COGNITIVE TECHNOLOGY
Beyond the Naked Brain

8

8.1 Sketches
8.2 Discussion
(A) The Paradox of Active Stupidity (and a Bootstrapping Solution)
(B) Modules and Mechanisms
(C) Neural Prerequisites
(D) Cash Value
(E) The Bounds of Self
8.3 Suggested Readings

8.1 Sketches

We have come a long way. From the initial image of the mind as a symbol-crunching meat machine, to the delights of vector coding and subsymbolic artificial intelligence, on to the burgeoning complexities of real-world, real-time interactive systems. As the journey continued, one issue became ever more pressing: how to relate the insights gained from recent work in robotics, artificial life, and the study of situated cognition to the kinds of capacity and activity associated with so-called higher cognition? How, in short, to link the study of "embodied, environmentally embedded" cognition to the phenomena of abstract thought, advance planning, hypothetical reason, slow deliberation, and so on—the standard stomping grounds of more classical approaches.

In seeking such a link, there are two immediate options:

1. To embrace a deeply hybrid view of the inner computational engine itself. To depict the brain as the locus both of quick, dirty "online," environment-exploiting strategies and of a variety of more symbolic inner models affording varieties of "offline" reason.
2. To bet on the basic "bag of tricks" kind of strategy *all the way up*—to see the mechanisms of advanced reason as deeply continuous (no really new

architectures and features) with the kinds of mechanisms (of dynamic coupling, etc.) scouted in the last two chapters.

In this chapter I investigate a third option—or perhaps it is really just a subtly morphed combination of the two previous options.

3. To depict much of advanced cognition as rooted in the operation of the same basic kinds of capacity used for online, adaptive response, but tuned and applied to the special domain of *external and/or artificial cognitive aids*—the domain, as I shall say, of *wideware* or *cognitive technology*.

It helps, at this point, to abandon all pretense at unbiased discussion. For the interest in the relations between mind and cognitive technology lies squarely at the heart of my own research program, taking its cue from Dennett (1995, 1996), Hutchins (1995), Kirsh and Maglio (1994), Donald (2001 2010), Deheane (2009), and others.

The central idea is that mindfulness, or rather the special *kind* of mindfulness associated with the distinctive, top-level achievements of the human species, arises at the *productive collision points* of multiple factors and forces—some bodily, some neural, some technological, and some social and cultural. As a result, the project of understanding what is distinctive about human thought and reason may depend on a much broader focus than that to which cognitive science has become most accustomed: one that includes not just body, brain, and the natural world, but the props and aids (pens, papers, PCs, institutions) in which our biological brains learn, mature, and operate.

A short anecdote helps set the stage. Consider the expert bartender. Faced with multiple drink orders in a noisy and crowded environment, the expert mixes and dispenses drinks with amazing skill and accuracy. But what is the basis of this expert performance? Does it all stem from finely tuned memory and motor skills? By no means. In controlled psychological experiments comparing novice and expert bartenders (Beach, 1988, cited in Kirlik, 1998, p. 707), it becomes clear that expert skill involves a delicate interplay between internal and environmental factors. The experts select and array *distinctively shaped glasses* at the time of ordering. They then use these persistent cues so as to help recall and sequence the specific orders. Expert performance thus plummets in tests involving uniform glassware, whereas novice performances are unaffected by any such manipulations. The expert has learned to sculpt and exploit the working environment in ways that transform and simplify the task that confronts the biological brain.

Portions of the external world thus often function as a kind of extraneural memory store. We may deliberately leave a film on our desk to remind us to take it for developing. Or we may write a note "develop film" on paper and leave that on our desk instead. As users of words and texts, we command an especially cheap and potent means of offloading data and ideas from the biological brain onto a variety of external media. This trick, I think, is not to be underestimated. For it affects not just the quantity of data at our command, but also the kinds of operation we can bring to bear on it. Words, texts, symbols, and diagrams often figure *intimately* in the problem-solving routines developed by biological brains nurtured in language-rich environmental settings. Human brains, trained in a sea of words and text, will surely develop computational strategies that directly "factor in" the reliable presence of a wide variety of such external props and aids.

Take, for example, the process of writing an academic paper. You work long and hard and at days end you are happy. Being a good physicalist, you assume that all the credit for the final intellectual product belongs to your brain: the seat of human reason. But you are too generous by far. For what really happened was (perhaps) more like this. The brain supported some rereading of old texts, materials, and notes. While rereading these, it responded by generating a few fragmentary ideas and criticisms. These ideas and criticisms were then stored as more marks on paper, in margins, on computer discs, and so on. The brain then played a role in reorganizing these data on clean sheets, adding new online reactions and ideas. The cycle of reading, responding, and external reorganization is repeated, again and again. Finally, there is a product. A story, argument, or theory. But this intellectual product owes a lot to those repeated loops out into the environment. Credit belongs to the embodied, embedded agent in the world. The naked biological brain is just a part (albeit a crucial and special part) of a spatially and temporally extended process, involving lots of extraneural operations, whose joint action creates the intellectual product. There is thus a real sense (or so I would argue) in which the notion of the "problem-solving engine" is really the notion of the *whole caboodle* (see Box 8.1): the brain and body operating within an environmental setting.

One way to understand the cognitive role of many of our self-created cognitive technologies is as affording *complementary* operations to those that come naturally to biological brains. Thus recall the connectionist image of biological brains as pattern-completing engines (Chapter 4). Such devices are adept at linking patterns of current sensory input with associated information: you hear the first bars of the song and recall the rest, you see the rat's tail and conjure the image of the rat. Computational engines of that broad class prove extremely good at tasks such as sensorimotor coordination, face recognition, voice recognition, and so forth. But they are not well suited to deductive logic, planning, and the typical tasks of sequential reason (see Chapters 1 and 2). They are, roughly speaking, "Good at Frisbee, Bad at Logic"—a cognitive profile that is at once familiar and alien: familiar because human intelligence clearly has something of that flavor; alien because we repeatedly transcend these limits, planning vacations, solving complex sequential problems, et cetera.

One powerful hypothesis, which I first encountered in McClelland, Rumelhart, Smolensky, and Hinton (1986), is that we transcend these limits, in large part, by combining the internal operation of a connectionist, pattern-completing device with a variety of external operations and tools that serve to reduce the complex, sequential problems to an ordered set of simpler pattern-completing operations of the kind our brains are most comfortable with. Thus, to take a classic illustration, we may tackle the problem of long multiplication by using pen, paper, and

Box 8.1

The Talented Tuna and the Artful Archer Fish

Consider, by way of analogy, the idea of a swimming machine. In particular, consider the bluefin tuna. The tuna is paradoxically talented. Physical examination suggests it should not be able to achieve the aquatic feats of which it is demonstrably capable. It is physically too weak (by about a factor of 7) to swim as fast as it does, to turn as compactly as it does, to move off with the acceleration it does, and so on. The explanation (according to the fluid dynamicists M. and G. Triantafyllou) is that these fish actively create and exploit additional sources of propulsion and control in their watery environments. For example, the tuna use naturally occurring eddies and vortices to gain speed, and they flap their tails so as to actively create additional vortices and pressure gradients, which they then exploit for quick takeoffs and the like. The real swimming machine, I suggest, is thus the fish *in its proper context*—the fish plus the surrounding structures and vortices that it actively creates and then maximally exploits. The *cognitive machine*, in the human case, looks similarly extended (see also Dennett, 1995, Chapters 12 and 13). We humans actively create and exploit multiple external media, yielding a variety of encoding and manipulative opportunities whose reliable presence is then factored deep into our problem-solving strategies. (The tuna story is detailed in Triantafyllou and Triantafyllou, 1995, and further discussed in Clark, 1997).

The Archer Fish provides another example of the canny use of external structure. As first reported in Schlosser (1764), this fish (once known as the "jaculator") targets insect prey that are hanging on branches above a mangrove swamp, using a powerful jet of water that knocks them into the water ready for consumption. The insects are firmly planted on the branches and vegetation, and are by no means easy to budge. The Archer Fish manages to displace them only because the water jet at impact is estimated at a specific power of 3000 W/kg. This far exceeds the maximum force that can be applied by a vertebrate muscle (around 500 W/kg). For many years, researchers sought (in vain) for the internal structure that was somehow amplifying the force of the jet. Recently, however, the mystery was solved. Vailati et al. (2012) show that:

> . . . the amplification of muscular power occurs outside of the fish, and is due to a hydrodynamic instability of the jet akin to those occurring in Drop-on-Demand inkjet printing.
>
> (Vailati et al., 2012, p. 1)

Using high-speed video analysis, Vailati et al. show that the Archer Fish uses its mouth to manipulate the velocity of the jet during exit, favoring the

(continued)

formation of a single large drop at the head of the jet. This leading drop is inflated, as the squirting proceeds, by the trailing edge of the jet, allowing (via a process of axial compression) mass and momentum to transfer from the tail of the jet to the head. The upshot is that, courtesy of this "external hydrodynamic lever" (op. cit., p. 1), the head of the jet delivers a force far in excess of that which the nonmodified jet could deliver. In this way:

> . . . archer fish deploy an external mechanism for the amplification of muscular power, just like an archer does with his bow."
>
> (Vailati et al., 2012, p. 5)

numerical symbols. We then engage in a process of external symbol manipulations and storage so as to reduce the complex problem to a sequence of simple pattern-completing steps that we already command, first multiplying 9 by 7 and storing the result on paper, then 9 by 6, and so on.

The value of the use of pen, paper, and number symbols is thus that—in the words of Ed Hutchins, a cognitive anthropologist—

> [such tools] permit the [users] to do the tasks that need to be done while doing the kinds of things people are good at: recognizing patterns, modeling simple dynamics of the world, and manipulating objects in the environment. (Hutchins, 1995, p. 155)

A moment's reflection will reveal that this description nicely captures what is best about *good* examples of cognitive technology: recent word-processing packages, web browsers, mouse and icon systems, and so on. It also suggests, of course, what is wrong with many of our first attempts at creating such tools—the skills needed to use those environments (early VCRs, word-processors, etc.) were *precisely* those that biological brains find hardest to support, such as the recall and execution of long, essentially arbitrary, sequences of operations. See Norman (1999) for discussion.

It is similarly fruitful, I believe, to think of the practice of using words and linguistic labels as *itself* a kind of original "cognitive technology"—a potent add-on to our biological brain that literally transformed the space of human reason. We noted earlier the obvious (but still powerful and important) role of written inscriptions as both a form of external memory and an arena for new kinds of manipulative activity. But the very presence of words as *objects* has, I believe, some further, and generally neglected (though see Dennett, 1994, 1996), consequences. A word, then, on this further dimension.

Words can act as potent filters on the search space for a biological learning device. The idea, to a first approximation, is that learning to associate concepts with discrete arbitrary labels (words) makes it easier to use those concepts to constrain future search and hence enables the acquisition of a progressive cascade of more complex and increasingly abstract ideas. The claim (see also Clark and Thornton, 1997) is, otherwise put, that associating a perceptually simple, stable,

external item (such as a word) with an idea, concept, or piece of knowledge effectively freezes the concept into a sort of cognitive building block—an item that can then be treated as a simple baseline feature for future episodes of thought, learning, and search.

This broad conjecture (whose statistical and computational foundations are explored in Clark and Thornton, 1997) seems to be supported by some recent work on chimp cognition. Thompson, Oden, and Boyson (1997) studied problem solving in chimps (*Pan troglodytes*). What Thompson et al. showed is that chimps trained to use an arbitrary plastic marker (a yellow triangle, say) to designate pairs of identical objects (such as two identical cups), and to use a different marker (a red circle, say) to designate pairs of different objects (such as a shoe and a cup), are then able to learn to solve a new class of abstract problems. This is the class of problems—intractable to chimps not provided with the symbolic training—involving recognition of *higher order* relations of sameness and difference. Thus presented with two (different) pairs of identical items (two shoes and two cups, say) the higher-order task is to judge the pairs as exhibiting the *same* relation, in other words to judge that you have two instances of *sameness*. Examples of such higher-order judgments (which even human subjects can find hard to master at first) are shown in Table 8.1.

The token-trained chimps' success at this difficult task, it is conjectured, is explained by their experience with external tokens. For such experience may enable the chimp, on confronting, say, the pair of identical cups, to retrieve a mental representation of the *sameness* token (as it happens, a yellow triangle). Exposure to the two identical shoes will likewise cause retrieval of that token. At that point, the higher-order task is effectively reduced to the simple, lower-order task of identifying the two yellow plastic *tokens* as "the same."

Experience with external tags and labels thus enables the brain itself—by *representing* those tags and labels—to solve problems whose level of complexity and abstraction would otherwise leave us baffled—an intuitive result whose

TABLE 8.1 Higher Order Sameness and Difference

Cup/Cup	Shoe/Shoe
=	two instances of first-order sameness
=	an instance of higher order sameness
Cup/Shoe	**Cup/Shoe**
=	two instances of first-order sameness
=	an instance of higher order sameness
Cup/Shoe	**Cup/Cup**
=	one instance of first-order difference and one of first-order sameness
=	an instance of higher order difference

widespread applicability to human reason is increasingly evident (see Box 8.2). Learning a set of tags and labels (which we all do when we learn a language) is, we may thus speculate, rather closely akin to acquiring a new perceptual modality. For like a perceptual modality, it renders certain features of our world concrete and salient and allows us to target our thoughts (and learning algorithms) on a new domain of basic objects. This new domain compresses what were previously complex and unruly sensory patterns into simple objects. These simple objects can then be attended to in ways that quickly reveal further (otherwise hidden) patterns, as in the case of relations between relations. And of course the whole process is deeply iterative—we coin new words and labels to concretize regularities that we could only originally conceptualize as a result of a backdrop of other words and labels. The most powerful and familiar incarnation of this iterative strategy is, perhaps, the edifice of human science itself.

The example of the plastic token–trained chimps is thus just one instance of what might well be a rather general, and amazingly potent, effect (Dennett, 1994; Clark, 1998a). Once fluent in the use of tags, complex properties and relations in the perceptual array are, in effect, artificially reconstituted as simple inspectable wholes. The effect is to reduce the descriptive complexity of the scene. Kirsh (1995), describes the intelligent use of space in just these terms. When, for example, you group your shopping in one bag and mine in another, or when the cook places washed vegetables in one location and unwashed ones in another, the effect is to use spatial organization to simplify problem solving by using spatial proximity to reduce descriptive complexity. It is intuitive that once descriptive complexity is thus reduced, processes of selective attention, and of action control, can operate on elements of a scene that were previously too "unmarked" to define such operations. Experience with tags and labels may be a cheap way of achieving a similar result. Spatial organization reduces descriptive complexity by means of physical groupings that channel perception and action toward functional or appearance-based equivalence classes. Labels allow us to focus attention on all and only the items belonging to equivalence classes (the red shoes, the green apples, etc.). In this way, both linguistic and physical groupings allow selective attention to dwell on all and only the items belonging to the class. And the two resources were seen to work in close cooperation. Spatial groupings are used in teaching children the meanings of words, and mentally rehearsed words may be used to control activities of spatial grouping.

Simple labeling thus functions as a kind of "augmented reality"[1] trick by means of which we cheaply and open-endedly project new groupings and structures onto a perceived scene. Labeling is cheap since it avoids the physical effort of actually putting things into piles. And it is open-ended insofar as it can group in ways that defeat simple spatial display—for example, by allowing us to selectively attend to the four corners of a tabletop, an exercise that clearly cannot be performed

[1] An example of such a display would be the projection, on demand, of green arrows marking the route to a university library onto an eyeglasses-mounted display. The arrows would appear overlaid upon the actual local scene, and would update as the agent moves.

Box 8.2

Numerical Competence

Stanislas Dehaene and colleagues adduce a powerful body of evidence for a similar claim in the mathematical domain. Biological brains, they suggest, display an innate but fuzzy and low-level numerical competence, a capacity to represent simple numerosity (1-ness, 2-ness, 3-ness), an appreciation of "more," "less," and of change in quantity. But human mathematical thought, they argue, depends on a delicate interplay between this innate system for low-grade, approximate arithmetic and the new cultural tools provided by the development of language-based representations of numbers. The development of such new tools began, they argue, with the use of body parts to provide a means of "pinning down" quantities for which we have no precise innate representation.

More concretely, Dehaene, Spelke, Pinel, Stanescu, and Triskin (1999) depict mature human arithmetical competence as dependent on the combined (and interlocking) contributions of two distinct cognitive resources. One is an innate, parietal lobe–based tool for approximate numerical reasoning. The other is an acquired, left frontal lobe–based tool for the use of language-specific numerical representations in exact arithmetic. In support of this hypothesis the authors present evidence from studies of arithmetical reasoning in bilinguals, from studies of patients with differential damage to each of the two neural subsystems, and from neuroimaging studies of normal subjects engaged in exact and approximate numerical tasks. In this latter case, subjects performing the exact tasks show significant activity in the speech-related areas of the left frontal lobe, whereas the approximate tasks recruit bilateral areas of the parietal lobes implicated in visuospatial reasoning. These results are together presented as a demonstration "that exact calculation is language dependent, whereas approximation relies on nonverbal visuo-spatial cerebral network" (Dehaene et al., 1999, p. 970) and that "even within the small domain of elementary arithmetic, multiple mental representations are used for different tasks" (p. 973). What is interesting about this case is that here the additional props and scaffolding (the number names available in a specific natural language) are rerepresented internally, so the process recruits images of the external items for later use. This is similar to the story about the chimps' judgments about higher-order relations, but quite unlike the case of artistic sketching that I consider later in the chapter. Dehaene (1997) offers a book-length treatment of these ideas, linking them to the idea (which he later dubbed *neuronal re-cycling*—see Dehaene, 2004; Dehaene and Cohen, 2007) that well-suited preexisting brain structures are repurposed, by cultural evolution, to new ends. For a parallel, elegantly presented, story about reading, see Dehaene (2009).

by physical reorganization! Linguistic labels, on this view, are tools for grouping and in this sense act much like real spatial reorganization. But in addition (and unlike mere physical groupings) they effectively and open-endedly add new "virtual" items (the recalled labels themselves) to the scene. In this way, experience with tags and labels warps and reconfigures the problem spaces for the cognitive engine.

A related effect may also be observed in recent work on language learning. Thus in a recent review, Smith and Gasser (2005) ask a very nice question. Why, given that human beings are such experts at grounded, concrete, sensorimotor-driven forms of learning, do the symbol systems of public language take the special and rather rarified forms that they do?

> One might expect that a multimodal, grounded, sensorimotor sort of learning would favor a more iconic, pantomime-like language in which symbols were similar to referents. But language is decidedly not like this [. . .] there is no intrinsic similarity between the sounds of most words and their referents: the form of the word *dog* gives us no hints about the kind of thing to which it refers. And nothing in the similarity of the forms of *dig* and *dog* conveys a similarity in meaning. (Smith and Gasser, 2005, p. 22)

The question, in short, is, "Why in a so profoundly multimodal sensorimotor agent such as ourselves is language an arbitrary symbol system?" (op. cit. p. 24).

One possible answer, of course, is that language is like that because (biologically basic) *thought* is like that, and the forms and structures of language reflect this fact. But another answer says just the opposite. Language is like that, it might be suggested, because thought (or rather, biologically basic thought) is *not* like that. The computational value of a public system of essentially context-free, arbitrary symbols, lies, according to this opposing view, in the way such a system can push, pull, tweak, cajole, and eventually cooperate with various nonarbitrary, modality-rich, context-sensitive forms of biologically basic encoding.[2]

Direct cognitive benefits from linguaform encodings are also suggested by a study due to Hermer-Vazquez, Spelke, and Katsnelson (1999). Prelinguistic infants were shown the location of a toy or food in a room, then were spun around or otherwise disoriented and required to try to find the desired item. The location was uniquely determinable only by remembering conjoined cues concerning the color of the wall and its geometry (e.g., the toy might be hidden in the corner between the long wall and the short blue wall). The rooms were designed so that the geometric or color cues were individually insufficient and would yield an unambiguous result only when combined together. Prelinguistic infants, though perfectly able to detect and use both kinds of cue, were shown to exploit only the geometric information, searching randomly in each of the two geometrically indistinguishable sites. Yet adults and older children were easily capable of combining the geometric and nongeometric cues to solve the problem. Importantly, success at combining

[2]This picture fits nicely with Barsalou's account (see section 8.2 above) of the relation between public symbols and "perceptual symbol systems"—see Barsalou (2003), and (for a fuller story about perceptual symbol systems) Barsalou (1999).

the cues was not predicted by any measure of the children's intelligence or developmental stage except for the child's use of language. Only children who were able to spontaneously conjoin spatial and (e.g.) color terms in their speech (who would describe something as, say, to the right of the long green wall) were able to solve the problem. Hermer-Vazquez et al. (1999) then probed the role of language in this task by asking subjects to solve problems requiring the integration of geometric and nongeometric information while performing one of two other tasks. The first task involved shadowing (repeating back) speech played over headphones. The other involved shadowing, with their hands, a rhythm played over the headphones. The working memory demands of the latter task were at least as heavy as those of the former. Yet subjects engaged in speech shadowing were unable to solve the integration-demanding problem, while those shadowing rhythm were unaffected. An agent's linguistic abilities, the researchers concluded, are in some way (for discussion, see 8.2 B) indeed actively involved in their ability to solve problems requiring the integration of geometric and nongeometric information.

The augmentation of biological brains with linguaform resources may also shed light on another powerful and characteristic aspect of human thought, an aspect mentioned briefly in the introduction but then abandoned throughout the subsequent discussion. I have in mind our ability to engage in second-order discourse, to think about (and evaluate) our own thoughts. Thus consider a cluster of powerful capacities involving self-evaluation, self-criticism, and finely honed remedial responses.[3] Examples would include recognizing a flaw in our own plan or argument and dedicating further cognitive efforts to fixing it; reflecting on the unreliability of our own initial judgments in certain types of situations and proceeding with special caution as a result; coming to see why we reached a particular conclusion by appreciating the logical transitions in our own thought; thinking about the conditions under which we think best and trying to bring them about. The list could be continued, but the pattern should be clear. In all these cases we are effectively thinking about either our own cognitive profiles or about specific thoughts. This "thinking about thinking" is a good candidate for a distinctively human capacity—one not evidently shared by the other, non-language using animals who share our planet. As such, it is natural to wonder whether this might be an entire species of thought in which language plays the generative role, that is not just reflected in, or extended by, our use of words but is directly dependent on language for its very existence.

It is easy to see, in broad outline, how this might come about. For as soon as we formulate a thought in words (or on paper), it becomes an object for both ourselves and for others. As an object, it is the kind of thing we can have thoughts about. In creating the object we need have no thoughts about thoughts—but once it is there, the opportunity immediately exists to attend to it as an object in its own right. The process of linguistic formulation thus creates the stable structure to

[3]Some treatments that emphasize these themes include Changeux and Connes (1995), Bickerton (1995), de Villiers and de Villiers (2003), and Bermúdez (2005, Chapter 10).

which subsequent thinkings attach. Just such a twist on the potential role of the inner rehearsal of sentences has been presented by Jackendoff (1996), who suggests that the mental rehearsal of sentences may be the primary means by which our own thoughts are able to become objects of further attention and reflection. The emergence of such second-order cognitive dynamics is plausibly seen as one root of the veritable explosion of varieties of external technological scaffolding in human cultural evolution. It is because we can think about our own thinking that we can actively structure our world in ways designed to promote, support, and extend our own cognitive achievements. This process also feeds itself, as when the arrival of written text and notation allowed us to begin to fix ever more complex and extended sequences of thought and reason as objects for further scrutiny and attention.

As a final example of cognitive technology (wideware) in action, let us turn away from the case of words and text and symbol-manipulating tools (PCs, etc.) and consider the role of sketching in certain processes of artistic creation. Van Leeuwen, Verstijnen, and Hekkert (1999, p. 180) offer a careful account of the creation of abstract art, depicting it as heavily dependent on "an interactive process of imagining, sketching and evaluating [then resketching, reevaluating, etc.]." The question the authors pursue is, why the need to sketch? Why not simply imagine the final artwork "in the mind's eye" and then execute it directly on the canvas? The answer they develop, in great detail and using multiple real case studies, is that human thought is constrained, in mental imagery, in some very specific ways in which it is *not* constrained during online perception. In particular, our mental images seem to be more interpretively fixed: less enabling of the discovery of novel forms and components. Suggestive evidence for such constraints includes the intriguing demonstration (Chambers and Reisberg, 1985; see Box 8.3) that it is much harder to discover the second interpretation of an ambiguous figure in recall and imagination than when confronted with a real drawing. It is quite easy, by contrast, to compose imagined elements into novel wholes—for example, to imaginatively combine the letters D and J to form an umbrella (see Finke, Pinker, and Farah, 1989).

To accommodate both these sets of results, van Leeuwen et al. suggest that our imaginative (intrinsic) capacities do indeed support "synthetic transformations" in which components retain their shapes but are recombined into new wholes (as in the J + D = umbrella case), but lack the "analytic" capacity to decompose an imagined shape into wholly new components (as in the hourglasses-into-overlapping-parallelograms case shown in Figure 8.2). This is because (they speculate) the latter type of case (but not the former) requires us to first undo an existing shape interpretation.

Certain forms of abstract art, it is then argued, depend heavily on the deliberate creation of "multilayered meanings"—cases in which a visual form, on continued inspection, supports multiple different structural interpretations (see Figure 8.3). Given the postulated constraints on mental imagery, it is likely that the discovery of such multiply interpretable forms will depend heavily on the kind of trial-and-error process in which we first sketch and then perceptually (not imaginatively)

Box 8.3

Imaginative versus Perceptual "Flipping" of Ambiguous Images

Chambers and Reisberg (1985) asked subjects (with good imagistic capacities) to observe and recall a drawing. The drawing would be "flippable"—able to be seen as either one of two different things, though not as both at once. Famous examples include the duck/rabbit (shown below), the old lady/young lady image, the faces/vase image, and many others.

The experimenters chose a group of subjects ranged across a scale of "image vividness" as measured by Slee's Visual Elaboration scale (Slee, 1980). The subjects, who did not already know the duck/rabbit picture, were trained on related cases (Necker cubes, face/vase pictures) to ensure that they were familiar with the phenomenon in question. They were briefly shown the duck/rabbit and told to form a mental picture so that they could draw it later. They were then asked to attend to their mental image and to seek an alternative interpretation for it. Hints were given that they should try to shift their visual fixation from, e.g., lower left to upper right. Finally, they were asked to draw their image and to seek an alternative interpretation of their drawing. The results were surprising.

> Despite the inclusion of several "high vividness" imagers, none of the 15 subjects tested was able to reconstrue the imaged stimulus. . . . In sharp contrast, all 15 of the subjects were able to find the alternate construal in their own drawings. This makes clear that the subjects did have an adequate memory of the duck/rabbit figure and that they understood our reconstrual task.
>
> (Chambers and Reisberg, 1985, p. 321)

The moral, for our purposes, is that the subject's problem-solving capacities are significantly extended by the simple device of externalizing information (*drawing* the image from memory) and then confronting the external trace using online visual perception. This "loop into the world" allows the subject to find new interpretations, an activity that (see text) is plausibly central to certain forms of artistic creation. Artistic intelligence, it seems, is not "all in the head."

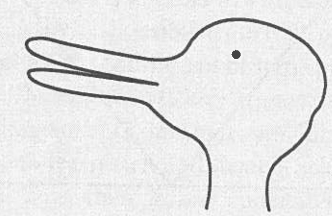

Figure 8.1 The Duck-Rabbit ambiguous image.

reencounter the forms, which we can then tweak and resketch so as to create an increasingly multilayered set of structural interpretations.

Thus understood, the use of the sketchpad is not just a convenience for the artist, nor simply a kind of external memory or durable medium for the storage of particular ideas. Instead, the iterated process of externalizing and reperceiving is

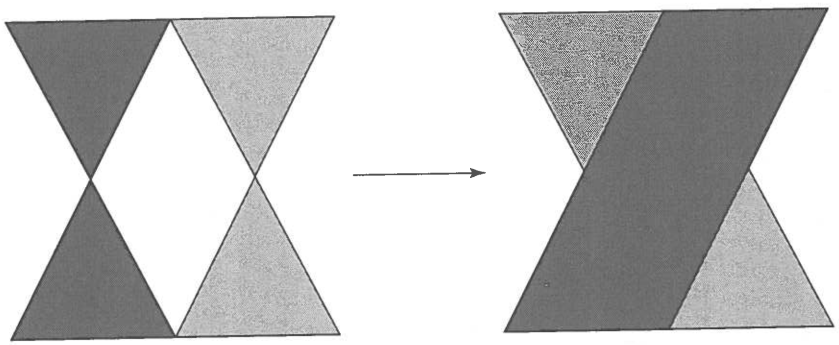

Figure 8.2 Novel decomposition as a form of analytic transformation that is hard to perform in imagery. The leftmost figure, initially synthesized from two hourglasses, requires a novel decomposition to be seen as two overlapping parallelograms. Reproduced from van Leeuwen et al. (1999) by kind permission of the authors and the publisher, University Press of America.

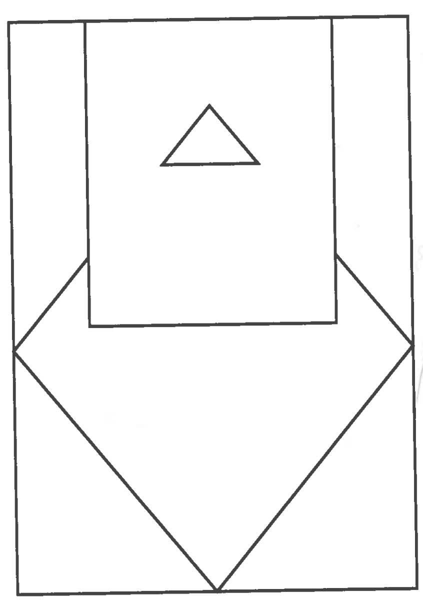

Figure 8.3 A simple example of the kind of multilayered structure found in certain types of abstract art. Reproduced from van Leeuwen et al. (1999) by kind permission of the authors and the publisher, University Press of America.

integral to the process of artistic cognition itself. A realistic computer simulation of the way human brains support this kind of artistic creativity would need likewise to avail itself of one (imaginative) resource supporting synthetic transformations, and another, environmentally looping, resource to allow its online perceptual systems to search the space of "analytic" transformations.

The conjecture, then, is that one large jump or discontinuity in human cognitive evolution involves the distinctive way human brains repeatedly create and exploit wideware—various species of cognitive technology able to expand and reshape the space of human reason. We, more than any other creature on the planet, deploy nonbiological wideware (instruments, media, notations) to *complement* our basic biological modes of processing, creating extended cognitive systems whose computational and problem-solving profiles are quite different from those of the naked brain.

8.2 Discussion

(A) THE PARADOX OF ACTIVE STUPIDITY (AND A BOOTSTRAPPING SOLUTION)

The most obvious problem, for any attempt to explain our distinctive smartness by appeal to a kind of symbiosis of brain and technology, lies in the threat of circularity. Surely, the worry goes, only intrinsically *smart* brains could have the knowledge and wherewithal to create such cognitive technologies in the first place. All that wideware cannot come from nowhere. This is what I shall call the *paradox of active stupidity*.

There is surely something to the worry. If humans are (as I have claimed) the only animal species to makes such widespread and interactive use of cognitive technologies, it seems likely that the explanation of this capacity turns, in some way, on distinctive features of the human brain (or perhaps the human brain and body; recall the once-popular stories about tool use and the opposable thumb). Let us be clear, then, that the conjecture scouted in the present chapter is not meant as a denial of the existence of certain crucial neural and/or bodily differences. Rather, my goal is to depict any such differences as the *seed*, rather than the full explanation, of our cognitive capabilities. The idea is that some relatively *small* neural (or neural/bodily) difference was the spark that lit a kind of intellectual forest fire. The brain is, let us assume, wholly responsible (courtesy, perhaps of some quite small tweak of the engineering) for the fulfillment of some precondition of cultural and technological evolution. Thus Deacon (1997) argues that human brains, courtesy of a disproportionate enlargement of our prefrontal lobes relative to the rest of our brains, are uniquely able to learn rich and flexible schemes associating arbitrary symbols with meanings. This, then, is one contender for the neural difference that makes human language acquisition possible, and language (of that type) is, quite plausibly, the fundamental "cognitive technology" (the UR-technology) that got the whole ball rolling. There are many alternative explanations (an especially