would be to exploit the brain's ability to use a contour fragment as a look-up key to unconscious knowledge (as when a hunted animal is partly obscured behind a bush). Hoffman and Richards (1984) suggest that the visual system decomposes object shapes into parts at regions of concavity along the visible object contour. Contour lines in sketches fit Marr's classification into: (1) contours that define an object's silhouette or surface discontinuity ("self-occluding contours"), (2) contours that mark a change in the orientation of a surface, and (3) contours that mark the edges of a shadow or change of reflectance within a surface. (In sketches lines are, of course, also used for non-contour purposes such as representing shadow and texture.) It is the first of these contours that are considered by Hoffman and Richards. According to their theory, part boundaries are defined by a rule that exploits a uniformity of nature termed "transversality." This regularity occurs because "when two arbitrarily shaped surfaces are made to interpenetrate they always meet in a contour of concave discontinuity of their tangent planes." Thus the profile of a face divides naturally into nose, lips, forehead, etc. according to this rule. The authors conclude that the visual system exploits transversality to categorize objects' parts as one of the regularities of nature that underlies the inference of parts from images. These parts can then be used for building an object description for recognition. Starting from similar premises, Biederman (1987) has developed a theory in which the input image is segmented at regions of concavity into 36 kinds of simple volumetric components such as blocks, cylinders, wedges, and cones. These are then used as primitives to derive structural descriptions of objects that are invariant for position, size, and orientation. Both these theories provide mechanisms by which incomplete sketch fragments can be exploited by the brain to elicit the retrieval of object knowledge.

As already mentioned, psychologists sometimes assess short-term memory capacity in terms of the number of "chunks" that can be handled simultaneously. A "chunk" is conceived as a meaningful structure of remembered parts that can be accessed as a whole, provided a retrieval cue with which it is associated is available. A number of studies have shown that specialized experts possess the ability to store and retrieve larger and more complex relevant memory chunks than non-experts (e.g., Chase and Simon 1973). In a series of studies, Ericsson and his colleagues have shown that mental expertise involves the manipulation of complex acquired "retrieval structures" in long-term memory. Because these can be accessed quickly from retrieval cues held in short-term memory, they allow skilled practitioners to use their long-term memory to expand the effective capacity of their working memory. These authors distinguish "short term working memory" from "long term working memory" (Ericsson and Kintsch 1995).

Reviews of expert performance have shown that, after thousands of hours of practice, experts can acquire support skills that allow them to compensate for the limited capacity of short-term memory. According to Ericsson and Delaney (1998), expert practice allows the formation of task-specific hierarchical structures in long-term memory that can be retrieved by simpler retrieval cues in short-term memory. Ericsson and Delaney showed, for example, that, with training, subjects were able to expand their memory for numbers from the normal range of about 7 digits to a level surpassing that of professional memorists (around 15–20) digits. This feat was achieved by hierarchically structuring the numbers into more easily remembered "chunks."

They have also demonstrated the skilled expansion of effective working memory in waiters (who often remember up to 16 meal orders at once without notes), chess players, and medical practitioners. There is every reason to suppose that skilled designers also have learned retrieval structures that can be accessed with shorter cues, perhaps unconscious, in short-term memory. However, this possibility is yet to be investigated experimentally.

Thus the evidence suggests that branches of the designer's descriptive–depictive tree that have been explored repeatedly will be stored in long-term memory as descriptive–depictive retrieval structures. These, when acquired, can be later accessed and manipulated by individually acquired retrieval cues in short-term memory. If this is so, then it is the brain's capacity to hold and manipulate retrieval cues to knowledge "chunks" rather than the chunks themselves that needs support.

Written notes and the untidy, incomplete contour fragments and object parts that occur in sketches are access keys to much larger memory components. These components of the sketch behave like descriptive–depictive catalysts by facilitating access to long-term visual memory retrieval structures or expert design "chunks." Improved memory retrieval facilitates the generation of a stream of depictive mental imagery. Because sketch retrieval cues contain much indeterminacy and because image generation occurs piecemeal (Kosslyn et al. 1988), this process can, in turn, generate new inventive, unexpected retrieval structures by mental recombination and synthesis.

The process proposed resembles catalysis because the semi-descriptive retrieval cues in the sketch combine temporarily in the brain with stored information during the process of remembering. A theory of retrieval by combined stimulus cue and memory trace was developed by Tulving (1983) to explain verbal episodic memory. He termed it "synergistic ecphory." In some respects, this is a visual application of his theory. Untidiness, accident, and indeterminacy amplify the inventiveness of these unconscious retrieval processes.

Manipulating and Scanning Spatial Images

In order to make the reverse translation and derive new descriptive information from depictive images, the brain provides a range of covert scanning and inspection processes. As a familiar example, suppose someone asks you, "How many windows has your house?" Most people report that, to answer this question, they take a mental walk around the rooms of their house, counting the windows as they do so. Here the inner voice and the inner eye cooperate to derive descriptive information from visual imagery. Another example is "How many corners has a sans serif, upper-case letter 'E'?" Most people report that they must mentally generate an image and count the corners to answer this question. Depictive information must be scanned to make information that is only implicit, explicit.

A series of elegant experiments on mental curve tracing (Jolicoeur et al. 1986) illustrates this. The time to determine whether or not two small marks are located on the same wiggly line is directly proportional to their distance apart on the lines, even though no eye movements are involved. An internal movement of focal attention, used to extract descriptive information, behaves as would be expected if metric distances and relations are preserved in