in Western societies have these skills become universal. It is unlikely that our brains have many innate resources for writing. Not only is the time-scale for such evolution too brief, but there has been too little selective pressure for a "writing instinct." There is no evidence that scribes produced more children than the illiterate aristocracy that employed them. As a consequence, reading and writing skills must draw on the working memory resources that evolved for visualizing. Evidence for this proposal is accumulating. Thus Brooks (1967) showed that the act of *reading* instructions interfered with a visualizing task, while *listening* to the same instructions did not. Reading can also interfere with comprehension. In an elegant series of studies Glass et al. (1985) asked their subjects either to read or to listen to high-imagery and to low-imagery sentences. They found that high-imagery sentences (e.g., "The stars on the American flag are white") take longer to verify than low-imagery sentences (e.g., "Biology is the study of living matter") when they are read, but *not* if they are heard.

Such findings should give educators pause for thought. Is it possible that the emphasis on teaching reading, writing, and arithmetic during the long period of postnatal brain growth diminishes our capacity to think with visual images? Is the postindustrial emphasis on thinking with symbols bought at the expense of thinking with images? Why do we teach all children to reason with symbols but only a few to reason with images? Perhaps one of the reasons for this imbalance in our use of cultural "mind-tools" is that we understand better how writing supports verbal thought than we understand how sketching supports visual thought. It is time to redress the balance. The ability to use untidy sketches to elicit and support our mental models is a difficult skill that we all deserve to be taught.

Description and Depiction: Interdependent Types

The cultural continuum

Twenty years ago, Palmer (1978) attempted to clarify what he considered to be muddled ideas about mental "representations," although these were (and are) central to theories of cognition. He defined a representation as an "ordered triple," consisting of a represented world, a representing world and an interpretive process that can map the first of these worlds on to the second. He then distinguished two fundamentally different systems of representation. One was the "propositional" (descriptive) system in which an arbitrary system of symbols with rules of combination (syntax) in the representing world can be mapped on to categories, propositions, and concepts in the representing world. The interpretive system must implement the rules that map the two worlds. The other was the "analogue" (depictive) system in which the representing world has varying degrees of structural similarity or isomorphism to the represented world. We can say roughly that these are "language-like" or "picture-like" representational classes. However, Palmer emphasized an interesting distinction. He termed the language-like or propositional representations "extrinsic" because the mechanisms by which they represent have to be learned and cannot be inferred from samples of the representations themselves. The other class of representations he termed "intrinsic" because, he argued, the interpretive process can be inferred from the isomorphisms within the representation itself.[3] However, there are other ways of distinguishing language-like and picture-like representations, all of which require discussion beyond the scope of this chapter (reviewed Fish 1996). Therefore, I will continue to use the vaguer but more widely understood terms "descriptive" and "depictive." Unlike descriptions, depictions are dependent on the medium of representation. Shepard (1982) has distinguished between depictions (analogue representations) with a "primary isomorphism" (as in pictures) where, for example, spatial structure is represented by similar spatial structure and colour by similar colour, with a "secondary isomorphism" in which the isomorphism is less direct. In Shepard's secondary isomorphisms, the relationship between the represented and the representing worlds is less direct, but corresponding attributes vary in corresponding ways and with similar dimensions. In contrast to descriptive systems, depictive systems cannot rely on rules of mapping but must infer representational meanings by analyzing the structure of the representation. For further discussion of these two contrasting systems, see Kosslyn (1980) and Sloman (1975).

Our culture provides us with a complex continuum of representational types that range from the very descriptive, such as language and mathematics, to the very depictive, such as film and photography or machine-generated "virtual reality." Sketches belong to a familiar class of intermediate types that possess both depictive and descriptive properties, as do maps and diagrams. Palmer pointed out that, in principle, a representational system can be infinitely extended using pointers and a hierarchical tree structure that allows descriptive and depictive systems to be combined. Thus a road map that represents space and distance depictively also contains positional descriptive symbols and these can be used as further look-up keys to descriptive or depictive information in a hierarchy of any arbitrarily determined depth. Ullman (1989) has suggested that a similar hierarchic system of depictive representations, combined with descriptive labels, might be used by the brain for object recognition.

Sketches differ from maps and diagrams in that much of the information they convey is only implicit and cannot be extracted either by analysis or by a rule system. I will argue that they are only partial representational systems that must be completed by the user's brain with which they interact. Their intermediate descriptive–depictive nature is shown by two characteristics: (1) viewer-centred depictive drawing is frequently mixed with descriptive notes and labels and (2) some of the representational elements used have both depictive and descriptive attributes. For example, the lines used to represent the silhouette contours of objects in sketches are partly descriptive. They do not exist in the pattern of luminances presented to the retinas of our eyes. Yet our visual systems seem to be able to use instinctively the information for object recognition they provide. According to a much respected model (Marr 1982), the visual system derives from the depictive image on the retina a description that can be used for comparison with stored models of objects in memory. At an early stage of processing, the brain uses a range of spatial frequency filters to extract and identify the silhouette edges of likely objects (Watt 1986). Marr calls these "the self-occluding contours" of objects. Thus the line contours found in drawings, from prehistoric times to today, probably work because they have a non-accidental correspondence with depictive to descriptive translation processes, performed by the early edge extraction stages of our visual brains (Fish 1996). Exactly how linear edge extraction works in drawings is still a subject of debate.