Thinking with Sketches

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Abstract

Sketches serve to externalize ideas, to render fleeting ideas permanent, to confer coherence on scattered concepts, to turn internal thoughts public. They can be created and recreated, examined and reexamined, configured and reconfigured, considered and reconsidered, for clarity and for creativity. The schematic vocabulary of sketches allows both expression and discovery of ideas. Sketching is integral to design, where vagueness encourages reinterpretation and discourages fixation. Using sketches to those ends requires *constructive perception*, a combination of a perceptual skill of reconfiguring and a cognitive skill of finding remote associations.

Why Sketch?

Designers sketch. One reason they sketch is that they design things that can be seen. A sketch can resemble what the designer wants to create. A sketch can be seen, unlike the contents of the imagination. Thus, sketches serve to amplify a designer's imagination and relieve limited capacity working memory. Sketches map things in the world or the imagination and their spatial relations to elements and relations on paper, a natural mapping. They can convey large spaces by by spaces that are smaller, hence easier to contemplate. Models can do that as well, perhaps more so, as models are three-dimensional. But models have disadvantages over sketching, especially in the early stages of design, when the designer is considering many alternatives, and those alternatives may be vague or partial. Models demand completeness. Sketching is faster than building models, and is kinder to trial and error. Sketches are straightforward to create and straightforward to revise. Sketches are two-dimensional, thus easier to think about, as thinking in two dimensions is easier than thinking in three. Sketches readily enable isolating different parts, different perspectives, and different scales and working on them separately. A designer can use a sketch to focus on some aspects of the design, ignoring aspects that may be distracting or confusing. Sketches are visible. Because they are visible they can be inspected and reinspected, considered and reconsidered. As shall be seen, designers can discover new properties and relations from their sketches as they inspect them, properties and relations that emerge from the sketch but were not intentionally put there (e. g., Goel, 1995; Goldschmidt, 1994; Schon, 1983; Suwa, Tversky, Gero, and Purcell, 2001). Sketches go beyond the visible. They can eliminate detail that is irrelevant and distracting in the service of capturing the essential. At the same time, sketches can exaggerate and even distort the essential. They can be enriched with words and other symbols, enhancing their meaning with ideas not easily expressed pictorially.

Yet designers of things that cannot be seen also sketch. Sketches can use elements and relations on paper to represent abstract elements and abstract relations.

Designers of experiments and of assembly lines, both of which occur in time, sketch possible sequences of events. Extending sketches from space to time is a natural step, as temporal events are described in part using the language of space, for example, *before* and *after, forward* and *back*. But designers of abstract ideas also sketch, designers of corporate organizations and of computer operating systems.

Couldn't people work these things out in their heads? To some extent they may, but ideas, whether spatial or abstract, that are complex or detailed are likely to be too massive to hold in mind, especially if they need examination, manipulation, or revision, all processes crucial to design. The pragmatics of putting ideas on paper demands a degree of coherence, completeness, and consistency, serving as a test of design ideas. Finally, the public nature of sketches facilitates communicating ideas to others and collaborating with others (Heiser and Tversky, 2004; Heiser, Tversky and Silverman, 2004). Sketches serve as an easy referent for words and gesture, so deictic expressions like *here* and *there* and *this part* and *that way* simultaneously make communication easier and more precise. In collaborations, they represent the ideas of the group, not of any individual, so all are committed to it. To summarize, when we've barely begun, sketches are useful because they externalize ideas, encourage coherence and completeness, allow expression of the vague as well as the specific, map large space to small, extract the crucial, enrich by annotation, make the abstract concrete, relieve limited working memory, facilitate information processing, encourage inference and discovery, and promote collaboration (Tversky, 1999, 2001, 2005). And more.

What is the Nature of Sketches?

Design sketches are sketchy, at least at the beginning. They are tentative, they do not commit to exact shapes or exact spatial relations. They use a limited vocabulary of abstract shapes whose meanings are suggested by their geometric or Gestalt properties. In early design in architecture, for example, blobs can stand for structures, buildings or rooms, and lines for the paths or corridors that connect them. Blobs are used to represent concepts we think of as three-dimensional (turned two-dimensional on paper) and lines to represent concepts we think of as two-dimensional (turned one-dimensional on paper).

Diagrams also use a limited vocabulary of shapes, but they contrast with sketches in being exact and definitive. In sketches, the tentative nature of shapes and spatial relations is directly suggested by irregularities, by imperfections, by inexact tracings and retracings. In diagrams such as circuit and molecular diagrams, shapes and lines tend to be symmetric or regular or straight. Whereas sketches are often meant to be suggestive, tentative, ambiguous, open to reinterpretation, diagrams are meant to be clear and unambiguous, so that there are no misinterpretations.

An example of a type of diagram we've worked out in detail is route maps. Route maps are meant for clear communication, not for creative design. Although route maps could be analog, they are not. In fact, they seem to schematize environments exactly the way human memory does, by straightening roads, making turns into right angles and roads parallel, by distorting distances (e. g., Tversky, 1981; 2005). An analysis of a corpus of route maps students spontaneously produced to guide a traveller revealed a small number of elements with quite specific meanings that may be concatenated in specific ways; in other words, a semantics and syntax (Tversky and Lee, 1998, 1999). The semantics consisted of what might be called *graphemes* for turns, L's, T's, and +'s, for straight paths, lines, for curved paths, arcs of circles, for landmarks, street names or blobs. Significantly, the semantics for verbal route descriptions revealed parallel elements, "make a," "take a," or "turn" for turns, "go down" for straight paths, "follow around" for curved paths, names for landmarks. Each set of semantic elements, descriptive or depictive, forms an essentially complete semantics of routes. New groups of participants were assigned one of the vocabularies to construct a wide range of routes, short or long, simple or complex (Tversky and Lee, 1998) and found either set virtually sufficient. The semantics of gestures used in describing routes include the same elements (Tversky, in press). The parallels between the semantics and syntax of depictions, descriptions, and gesture of routes suggest that they derive from same underlying mental model.

At an even more abstract level, the primary elements in route maps indicate things that are thought of as points, as lines, as areas, and as volumes. Design sketches also use these elements. Interestingly, a similar tripartite distinction is one that Talmy (1984) has proposed to characterize the language of space and time, one-dimensional points, two-dimensional areas, and three-dimensional volumes. We say the group will meet at the corner at 1:45, point-like spatial and temporal concepts. The hike will go from the Capitol to the pond from 2 to 4, both like lines or areas. It will take place in two days' time in Austin, both volume-like concepts. These conceptual distinctions have metaphoric extensions: someone can be *at* a crisis but *on* top of things, so not *in* a panic.

The comparison of the semantics and syntax used to convey routes in descriptions, depictions, and gesture, then, have revealed the underlying mental models people have for routes. A route consists of landmarks and paths, nodes and edges, turns and progressions. Exact distances and directions are not important, as they can be inferred from context, nor are the regions not along the route. Knowing the underlying mental model and the graphic devices used to convey it can serve as cognitive design principles for creating sketches or diagrams that are useful and effective. This program, of eliciting mental models from depictions and descriptions, extracting from cognitive design principles from them, and incorporating the cognitive design principles into algorithms to generate diagrams on demand has been successfully applied to both route maps and assembly instructions (Tversky, Agrawala, Heiser, Lee, Hanrahan, Phan, Stolte, and Daniel, 2007). The program can be adopted for other domains. The productions of depictions and descriptions (and also gestures, see Tversky, in press) simultaneously reveal the underlying mental models and suggest effective depictive and descriptive semantic elements and syntactic rules.

As they progress, the vocabularies of design and other sketches expand; they are typically enriched and articulated so that shapes of paths and regions, parts and wholes, are more specific, and can be recognized as such. Do and Gross (summarized in Do, 2005) have studied the visual vocabularies of architects as they expand. Even expanded and articulated, the elements remain sketchy and schematic, for example, people are represented as stick figures and rooms as rectangles with openings for doors.

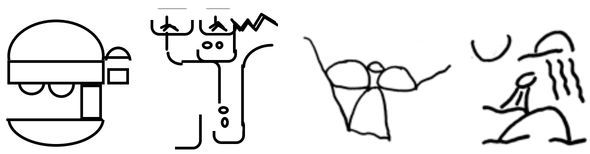
How are Design Sketches Used?

Early design sketches are even sketchier than route maps. One reason is that the designer hasn't yet committed to specifics. Another, intended or unintended, is that sketchy sketches, because they are ambiguous, support many interpretations. The ambiguity of design sketches, rather than promoting confusion, promotes innovation. Because they support many interpretations, such sketches can be used for discovery and reinterpretation to further the design. Schon (1983) has described this as a conversation the designer has with his or her sketches. The designer creates the sketch to represent one set of constraints, elements and relations, but on studying the sketch, sees other elements, relations, and patterns (e. g. Goldschmidt, 1994; Suwa, Gero, & Purcell, 2000; Suwa & Tversky, 1997). These unintended discoveries advance the design. In one study, novice and experienced architects were asked to design a museum on a particular site (Suwa & Tversky, 1997). Their design sessions were filmed, and afterwards, the designers viewed their sessions and explained what they were thinking at each stroke of the pencil. Both novice and expert architects got new ideas from examining their own sketches. However, the expert architects were more likely to get functional ideas from their sketches. The novices discovered structural features and relations in their own sketches; arguably, these require little interpretation as the structural features and relations are "there" in the sketch. Experts, by contrast, could "see" functional features and relations in their sketches, changes of light or flow of traffic. These functional features and relations are not directly visible in the sketch, but require complex inferences requiring expertise. Seeing function in structure is a hallmark of expertise, for example, in chess (Chase & Simon, 1973; de Groot, 1965) and in engineering diagrams (Heiser & Tversky, submitted). Expertise, then, promotes seeing function in form.

How can Sketches be Effectively Reinterpreted?

What leads to these reinterpretations, so crucial to advancing design? A detailed study of one expert architect revealed that most of his new ideas came from when he saw the elements of the sketch differently, that is, he reconfigured them into a different pattern (Suwa, Gero, and Purcell, 2000). A new idea then allowed him to reconfigure the sketch yet again, so that a positive cycle ensued, perceptual reorganization generated new conceptions and new conceptions generated perceptual reorganizations.

Is this strategy of searching for new perceptual relations a general one? The next step was to turn from designers to undergraduates (Suwa, Tversky, Gero, and Purcell, 2001). We showed undergraduates a series of ambiguous but suggestive sketches, those in Figure 1. Their task, adapted from a procedure used by Howard-Jones (1998) was to generate as many new interpretations as they could think of for each, four minutes for each sketch in turn. Approximately two-thirds of them used a strategy of attending to the parts of each sketch, either focussing successively on different parts or attempting to rearrange the parts mentally, for the purpose of coming up with new interpretations. Those who adopted an attention-to-parts strategy were more successful than those who didn't. Those who attended to different parts came up with 45 interpretations and those who rearranged parts produced 50 interpretations, both in contrast to the participants who did not perceptually reconfigure the sketch and who produced 27 interpretations on average.



Drawing 1 Drawing 2 Drawing 3 Drawing 4

Figure 1. Four Ambiguous Drawings

The parts-focus strategy was also effective against fixation, the plague of designers, of getting stuck on a particular design and not being able to see alternatives. During the early phases of design, designers typically generate many ideas, but as they work and their designs become more constrainted, they find it more and more difficult to see alternative solutions. Those undergraduates who adopted the parts focus strategy succeeded in producing more ideas in the second half of each session than those who did not.

Perhaps not surprisingly, practicing designers were more fluent at the task of generating new ideas and produced more of them than design students and laypeople (Suwa and Tversky, 2001; 2003). This suggests that experience encourages the required skills. The practicing designers reported a variety of ways to perceptually reconfigure the sketches, notably regrouping the parts and changing reference frames. In addition, they sometimes reversed figure and ground relations in the sketches. However, perceptual reorganization is only half the process of coming up with new interpretations. Those interpretations must have meaning. To some extent, both the perceptual skill and the conceptual skill can be measured. The perceptual skill is measured by the embedded figures test, in which participants' ability to see a simple geometric figure in a complex one is assessed. The conceptual skill is measured by an associative fluency task in which participants' ability to find a meaningful association relating two unrelated words is assessed. The number of interpretations provided increased with each of these abilities independently. That is, those proficient in perceiving embedded figures and those high in associative fluency produced more interpretations, but the two abilities were not correlated.

Integrating these results suggests that actively reconfiguring sketches and finding meanings in them, termed *constructive perception*, promotes new design ideas and protects against fixation. The fact that designers are more proficient than lay persons suggests that the skill can be fostered. The fact that abstract ideas can be sketched suggests that constructive perception may have applications beyond the design of real objects and structure to the design of abstract objects and structures.

Implications

Design entails generating ideas and adapting them to users. This requires thinking broadly about possibilities and linking those possibilities to meaningful uses. This process is iterative, and facilitated by sketches. Sketches allow designers to express ideas both vague and definite, and then see their ideas, to contemplate them, to alter them, and to refine them. This iterative process, constructing, examining, and reconstructing has been called a kind of conversation (Schon, 1983). Successful conversation with sketches depends on finding new perceptual configurations as well as finding new meanings, and connecting the configurations to the meanings, seeing function in form.

There have been a number of efforts to create tools to facilitate the design process applying these insights, that sketchy sketches are helpful early on, but become more articulated as design progresses and that sketches use a limited range of domain-specific visual elements (e. g., Do, 2005; Hearst, Gross, Landay, Stahovich, 1996). These tools try to facilitate design first by aiding sketching: by recognizing the primitive elements, often completing and remembering them, allowing them to be manipulated and replicated. The tools can also enhance design in ways that go beyond sketching, by retrieving examples that use similar elements or have similar goals so that the designer can use these as examples or analogies. These other examples can be other artifacts, such as other spiral staircases or buildings, or natural objects with similar shapes or goals, such as snails. By retrieving examples that are functionally similar as well as examples that are perceptually similar, these tools can aid both perceptual and functional aspects of constructive perception. A rich and relevant source of examples can increase innovation by providing the designer with ideas the designer might not otherwise consider. A broad range of new examples can also break fixation, a persistent problem for designers. These new tools have the potential not only to facilitate innovative design but also to make it more fun.

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