews related work on analogy and metaphor in design.

2. Visual references and the computational design environment

We have argued that references play an important role in creative designing, and that they are incorporated into design through the act of drawing. We therefore propose two new functions of a computational design environment that could help. First, the computational environment should support importing and integrating visual references from diverse sources into design documents. Second, the environment should support the designer in making freehand drawings.

2.1 Integrating references into the design environment

The traditional design process can be characterized as a seamless integration of media and design development. The designer moves smoothly from sketchy diagrams to physical models and hardline drawings. Throughout the work, the designer takes notes, makes sketches, clips pictures, traces and copies images from books, design folios and various visual references of interest. In contrast, computational design environments are isolated from the rest of the design process and CAD programs are used mainly for presentation and construction drawing. To use CAD, however, the designer typically first enter a

preliminary design, then remains within the scope of a single program. It is difficult to move back and forth between paper sketches and the more rigid computer representations except by tracing over printed drawings. On line collections of visual references (e.g. [10, 11]), when available, are typically restricted to image viewing only. We do not know of any CAD program that integrates reference sources with the design environment.

We would like to bring retrieved images into the design environment so that the designer can work with them. This involves copying and pasting images from a library into a design document. As with paper media, these images can serve as trace underlays during design. The images should be machine readable so that the designer can work retrieved references into her designs. Therefore, we propose a scheme that allows the designer to clip, trace, and transform images into her design environment.

2.2 A Drawing Environment

The use of visual references in creative design is intimately bound with the act of freehand drawing. Le Corbusier says, "...to draw oneself, to trace the lines, handle the volumes, organize the surface...all this means first to look, then to observe, and finally perhaps to discover...and it is then that inspiration may come." [5] (p 86) Fraser and Henmi remark, "...architects use drawing to refer to observed scenes, as a particular mode of seeing, as a means to understand a reference in a particular way." [5] (p 92) In other words, the designer comes to understand and interpret a reference by representing it in a freehand drawing.

Therefore we have built our visual reference system using a program that supports freehand design drawing, the Electronic Cocktail Napkin [12]. The Cocktail Napkin enables the designer to make marks using a pen and digitizing tablet. The designer can work with various simulated instruments, for example, a brush, a thick felt tip marker, or a thin ink pen. The Cocktail Napkin attempts to recognize and interpret the designer's drawing. It recognizes simple shapes such as circles, triangles, lines, and arrows, as well as configurations of shapes such as the symbols for female or house (see figure 1). The designer can train the Napkin interactively to recognize other shapes and configurations; however, it is important that the program also retains unrecognized and / or ambiguous marks. The designer is not limited to working with a predefined set of graphic primitives, as with more structured CAD programs. Yet unlike paint-style programs that emulate traditional media (e.g. Fractal Painter) the Napkin recognizes these drawing elements as objects that can be manipulated. Thus it enables the designer to draw freely and to train the program to recognize her personal drawing style (figure 1).

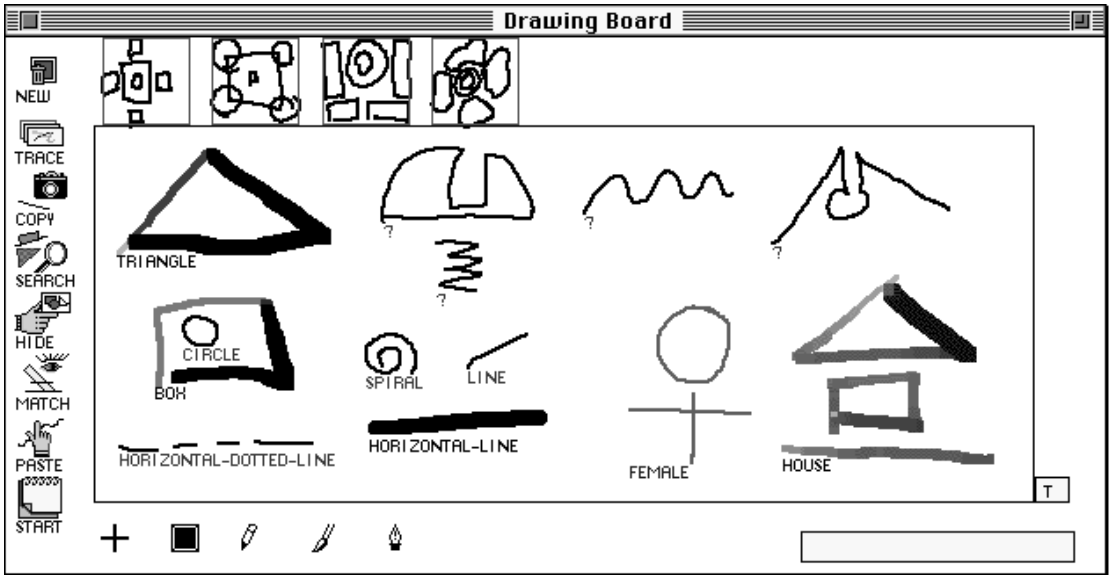
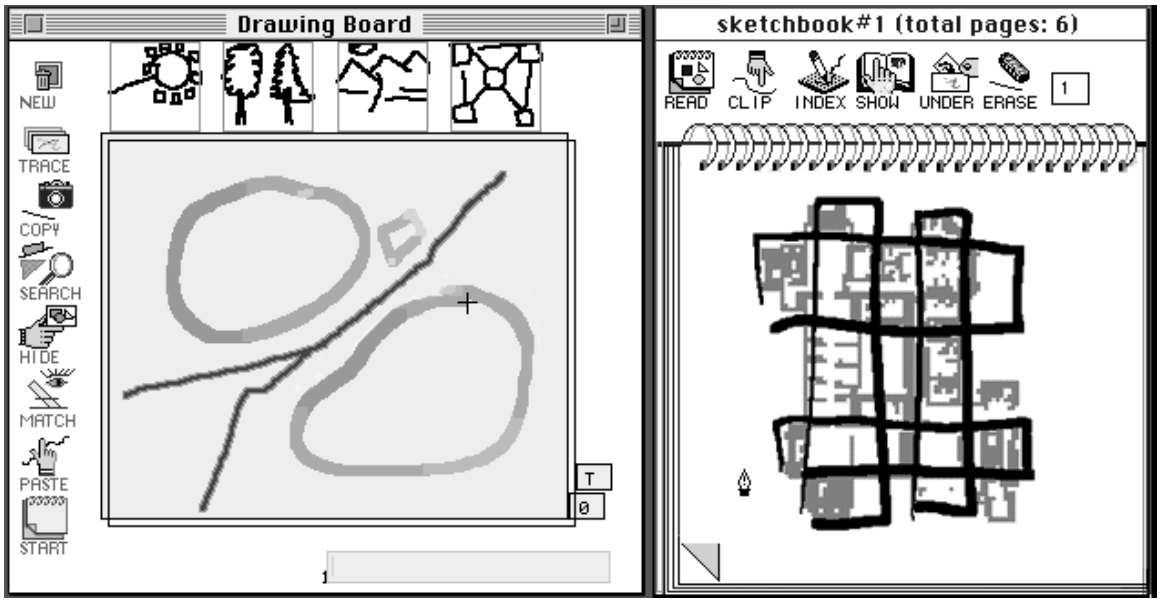


Figure 1. The Napkin Drawing Board simulates different pen types, carries recognized and ambiguous figures, and identifies configurations.

In addition to recognition, the Napkin facilitates drawing management; for example, it provides tracing paper and underlays, and a bulletin board for posting drawings. On the Drawing Board window, the designer can use tracing paper to copy over earlier design drawings. She can also set aside drawings on the bulletin board for future use just like pin-ups in the studio (Figure 2a top). The Napkin also provides a sketchbook for collecting the designer's freehand drawings as well as pictures from external sources. The designer can keep and browse different sketchbooks, and she can bring an image into her sketchbook and use it as an underlay picture (Figure 2b).



[a] [b]

Figure 2. The Napkin Drawing Environment. [a] Drawing Board with trace layers and pin-ups. Small drawings are pinned up along the top; the two boxes at lower right are for selecting and moving layers. Icons along the left are command buttons. [b] Sketchbook, with a diagram traced over a floor plan underlay.

3. Shape based reminding in the Drawing Analogies program

The Drawing Analogies program combines the Cocktail Napkin drawing environment and recognition facilities with an expandable visual collection. Currently this visual collection has three distinct databases. They are 1) Archie [13, 14], a case-based design aid written in Macintosh Common Lisp, 2) The Great Buildings Collection [15], a hypercard stack with images of over 700 famous buildings, and 3) Flora, a Filemaker Pro picture collection of Rocky Mountain flowers. These visual databases and the Cocktail Napkin's drawing environment are linked by a scheme for comparing drawing similarity. Drawing Analogies enables a designer to index items in a visual collection by making diagrams and sketches, and to later retrieve these items by making similar drawings.

The action takes place in three venues: a window designated as the designer's drawing board, a sketchbook window for browsing and visual note taking, and the various visual databases indexed by the sketchbook. The designer designs on the drawing board; the visual databases display photographs and drawings of diverse subjects; and the sketchbook links the drawing board with the databases and serves as a repository for collecting drawings and visual references.

We begin as the designer explores layouts by sketching on the drawing board. To represent a functional arrangement, she draws four boxes surrounding a circle that contains a box (Figure 3a). Next, she asks the Drawing Analogies program to find a sketchbook page that most closely resembles her sketch. The program opens the sketchbook to the best matching page (figure 3b), a similar drawing with the inner box and circle exchanged. This retrieved page is linked to several associated data. One is a building floor plan in "The Great Buildings Collection," (figure 3d) in this case, the Villa Capra by Palladio. The same page also indexes an illustrated layout story in Archie (figure 3e) and a flower page in "Flora," (figure 3f).

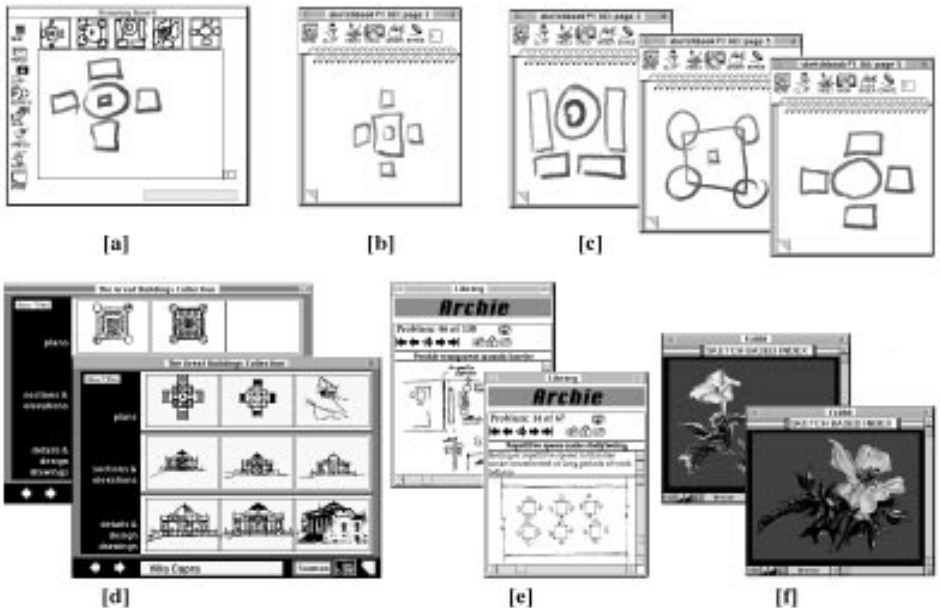


Figure 3. The sketchbook is the intermediary for indexing and retrieval from visual databases; [a] original sketch; [b] sketchbook page most similar to the original; [c] other pages retrieved with different similarity measures; [d] images from The Great Buildings Collection; [e] stories from Archie; [f] cards from Flora database.

Drawing Analogies uses the features of a query drawing to find similar drawings in the sketchbook, which are linked with images from visual databases. The program's similarity measure will always select a best match candidate for retrieval. However, informal observations of designers using Drawing Analogies reveal that a fixed definition of similarity might not completely satisfy designers. For example, when a designer draws a sun composed of a circle and five radial rays (figure 4a), the closest match may be a stick person also composed of a circle and five lines (figure 4b). Both figures share the same element types with minor differences in spatial configuration. The designer might come to realize that the stick person is not relevant and decide to look for images with radial features. In this case, spatial relations are more important than matching elements. Thus a changeable similarity scheme would be useful. First, an exact match of a drawing is unlikely. Therefore, we need to compare drawing similarity rather than trying to find an exact match, providing a ranked list of candidates. Even if we find an exact match to the query, designers might want to explore other similar references. Second, different definitions of similiarity will yield different retrieval candidates, and different rankings. We describe some dimensions of similarity in section 4, following.

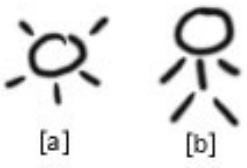


Figure 4. A sun and a stick person have the same elements.

Changing the program's definition of similarity, the designer can explore pages that correspond to different similarity measures (figure 3c). She examines and copies these pages into her design drawing. She sets them along the top of the drawing board as reminders (figure 3a, top of drawing board). Each of these small drawings represents an image found from the sketchbook according to different similarity definitions. For example, several varied configurations of boxes and circles may be of interest. The designer can draw on a large pool of images from different sources, because each sketchbook page may be associated with items in several databases (figures 3d, e, f).

The designer might select one of the retrieved images from the Flora database for her design. She might then transform the reference image, combining it with other references while adding and deleting features to meet the needs of the design. Or she might use one of the retrieved floor plans as an underlay, scaling the image to match the working size of her drawings, and tracing over it (Figure 2b). Perhaps the flower stem will become a main corridor, the leaves classrooms, and the flower an auditorium. Or she might combine the images of flowers and floor plans together in her design. Gradually, the exploration of these reference images may help to shape a creative design form.

4. Assessing the similarity of drawings

The problem of searching for similar shapes is not limited to the domain of design. The computer vision and image processing communities have built image retrieval systems, which typically use extracted features from pre-processed images

as retrieval keys [16-18]. In real life photographs, foreground objects often occlude other objects behind them, so many image processing projects focus on finding boundary features and solving occlusion problems. Most retrieval mechanisms only examine specific line features of a shape, for example, concavity and convexity, and do not treat the images as compositions of objects in which spatial relationships are important.

Our scheme for assessing drawing similarity depends not only on simple shape profile features, but also takes into account spatial relationships among drawing elements. Drawing elements may include simple shapes such as lines, circles, and triangles, as well as configurations such as columns, windows, and trees that are composed from simpler shapes. Relations are restricted to a predetermined list, including adjacent, above, contains, concentric, and overlapping. In the following, we discuss first how we assess the similarity of shapes, and then how we assess the similarity of drawings.

A shape is described by various features: the path of the pen through a 3 x 3 grid, the number of corners, strokes, size, and aspect ratio. The similarity of two shapes can be assessed by comparing these features. For example, comparing a circle and a box, the pen path, size, and aspect ratio are quite similar, but the box has more corners (figure 5b, c). Likewise, an oval and a circle are the same except for aspect ratio (figure 5a, b). Drawing speed and pressure data are also stored with the simple shapes although we do not use these properties in comparing shapes -- yet.

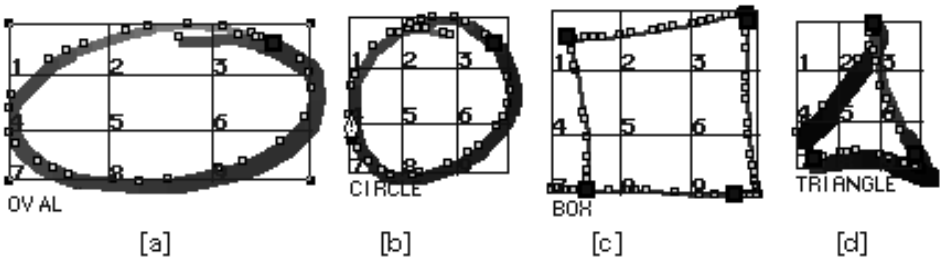


Figure 5 - Different elements with their features -- paths, corners, size and aspect ratio.

Our Drawing Analogies program provides several primitive matching functions that may be aggregated in a weighted sum to score the similarity of any two drawings. These primitive matching functions are described below and illustrated in figure 9 in the order they are presented in the text. By putting weight factors on each of the matching primitives, the overall similarity scoring can be adjusted. The designer can change the weights based on her interests. For example, if spatial relationships are a high priority, then the element type weight can be set correspondingly lower.

a. Element count match

The simplest matching primitive just compares the number of elements. Two drawings are identical with respect to this measure if they have exactly the same number of elements.

b. Element type match

Another very simple matching primitive compares the element types in the two drawings. Two drawings are identical with respect to this measure if they have exactly the same element types (irrespective of the number of elements). For example,

two drawings composed only of boxes, circles, and lines (figure 6) are identical with respect to element type matching, even though they are arranged in entirely different configurations and have different numbers of each element type.

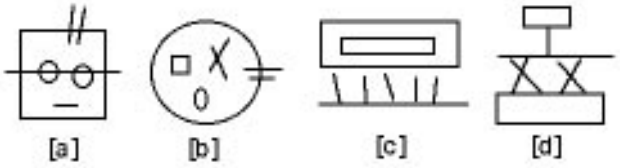


Figure 6. Element Type Match: pairs [a, b] and [c, d] have exactly the same element types.

c. Relations match

Another matching primitive compares spatial relations only. Two drawings are identical with respect to this measure if they contain exactly the same spatial relations, regardless of the elements involved. For example, a 'box containing a circle' and a 'triangle containing a line' are identical (figure 7a, b), because in both drawings one element contains another. The same rules apply to configurations as well, so all the drawings in figure 7 have the same 'containment' relation.

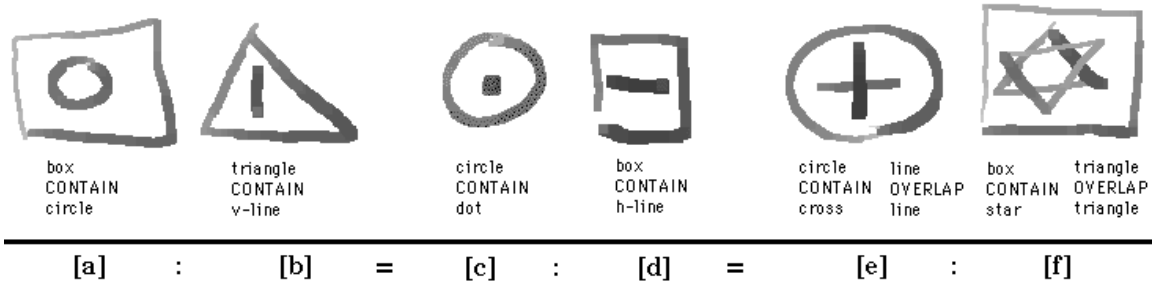


Figure 7. Relations match -- all figures exhibit 'containment'.

d. Element type&relations match

The element type&relations match combines the previous matching primitives to provide a finer comparison of drawings that considers elements and their spatial relations together. Two drawings are identical if they comprise exactly the same elements arranged in exactly the same spatial relations. For example, the pair of drawings in Figure 8 a and b are identical; 8c has a different relationship and 8d has different element types.

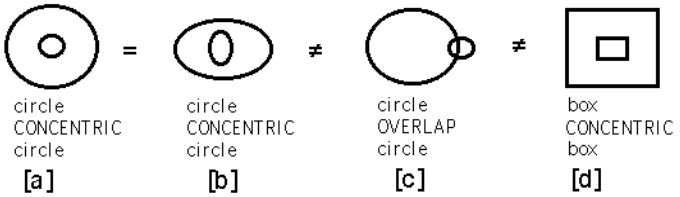


Figure 8. Element type&relations match; [a] is similar to [b], but not to [c] or [d].

Figure 9 illustrates the dimensions of similarity discussed above. The original query (the figure at the top left, column [a]) is compared with six other figures (columns [b-g]). The second row gives an example of data that might be associated with each figure, which would be retrieved if it were deemed to match the query. The next four rows illustrate each of the four

matching primitives applied to the candidate figures. The last row summarizes the similarity scores for each figure compared with the query, on a scale of 0 to 1, where 1 denotes 'identical'.

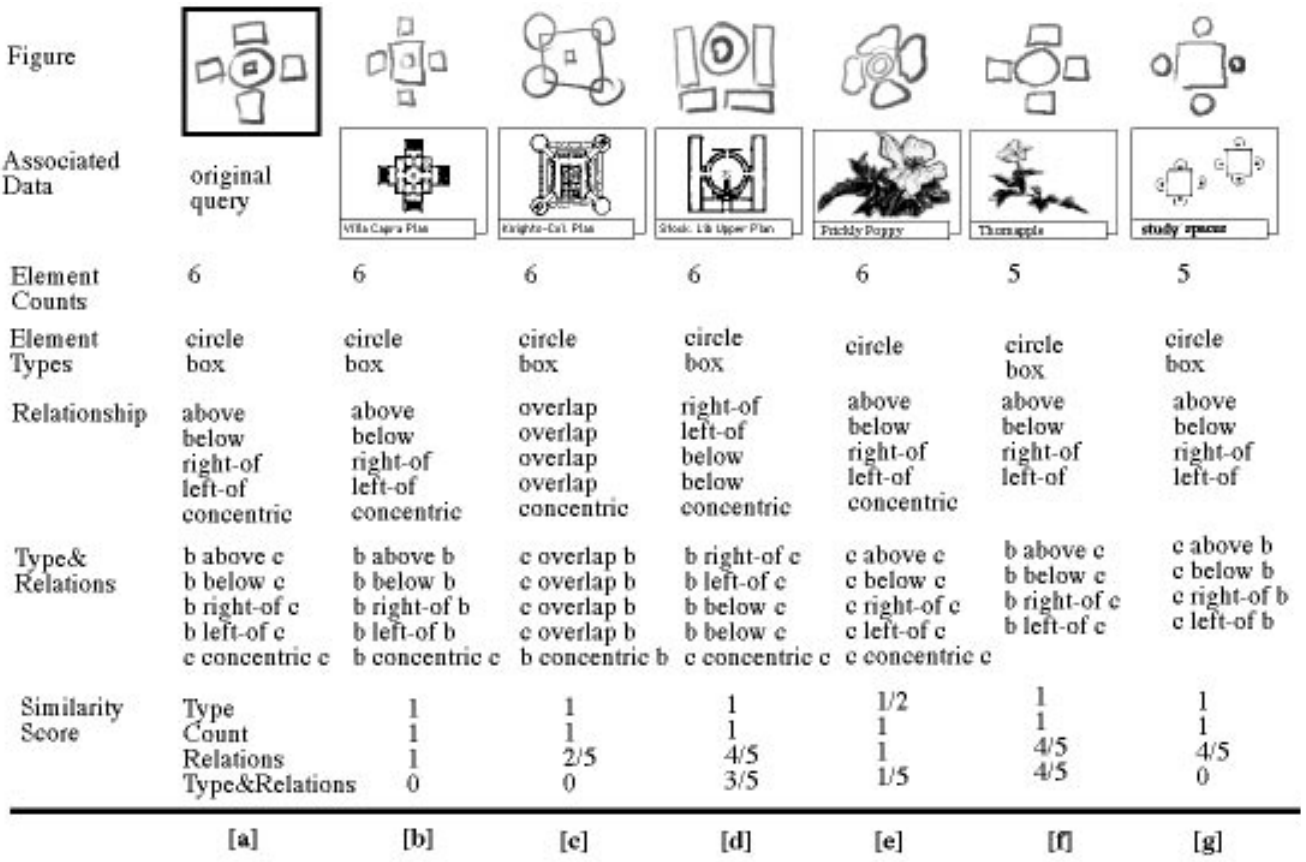


Figure 9. Drawing similarity measures: [a] is compared with [b], [c], [d], [e], [f], [g] according to various matching primitives.

5. Discussion: drawing and analogy

Our approach, supporting creative design with shape based reminding, should be considered in the context of related studies of drawing, visual reasoning, and the role of metaphor and analogy in design.

Many designers tell stories about the role of analogy in design ideation. Denise Scott Brown, quoted in Lawson's "Design in Mind," says "Analogy is there all the time in our thinking, ... Bob is quite likely to say something like ‘this fountain should be like an Edwardian lady's hat.'" [19] (p 100). Anthony Antoniades says "We all perform metaphoric acts whenever we... attempt to 'see' a subject (concept or object) as if it were something else.... in the hope that by comparison or through extension we can illuminate our contemplated subject in a new way...." Broadbent describes Le Corbusier spending his lifetime "building up a store of analogies," his years of traveling and "his years of sketching being particularly fruitful" so "when faced with any design problem, an analogy pops out at precisely the right moment [6] (p 343). He also suggests "we all have our stores of analogies, not perhaps as rich as Le Corbusier's but valuable nevertheless because they are personal."

Moreover, several books emphasize the importance of drawing and visual thinking in the creative design process. They provide examples of how architects develop designs through visual analogies and they suggest employing analogies while drawing, to inspire design. William Gordon's Synectics, a method for enabling creativity, identifies four types of analogy -- symbolic, direct, personal and fantasy [20]. Paul Laseau in his influential book, "Graphic Thinking for Architects and Designers" encourages designers to use analogy for discovery [21]. He suggests that sources of analogies may be physical, organic, and cultural and he provides example drawings to illustrate Gordon's four types of analogy. For example, by symbolic analogy, a pitcher is like a house -- both are containers. By direct analogy, a house with shade and air movement is like a tree. A house sited below the crest of a hill where a person might choose a place to rest is a personal analogy. A house that opens and closes like a tulip is a fantasy analogy.

Drawing plays an important role in design thinking. For example, Michael Graves in "The Necessity for Drawing" [22] argues that drawing is central in architectural design and he identifies various functions that drawing fulfills. Graves explains that a "referential sketch....is a shorthand reference ... which has the power to develop into a more fully elaborated composition when remembered and combined with other themes.... [It] is a metaphorical base which may be used, transformed, or otherwise engaged in a later composition." Robert Oxman points out, "In sketching, we frequently see the designer referencing an analogy as a form of 'stepping outside of the limitations of the design task environment'." [23] Oxman sees the designer sketching to explore an analogy, thereby restating the design problem before returning to develop the design.

Design research studies also support these designers' introspective observations on visual thinking in design process. For example, in "Design Thinking" Peter Rowe discusses analogy in design, saying "...initial design ideas appropriated from outside the immediate context of a specific problem are often highly influential in the making of design proposals." [24] (p 31). He identifies several kinds of analogies or as he puts it, ‘solution images' that designers use as heuristics to constrain design problem spaces. Closest to our work is Rowe's ‘literal analogy', which "involves borrowing known or found form-giving constructs as a point of departure for structuring a design problem." (p 80). However, Rowe merely identifies various types of analogy and gives examples, but does not suggest how analogy functions in design thinking. Alexander Tzonis [25] argues that analogical reasoning and the use of precedents play important roles in architectural design, and suggests how computers might support these activities. He sketches a computational process through which Le Corbusier could have derived the form of his Unité d' Habitation by analogy with three known objects: a peasant hut, a wine bottle rack, and an ocean liner, in order to satisfy three performance requirements for the building.

Research on visual thinking also sheds light on how drawing facilitates design development. Schön [26], for example, sees designing as a ‘conversation' between the designer and the materials of design (the sketch, the drawing) in which a designer engages in various 'kinds of seeing'. The designer sees the visual marks she has made on paper, sees that these marks have some qualities or characteristics she has previously learned to recognize, and she may see the form of the marks as one or another gestalt. Schön does not discuss the use of analogies and metaphor per se; nevertheless the ability to see one's drawing as an instance of a previously learned pattern would seem to be a key operator in visual analogy. In another

example, Laseau says "the graphic thinking sketches which architects have used provide evidence for analogy-taking in their design process. Often these sketches are small in order to pursue many different analogies on the same piece of paper...This permits the designer to work loosely and entertain all sorts of ideas; original trains of thought are recorded and can be returned to at will. Combining images derived from sketches can also generate further variations." [21] (p 117)

A recent analysis by Gabriela Goldschmidt looks at how visual representations, in particular sketching, functions in analogical design reasoning. Goldschmidt argues that visual analogy involves "a) retrieval and representation of base analogues -- any image; b) diagrammatic representation that is sufficiently abstract to accommodate any number of images; c) matching a target image from the context of the task at hand to that same diagram." [27] (p 68) The key idea is the power of the diagram to represent abstractions. She suggests, for example, that in the case of the Le Corbusier crab-shell / Ronchamp roof analogy, "the ‘abstractions' that Le Corbusier saw in his mind's eye, and probably never committed to paper, are none other than diagrams, of both the crab shell and the roof." [28] That is, Goldschmidt sees the diagram, a highly abstract kind of sketch, as the graphic representation of analogs and a crucial element in the graphic mapping from one domain to another.

It is easy to find additional stories and studies to support our hypothesis that a scheme for helping designers store and retrieve visual references based on spatial form would support creative designing. However, we do not argue that analogy is essential in creative design, or the only means possible. Nor have we tried to make a deep argument about how analogical reasoning and visual thinking work together, although we hope to pursue this topic more carefully in future work. Our Drawing Analogies program rests only on the surface features of images and drawings, which the accumulation of anecdotes has led us to think may be useful.

In summary, the Drawing Analogies program links hand drawn sketches and diagrams in a sketchbook with items in diverse visual databases. Our linking scheme depends on operators for comparing the similarity of drawings and it requires that connections between drawings and databases be made a-priori. In future work we intend to try to make this indexing easier and to test the Drawing Analogies program in the design studio where its value as an aid to creativity may be examined more closely.

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About the authors

Ellen Yi-Luen Do, when not hacking innovative design software, enjoys singing, free hand sketching (of course), telling stories, water color painting, making photographs, buying books, skiing, watching movies, hiking, playing tuba, creating origami, listening to classical music, traveling around the world, window shopping, browsing the web and eating noodles.

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