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SEEING INTO SKETCHES: REGROUPING PARTS ENCOURAGES NEW INTERPRETATIONS

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Abstract. One surprising benefit of sketches is the insights they provide to the sketcher. Sketches are ambiguous, allowing even their creators to reinterpret them, a process more difficult to do in the mind. How is it that sketchers can see new things in their own sketches? One possibility is that they regroup the parts into new wholes, with different meanings. A protocol analyses of an experienced architect confirmed this hypothesis: regrouping parts of sketch drove detection of new features in sketches. Further, novices who adopted this strategy generated more interpretations of ambiguous sketches than those who didn't adopt the strategy. Regrouping seems to be a general skill for generating multiple interpretations, applicable to many kinds of sketches. Encouraging this skill should enhance design.

1. Introduction: Sketches inform their Inventors

Early in the process, designers generate as many ideas as possible. Sketches are integral to this process, raw sketches that can be readily generated, revised, refined, and consolidated in concert with development of the ideas. Sketches serve as a thinking tool for designers (Robbins, 1994; Schon, 1983; Goldschmidt, 1994; Scrivener,1982). They externalize ideas, reducing load on working memory, facilitating effortful computations (Tversky, in press, c). As Goldschmidt (1994) has observed, sketches provide a designer with perceptual cues that permit detection of unintended features. A typical example is

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detection of a spatial relation, for example, proximity, or a spatial feature, for example, shape, that was an unintentional byproduct of sketching some other idea. How can this happen? As Stenning and Oberlander (1995) observed, depictions force specificity of certain spatial properties, like proximity and shape. Although these features and relations may be intended for some of the structures that are drawn, they have consequences for all the elements of a design. As shown by Suwa, Gero, and Purcell (2000), detection of unintended features is a key vehicle for generation of design ideas.

Despite its utility, detection of unintended features is not automatic, it is not a necessary accompaniment of using freehand sketches. Rather, it requires skill, a skill which is acquired with experience. Professional architects, for example, are more adept at seeing functional and abstract properties in their sketches than students of architecture (Suwa and Tversky, 1997).

A frequent barrier to detecting unintended aspects of one's own sketches, even for professional designers, is *fixation,* a common process in perception, problem solving, and design. Once an interpretation has been reached, even if it has been achieved with great effort, it is difficult to see alternatives. What's more, fixation intensifies with increased inspection of a diagram. Howard-Jones (1998) found that the rate of generating new interpretations of an ambiguous drawing decreased after the first minute of trying. Although fixation is a general problem of cognition, it is particularly relevant to design. Information that is intended to facilitate design may actually inhibit it, by increasing fixation. For example, showing students a diagram of what they are supposed to design increases fixation (Jansson and Smith, 1991). As Purcell, Gero, Edwards, and Matka (1994) noted, the reminding of a familiar concept associated with some part of a diagram made it hard for students to free themselves from it.

How, then, can designers make use of their sketches without getting trapped by the fixation effect? What kind of skill is needed to detect unintended features, to derive new interpretations? To see new things in a sketch seems to require reorganizing the elements of the sketch or the entire sketch with respect to a reference frame (Cornoldi, Logie, Brandimonte, Kaufmann, and Reisberg, 1996). Reisberg and Chambers (1991) noted, for example, that ambiguous figures can be reinterpreted by changing their orientation with respect to a reference frame. Here, we investigate regrouping parts of a sketch as a technique for generating new interpretations in two contexts. In the first, reported in Section 3, we analyze in detail the protocol of a professional architect for occasions where he spontaneously adopted the regrouping strategy. In the second, reported in Section 4, we compare students who adopt this strategy to those who don't in their facility in generating new interpretations of ambiguous drawings.

2. Detecting Unintended Features Promotes Generating Ideas

The starting point for any design project is the initial set of design requirements that prescribes the functions to be realized in the end product as well as the design issues to be considered during the process. However, these requirements are not sufficient to obtain a design solution. Designers supplement the given requirements with invented requirements of their own (Lawson, 1990). The early phases of design demand the generation of ideas, and the success of those ideas hinges on the supplemental design requirements the designer invents.

In earlier research (Suwa, Gero, and Purcell, 1998; 2000), we examined the cognitive processes that enable an experienced architect to invent design requirements. The finding was that design requirements are invented on the fly through cognitive interactions with sketches (Suwa, Gero and Purcell, 1998). Further, detection of unintended features has significant bearing on invention of design requirements (Suwa, Gero and Purcell, 2000); instances of invention of design requirements were likely to occur immediately after occurrences of detection of unintended features. This indicates that, for the architect studied, detection of unintended features motivated the invention of design requirements. Thus, detection of unintended features is a key to the invention of design requirements which in turn is crucial to idea generation.

3. How to See Unintended Features in Sketches

A promising way to enhance the detection of unintended features in sketches is to encourage designers to reinterpret their own sketches. There are many possibilities. One set of methods would be to direct designers to focus on conceptual aspects of design. A related set of methods would be to direct designers to focus on functional aspects of design. Yet another set of methods would be to direct designers to focus on perceptual reorganization of the sketch or parts of the sketch. Sketches, like all graphics, consist of elements arranged in space relative to each other and to a reference frame and perspective (Tversky, 1995; in press a, b, c). Interpreting a sketch means grouping certain elements and not others as well as assigning a reference frame and perspective. Changing any of these relations, then, can lead to reinterpretations of the sketch, enabling new design ideas. Early designs tend to be more ambiguous than later ones for obvious reasons; ambiguity disappears as ideas are made more specific. Ambiguity plays an interesting dual role in reinterpretation: the more ambiguous the sketch, the easier it is to reinterpret (Goel, 1995); however, the more ambiguous the sketch, the harder it is to assign any interpretation at all.

Here, we investigate the role of one form of perceptual reorganization as an aid to reinterpretation and detection of unintended features, namely, re-grouping parts of a sketch with attention to their organization and reorganization, from basic figure/ground relations to complex interrelations of parts. Re-grouping parts can yield new wholes, inspiring new interpretations. A simple example is the duck/rabbit ambiguous figure. Which figure emerges depends on which part is focused on (Chambers and Reisberg, 1985).

How might this play out in design? Suppose that a designer paid attention to a set of elements in a sketch simultaneously and thereby associated its grouping with an intention or interpretation. Typically, if the designer revisits the same set of elements later, the designer will retrieve the same intention or interpretation. This is the start of fixation. However, if the designer can be induced to attend to sketched elements differently, the designer may detect unintended features in the same sketch.

3.1 RETROSPECTIVE PROTOCOL ANALYSIS OF AN EXPERIENCED ARCHITECT

In order to verify whether regrouping facilitates detection of unintended features, we examined the cognitive processes of an experienced architect using a retrospective protocol analysis. We analyzed data collected previously (Suwa and Tversky, 1997). The experiment consisted of two sessions. The first was a design session, in which the architect worked on the design of a museum on a prescribed site, sketching on tracing paper. His sketching activities were videotaped. As soon as the design session ended, the designer viewed a videotape of the session and reported what he was thinking for each stroke of the pencil.

In spite of the fact that the think-aloud method of collecting verbal protocols is widely used, we chose to use retrospective reports. We sought to capture the phenomenon of perceptual reorganization. There is, however, evidence suggesting that introspecting aloud while working on a task may interfere with or even alter performance on the task (Lloyd, 1995). This would undermine the purpose of our research, even though there is some literature suggesting the contrary (Gero and Tang, 2001). In contrast, the technique of retrospective report enables the designer to report, without any interference, on perceptual actions that occurred during the process.

Retrospective reports, however, are not without disadvantages. There could be at least two undesirable effects: decay of memory and selective recall. As Ericcson and Simon (1986) pointed out, retrospective reports may select events relevant to the provided retrieval cues, neglecting other events. We believe that providing the architect with the video of his own design session as a retrieval cue alleviates both these effects. Showing the exact sequence of sketching, including the timing, hesitations, returns, and re-drawings provides memory cues that should enable the architect to retrieve his past thoughts in the order in which they actually happened.

3.2 CODING THE PROTOCOL

The coding scheme was described in detail elsewhere (Suwa, Purcell, and Gero, 1998), and will be reviewed here only briefly. First, in common with previous protocol analyses (e.g. Goldschmidt, 1991; Van Someren et. al, 1994; Suwa and Tversky 1997; Gero and McNeill, 1998), the entire verbal protocol was divided into small segments. A segment was defined as a set of thoughts and/or actions that are interpreted as having occurred simultaneously.

Then, for each segment, we coded instances of regrouping parts of a sketch and those of detection of unintended features, if any. This coding was part of a larger analysis of different modes of cognitive actions. Actions of regrouping parts of a sketch belong to the physical mode, and detection of unintended features to the perceptual mode in this coding scheme.

3.2.1 Coding of actions of re-grouping parts of a sketch

Actions referring to sketched elements were classified as physical mode, called physical actions. They were subdivided into drawing actions and looking actions. Drawing actions were coded as drawing a new element or retracing an old one. In coding a drawing action, the sketched element drawn or retraced was assigned a name taken from the protocol for identification purposes. Looking actions are ones of inspecting elements without drawing. In coding a looking action, the element involved was assigned a name taken from the protocol.

We coded actions of re-grouping parts of a sketch in the following manner. First, we assumed that a designer was paying simultaneous attention to the sketched elements involved in all the physical actions in a segment. This seems plausible in light of the definition of segmentation. Thus, we defined *a set of simultaneously attended elements* in a segment to be the sum of elements involved in drawing actions and looking actions. By contrast, we defined *a set of elements revisited* in a segment to be the sum of actions of retracing old elements and looking actions. Based on these definitions, we judged, for every segment, whether or not there was an instance of re-grouping parts of a sketch. If a set of revisited elements in a segment was not null, and nor the same as, nor a subset of, a set of simultaneously attended elements in any earlier segment, then we judged that the designer regrouped elements in that segment in a new way. By contrast, if a set of revisited elements in a segment was null, and was the same as, or a subset of, a set of simultaneously attended elements in at least one earlier segment, then we judged that the designer grouped elements as previously. If a set of revisited elements in a segment was null, then the designer did not revisit any sketched elements in that segment.

3.2.2 Coding of detection of unintended features

We refer to actions of attending to visual/spatial features of sketched elements as perceptual actions. They are subdivided into four: actions of attending to (1) visual features of elements, such as shapes, sizes, or textures, (2) spatial relations among elements, such as proximity, remoteness, alignment, intersection, connectedness and so on, (3) organizational relations or comparison among elements, such as chunking, uniformity/similarity, contrast/difference, and (4) implicit spaces that exist in-between elements. We collected instances of perceptual actions from the verbal protocols, interpreting the semantic contents of the protocol. The coding of a perceptual action always involved coding the names of elements whose visual/spatial features the designer attended to. For example, when a designer attended to a spatial relation, proximity, between two elements, we coded not only a perceptual action, proximity, but also the names of the two elements.

We defined *detection of unintended features* be a particular perceptual action; namely, first-time perception of a visual/spatial feature of element(s) that were drawn in a previous segment. For example, if a designer attended to proximity between two elements for the first time in a segment and if both elements had been drawn in a previous segment, then perception of proximity is an instance of detection of unintended features. The proximity had existed prior to the designer's attending to it.

A contrasting case not coded as an instance of detection of unintended features is the following. Designers frequently draw a new element, intending to form a new spatial relation between the new element and another existing element, for example, drawing a new element near another. In this case, one of the two elements was drawn in the same segment as the perception of proximity.

3.2.3 Coding Reliability

Here, we discuss issues concerning the reliability of coding, the coding scheme itself and the coding of the architect's data using the scheme. The current coding scheme is an extension of Suwa and Tversky's coding (1997), revised to capture the complexity of the cognitive processes during conceptual design. The process of revision took place over a long period of time and involved detailed discussion among us with trial coding of parts of the protocol data of our architect. That way, we were able to both identify the details of the cognitive processes and increase the reliability of the coding scheme itself to allow its application to actual protocol data as unambiguously as possible. See our earlier paper (Suwa, Purcell and Gero, 1998) for the details of the coding scheme.

For the analysis of the architect reported in this paper, the first author carried out the coding using the method of a repeated series of codings to increase the reliability of the coding. As soon as he finished coding the protocol data for the first time, he coded the same data for a second time without consulting the previous coding. Whenever there was a discrepancy he selected the coding that better conformed to the coding scheme. Then he coded the same data for a third time without consulting previous codings. There were fewer discrepancies.

As before, he selected the coding that better conformed to the scheme. The data reported are based on this third coding. We assume that most careless errors and inconsistencies of the coder were removed through repeated codings.

3.3 RESULTS: DID RE-GROUPING PARTS OF A SKETCH MOTIVATE DETECTION OF UNINTENDED FEATURES?

The entire protocol of the architect contained 340 segments. Table 1 shows how many of these were instances of regrouping elements in a new way, of inspecting elements in a previous way of grouping, and of no revisiting, respectively. It is evident from Table 1 that regroupings were common, consisting of 40% of the entire segments.

TABLE 1. The ways in which our architect revisited sketched elements

Ways of grouping of revisited elements in a segment	Number of segments	Percentage of the total (%)
New grouping	136	40
Previous grouping	182	54
No revisiting	22	6
total	340	100

The next step was to relate the regroupings to detection of unintended features. The entire protocol contained 606 perceptual actions, 171 of which were instances of detection of unintended features. The fact that 28% of the perceptual actions were detection of unintended features illustrates its importance in the design process of our architect.

How many instances of detection of unintended features occurred under regrouping? The answer is in Table 2. Considerably more detections of unintended features occurred under regrouping than under a previous grouping. The chi-square analysis indicates a statistical significance of this effect, $\chi 2(1) = 9.43$ ($p<0.005$). Clearly, regrouping fosters detection of unintended features for an experienced architect.

TABLE 2. The occurrences of detection of unintended features in segments categorized in terms of the occurrences of re-grouping of parts of a sketch

Ways of grouping of revisited elements in a segment	number of segments	Instances of detection of unintended features
New grouping	136	93

Previous grouping	182	78
total	318	171
Chi-square test of distribution		$\chi2(1)=9.43$ ($p<0.005$)

4. Re-grouping as a General Cognitive Skill

Are the benefits of regrouping for seeing new things in sketches limited to experts or to architecture, or might this be a more general strategy that can be applied by novices and to other domains?

4.1 MULTIPLE INTERPRETATIONS OF AMBIGUOUS DRAWINGS: EXPERIMENTAL DESIGN

In order to address that question, we adapted a technique used by Howard-Jones (1998). In the adaptation, participants examined four ambiguous line-drawings for four minutes, each with the goal of generating as many interpretations as possible. For each four-minute session with each line-drawing, participants had a pile of pages, each containing the drawing and a space for writing an interpretation. They studied the drawing, then wrote an interpretation of it, then removed it and repeated until the four minutes had passed. Participants were told that their interpretations did not have to include every part of each drawing. They were instructed not to rotate the sheet of paper.

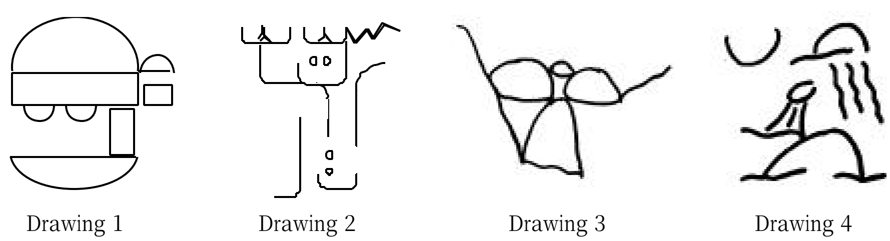

Figure 1. Four ambiguous drawings employed

Figure 1 shows the four drawings that we used. The left two used rigid lines; the right two used sketchy lines. Of each set, two contained primarily closed figures (the left of each set) and two contained relatively open structures.

The 36 New York University Psychology 1 students participated in the experiment and were divided into two equal-sized groups. Those in the

Regroup-parts group were instructed to regroup parts of each drawing in order to construct a new interpretation. The Attend-only group was just told to look at each drawing carefully. After completing the task, participants were interviewed to ascertain the strategy they actually used.

4.2 RESULTS

4.2.1 Regrouping participants

The post-experiment interview revealed that 11 of the Regroup-parts group found the strategy useful, but 7 were not able to adopt it. Similarly, 12 students in the Attend-only group reported that they invented and used a perceptual strategy that focused on different parts to construct new interpretations, though none of them explicitly referred to regrouping. The remaining 6 did not explicitly mention parts, though some reported mentally rotating the drawing to a new orientation. Because some instructed to use the regroup-parts strategy did not and some not instructed did, we classified participants by reported strategy rather than by instructed strategy. That yielded three self-selected groups of participants: *No Parts*, those who did not attend to parts, *Different Parts*, those who focused on different parts, and *Regroup Parts*, those who regrouped parts. The groups were approximately equal in size.

4.2.2 Difference among drawings

There were no effects of the particular drawings, perhaps because they were all abstract and equally complex. The total number of interpretations generated for Drawing One was 371, for Drawing Two, 334, for Drawing Three, 364, and for Drawing Four, 394. The chi-square test indicates that the numbers of generation of interpretations did not differ in a statistically significant manner, $\chi^2(3)=5.02$ ($p>0.1$). Hence, subsequent analyses were grouped over drawings.

4.2.3 Number of interpretations

The number of interpretations for each participant over the four drawings was averaged within groups and appears in Table 3.

TABLE 3. The total number of interpretations for each group

Groups	Number of participants	Total number of interpretations	
		Average	Deviation
No Parts	13	27.2	12.2

Different Parts	12	44.6	12.0
Regroup Parts	11	49.6	30.4

Participants who reported attending to parts produced nearly twice as many interpretations as those who did not. This was confirmed by a one-way ANOVA test showing significant differences between the Different Parts and the No Parts groups, $F(1, 23) = 12.9$ ($p<0.01$), as well as between the Regroup Parts and the No Parts group, $F(1,22) = 5.96$ ($p<0.05$). The Different Parts and Regroup parts groups did not differ, $F(1,21) = 0.27$.

4.2.4. Decay of generation of interpretations

Similar to Howard-Jones's results, there was a decrease in the rate of generating new interpretations over time. For each participant we calculated the ratio of the number of interpretations for the last two minutes to the number for the first two minutes, grouping over drawings. The averages of these ratios for each group of participants appear as percentages in Table 4. The decrease was lower for the two groups that attended to parts than for the group that did not. Decay of generation of new interpretations was lower for both the Different Parts ($F(1,23) = 11.5$ ($p<0.01$)) and the Regroup Parts ($F(1,22) = 24.3$ ($p<0.01$)) than for the No Parts group. The two groups that attended to parts did not differ. These results indicate that participants who reported having attended to parts, whether by focusing on different parts or by regrouping parts, showed slower decline in producing new interpretations than those who did not. Together with the previous finding, this suggests that attending to parts reduces fixation on previous interpretations.

TABLE 4. The decrease of the number of interpretations in the last 2 minutes, for each group

Groups	Number of participants	The ratio of the number of interpretations for the last two minutes to the number for the first two minutes (%)	
		Average	Deviation
No Parts	13	49.1	10.7
Different Parts	12	62.9	9.5
Regroup Parts	11	68.2	7.7

4.3 SUMMARY

Attending to parts, whether by regrouping them or by focusing on different parts, was associated with increased generation of interpretations and decreased rate of decline of generation of interpretations over time. Thus, attending to parts is a strategy that applies to novices and applies to other kinds of drawings, even ones that have no apparent function. It is possible that the participants who reported focusing on different parts in fact regrouped parts, and that the facilitation was due to regrouping, not mere focus. This will be examined in future work.

It is not clear how easy this strategy is to adopt. True, approximately the same proportion of participants spontaneously invented the strategy as those who used it when instructed. It is possible that with more training, more participants would be able to wittingly attend to parts and consequently produce more interpretations. Without further research, we cannot be sure that attending to parts per se led to the increases. It is possible that whatever spatial ability allowed some participants to use the strategy, whether instructed to or not, also allowed them to see more meanings in the sketches.

5. Summary and Implications

Sketches are used by professionals not just to express ideas but also to generate new ones. Reexamining old sketches, even one's own, can lead to the discovery of new ideas. It is through their reinterpretations that old sketches may be used to generate new ideas. One way this may happen is through regrouping parts of a sketch to form new wholes. Two studies supported the idea that regrouping parts is a source of insight. In the first study, the discovery of new features unintended in the construction of the sketch was associated with regrouping elements of the sketch in an expert architect. The second study expanded this finding to novices and to meaningless sketches. Students who reported focusing on different parts or regrouping parts produced more interpretations of the sketches than students who did not report focusing on parts. Moreover, for the students, focusing on or regrouping parts slowed the decline in generation of new ideas with time spent studying a sketch. For both an expert architect and novices, for technical design sketches and for meaningless ones, regrouping parts is associated with generating new interpretations.

These findings have clear implications for design education: teaching designers to reorganize the parts of their sketches, especially in the early stages of design when sketches are ambiguous and fixation has not set in, has the potential to produce new interpretations. The study on novices suggests that training to regroup parts may require more than just saying it. One-third of the students instructed to use the strategy were not able to do so. Interestingly, that was approximately the same proportion of uninstructed students who did not spontaneously use a part-focus strategy for reinterpreting sketches. Supplementing the overall suggestion to regroup parts with concrete examples of how to do it is likely to be effective, just as it is effective in other problem solving situations. Teaching designers to reorganize parts of their own sketches should have payoffs in designs that are more creative and more functional as well.

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