CHAPTER THREE

KNOWLEDGE IN THE HEAD AND IN THE WORLD

A friend kindly let me borrow his car, an older, classic Saab. Just before I was about to leave, I found a note waiting for me: "I should have mentioned that to get the key out of the ignition, the car needs to be in reverse." The car needs to be in reverse! If I hadn't seen the note, I never could have figured that out. There was no visible cue in the car: the knowledge needed for this trick had to reside in the head. If the driver lacks that knowledge, the key stays in the ignition forever.

Every day we are confronted by numerous objects, devices, and services, each of which requires us to behave or act in some particular manner. Overall, we manage quite well. Our knowledge is often quite incomplete, ambiguous, or even wrong, but that doesn't matter: we still get through the day just fine. How do we manage? We combine knowledge in the head with knowledge in the world. Why combine? Because neither alone will suffice.

It is easy to demonstrate the faulty nature of human knowledge and memory. The psychologists Ray Nickerson and Marilyn Adams showed that people do not remember what common coins look like (Figure 3.1). Even though the example is for the American one-cent piece, the penny, the finding holds true for currencies across the world. But despite our ignorance of the coins' appearance, we use our money properly.

Why the apparent discrepancy between the precision of behavior and the imprecision of knowledge? Because not all of the knowledge required for precise behavior has to be in the head. It can be distributed—partly in the head, partly in the world, and partly in the constraints of the world.

FIGURE 3.1. Which Is the US One-Cent Coin, the Penny? Fewer than half of the American college students who were given this set of drawings and asked to select the correct image could do so. Pretty bad performance, except that the students, of course, have no difficulty using the money. In normal life, we have to distinguish between the penny and other coins, not among several versions of one denomination. Although this is an old study using American coins, the results still hold true today using coins of any currency. (From Nickerson & Adams, 1979, *Cognitive Psychology*, 11 (3). Reproduced with permission of Academic Press via Copyright Clearance Center.)

Precise Behavior from Imprecise Knowledge

Precise behavior can emerge from imprecise knowledge for four reasons:

1. **Knowledge is both in the head and in the world.** Technically, knowledge can only be in the head, because knowledge requires interpretation and understanding, but once the world's structure has been interpreted and understood, it counts as knowledge. Much of the knowledge a person needs to do a task can be derived from the information in the world. Behavior is determined by combining the knowledge in the head with that in the world. For this chapter, I will use the term "knowledge" for both what is in the head and what is in the world. Although technically imprecise, it simplifies the discussion and understanding.
2. **Great precision is not required.** Precision, accuracy, and completeness of knowledge are seldom required. Perfect behavior results if the combined knowledge in the head and in the world is sufficient to distinguish an appropriate choice from all others.
3. **Natural constraints exist in the world.** The world has many natural, physical constraints that restrict the possible behavior: such things as the order in which parts can go together and the ways by which an object can be moved, picked up, or otherwise manipulated. This is knowledge in the world. Each object has physical features—projections, depressions, screw threads, appendages— that limit its relationships with other objects, the operations that can be performed on it, what can be attached to it, and so on.
4. **Knowledge of cultural constraints and conventions exists in the head.** Cultural constraints and conventions are learned artificial restrictions on behavior that reduce the set of likely actions, in many cases leaving only one or two possibilities. This is knowledge in the head. Once learned, these constraints apply to a wide variety of circumstances.

Because behavior can be guided by the combination of internal and external knowledge and constraints, people can minimize the amount of material they must learn, as well as the completeness, precision, accuracy, or depth of the learning. They also can deliberately organize the environment to support behavior. This is how nonreaders can hide their inability, even in situations where their job requires reading skills. People with hearing deficits (or with normal hearing but in noisy environments) learn to use other cues. Many of us manage quite well when in novel, confusing situations where we do not know what is expected of us. How do we do this? We arrange things so that we do not need to have complete knowledge or we rely upon the knowledge of the people around us, copying their behavior or getting them to do the required actions. It is actually quite amazing how often it is possible to hide one's ignorance, to get by without understanding or even much interest.

Although it is best when people have considerable knowledge and experience using a particular product—knowledge in the head— the designer can put sufficient cues into the design—knowledge in the world—that good performance results even in the absence of previous knowledge. Combine the two, knowledge in the head and in the world, and performance is even better. How can the designer put knowledge into the device itself?

Chapters 1 and 2 introduced a wide range of fundamental design principles derived from research on human cognition and emotion. This chapter shows how knowledge in the world combines with knowledge in the head. Knowledge in the head is knowledge in the human memory system, so this chapter contains a brief review of the critical aspects of memory necessary for the design of usable products. I emphasize that for practical purposes, we do not need to know the details of scientific theories but simpler, more general, useful approximations. Simplified models are the key to successful application. The chapter concludes with a discussion of how natural mappings present information in the world in a manner readily interpreted and usable.

KNOWLEDGE IS IN THE WORLD

Whenever knowledge needed to do a task is readily available in the world, the need for us to learn it diminishes. For example, we lack knowledge about common coins, even though we recognize them just fine (Figure 3.1). In knowing what our currency looks like, we don't need to know all the details, simply sufficient knowledge to distinguish one value of currency from another. Only a small minority of people must know enough to distinguish counterfeit from legitimate money.

Or consider typing. Many typists have not memorized the keyboard. Usually each key is labeled, so nontypists can hunt and peck letter by letter, relying on knowledge in the world and minimizing the time required for learning. The problem is that such typing is slow and difficult. With experience, of course, hunt-and-peckers learn the positions of many of the letters on the keyboard, even without instruction, and typing speed increases notably, quickly surpassing handwriting speeds and, for some, reaching quite respectable rates. Peripheral vision and the feel of the keyboard provide some knowledge about key locations. Frequently used keys become completely learned, infrequently used keys are not learned well, and the other keys are partially learned. But as long as a typist needs to watch the keyboard, the speed is limited. The knowledge is still mostly in the world, not in the head.

If a person needs to type large amounts of material regularly, further investment is worthwhile: a course, a book, or an interactive program. The important thing is to learn the proper placement of fingers on the keyboard, to learn to type without looking, to get knowledge about the keyboard from the world into the head. It takes a few weeks to learn the system and several months of practice to become expert. But the payoff for all this effort is increased typing speed, increased accuracy, and decreased mental load and effort at the time of typing.

We only need to remember sufficient knowledge to let us get our tasks done. Because so much knowledge is available in the environment, it is surprising how little we need to learn. This is one reason people can function well in their environment and still be unable to describe what they do.

People function through their use of two kinds of knowledge: knowledge *of* and knowledge *how*. Knowledge *of*—what psychologists call *declarative knowledge*—includes the knowledge of facts and rules. “Stop at red traffic lights.” “New York City is north of Rome.” “China has twice as many people as India.” “To get the key out of the ignition of a Saab car, the gearshift must be in reverse.” Declarative knowledge is easy to write and to teach. Note that knowledge of the rules does not mean they are followed. The drivers in many cities are often quite knowledgeable about the official driving regulations, but they do not necessarily obey them. Moreover, the knowledge does not have to be true. New York City is actually south of Rome. China has only slightly more people than India (roughly 10 percent). People may know many things: that doesn’t mean they are true.

Knowledge *how*—what psychologists call *procedural knowledge*—is the knowledge that enables a person to be a skilled musician, to return a serve in tennis, or to move the tongue properly when saying the phrase “frightening witches.” Procedural knowledge is difficult or impossible to write down and difficult to teach. It is best taught by demonstration and best learned through practice. Even the best teachers cannot usually describe what they are doing. Procedural knowledge is largely subconscious, residing at the behavioral level of processing.

Knowledge in the world is usually easy to come by. Signifiers, physical constraints, and natural mappings are all perceivable cues that act as knowledge in the world. This type of knowledge occurs so commonly that we take it for granted. It is everywhere: the locations of letters on a keyboard; the lights and labels on controls that remind us of their purpose and give information about the current state of the device. Industrial equipment is replete with signal lights, indicators, and other reminders. We make extensive use of written notes. We place items in specific locations as reminders. In general, people structure their environment to provide a considerable amount of the knowledge required for something to be remembered.

Many organize their lives spatially in the world, creating a pile here, a pile there, each indicating some activity to be done, some event in progress. Probably everybody uses such a strategy to some extent. Look around you at the variety of ways people arrange their rooms and desks. Many styles of organization are possible, but invariably the physical layout and visibility of the items convey information about relative importance.

WHEN PRECISION IS UNEXPECTEDLY REQUIRED

Normally, people do not need precision in their judgments. All that is needed is the combination of knowledge in the world and in the head that makes decisions unambiguous. Everything works just fine unless the environment changes so that the combined knowledge is no longer sufficient: this can lead to havoc. At least three countries discovered this fact the hard way: the United States, when it introduced the Susan B. Anthony one-dollar coin; Great Britain, a one-pound coin (before the switch to decimal currency); and France, a ten-franc coin (before the conversion to the common European currency, the euro). The US dollar coin was confused with the existing twenty-five-cent piece (the quarter), and the British pound coin with the then five-pence piece that had the same diameter. Here is what happened in France:

> *PARIS With a good deal of fanfare, the French government released the new 10-franc coin (worth a little more than $1.50) on Oct. 22 [1986]. The public looked at it, weighed it, and began confusing it so quickly with the half-franc coin (worth only 8 cents) that a crescendo of fury and ridicule fell on both the government and the coin.*
>
> *Five weeks later, Minister of Finance Edouard Balladur suspended circulation of the coin. Within another four weeks, he canceled it altogether.*
>
> *In retrospect, the French decision seems so foolish that it is hard to fathom how it could have been made. After much study, designers came up with a silver-colored coin made of nickel and featuring a modernistic drawing by artist Joaquim Jimenez of a Gallic rooster on one side and of Marianne, the female symbol of the French republic, on the other. The coin was light, sported special ridges on its rim for easy reading by electronic vending machines and seemed tough to counterfeit.*
>
> *But the designers and bureaucrats were obviously so excited by their creation that they ignored or refused to accept the new coin's similarity to the hundreds of millions of silver-colored, nickel-based half-franc coins in circulation [whose] size and weight were perilously similar.* (Stanley Meisler. Copyright © 1986, *Los Angeles Times*. Reprinted with permission.)

The confusions probably occurred because the users of coins had already formed representations in their memories that were only sufficiently precise to distinguish among the coins that they were accustomed to using. Psychological research suggests that people maintain only partial descriptions of the things to be remembered. In the three examples of new coins introduced in the United States, Great Britain, and France, the descriptions formed to distinguish among national currency were not precise enough to distinguish between a new coin and at least one of the old coins.

Suppose I keep all my notes in a small red notebook. If this is my only notebook, I can describe it simply as "my notebook." If I buy several more notebooks, the earlier description will no longer work. Now I must identify the first one as small or red, or maybe both small and red, whichever allows me to distinguish it from the others. But what if I acquire several small red notebooks? Now I must find some other means of describing the first book, adding to the richness of the description and to its ability to discriminate among the several similar items. Descriptions need discriminate only among the choices in front of me, but what works for one purpose may not for another.

Not all similar-looking items cause confusion. In updating this edition of the book, I searched to see whether there might be more recent examples of coin confusions. I found this interesting item on the website Wikicoins.com:

> *Someday, a leading psychologist may weigh in on one of the perplexing questions of our time: if the American public was constantly confusing the Susan B. Anthony dollar with the roughly similar-sized quarter, how come they weren't also constantly confusing the $20 bill with the identical-sized $1 bill?* (James A. Capp, "Susan B. Anthony Dollar," at www.wikicoins.com. Retrieved May 29, 2012)

Here is the answer. Why not any confusion? We learn to discriminate among things by looking for distinguishing features. In the United States, size is one major way of distinguishing among coins, but not among paper money. With paper money, all the bills are the same size, so Americans ignore size and look at the printed numbers and images. Hence, we often confuse similar-size American coins but only seldom confuse similar-size American bills. But people who come from a country that uses size and color of their paper money to distinguish among the amounts (for example, Great Britain or any country that uses the euro) have learned to use size and color to distinguish among paper money and therefore are invariably confused when dealing with bills from the United States.

More confirmatory evidence comes from the fact that although long-term residents of Britain complained that they confused the one-pound coin with the five-pence coin, newcomers (and children) did not have the same confusion. This is because the long-term residents were working with their original set of descriptions, which did not easily accommodate the distinctions between these two coins. Newcomers, however, started off with no preconceptions and therefore formed a set of descriptions to distinguish among all the coins; in this situation, the one-pound coin offered no particular problem. In the United States, the Susan B. Anthony dollar coin never became popular and is no longer being made, so the equivalent observations cannot be made.

What gets confused depends heavily upon history: the aspects that have allowed us to distinguish among the objects in the past. When the rules for discrimination change, people can become confused and make errors. With time, they will adjust and learn to discriminate just fine and may even forget the initial period of confusion. The problem is that in many circumstances, especially one as politically charged as the size, shape, and color of currency, the public's outrage prevents calm discussion and does not allow for any adjustment time.

Consider this as an example of design principles interacting with the messy practicality of the real world. What appears good in principle can sometimes fail when introduced to the world. Sometimes, bad products succeed and good products fail. The world is complex.

CONSTRAINTS SIMPLIFY MEMORY

Before widespread literacy, and especially before the advent of sound recording devices, performers traveled from village to village, reciting epic poems thousands of lines long. This tradition still exists in some societies. How do people memorize such voluminous amounts of material? Do some people have huge amounts of knowledge in their heads? Not really. It turns out that external constraints exert control over the permissible choice of words, thus dramatically reducing the memory load. One of the secrets comes from the powerful constraints of poetry.

Consider the constraints of rhyming. If you wish to rhyme one word with another, there are usually a lot of alternatives. But if you must have a word with a particular meaning to rhyme with another, the joint constraints of meaning and rhyme can cause a dramatic reduction in the number of possible candidates, sometimes reducing a large set to a single choice. Sometimes there are no candidates at all. This is why it is much easier to memorize poetry than to create poems. Poems come in many different forms, but all have formal restrictions on their construction. The ballads and tales told by the traveling storytellers used multiple poetic constraints, including rhyme, rhythm, meter, assonance, alliteration, and onomatopoeia, while also remaining consistent with the story being told.

Consider these two examples:

> *One. I am thinking of three words: one means "a mythical being," the second is "the name of a building material," and the third is "a unit of time." What words do I have in mind?*
>
> *Two. This time look for rhyming words. I am thinking of three words: one rhymes with "post," the second with "eel," and the third with "ear." What words am I thinking of?* (From Rubin & Wallace, 1989.)

In both examples, even though you might have found answers, they were not likely to be the same three that I had in mind. There simply are not enough constraints. But suppose I now tell you that the words I seek are the same in both tasks: What is a word that means a mythical being and rhymes with "post"? What word is the name of a building material and rhymes with "eel"? And what word is a unit of time and rhymes with "ear"? Now the task is easy: the joint specification of the words completely constrains the selection. When the psychologists David Rubin and Wanda Wallace studied these examples in their laboratory, people almost never got the correct meanings or rhymes for the first two tasks, but most people correctly answered, “ghost,” “steel,” and “year” in the combined task.

The classic study of memory for epic poetry was done by Albert Bates Lord. In the mid-1900s he traveled throughout the former Yugoslavia (now a number of separate, independent countries) and found people who still followed the oral tradition. He demonstrated that the “singer of tales,” the person who learns epic poems and goes from village to village reciting them, is really re-creating them, composing poetry on the fly in such a way that it obeys the rhythm, theme, story line, structure, and other characteristics of the poem. This is a prodigious feat, but it is not an example of rote memory.

The power of multiple constraints allows one singer to listen to another singer tell a lengthy tale once, and then after a delay of a few hours or a day, to recite “the same song, word for word, and line for line.” In fact, as Lord points out, the original and new recitations are not the same word for word, but both teller and listener perceive them as the same, even when the second version was twice as long as the first. They are the same in the ways that matter to the listener: they tell the same story, express the same ideas, and follow the same rhyme and meter. They are the same in all senses that matter to the culture. Lord shows just how the combination of memory for poetics, theme, and style combines with cultural structures into what he calls a “formula” for producing a poem perceived as identical to earlier recitations.

The notion that someone should be able to recite word for word is relatively modern. Such a notion can be held only after printed texts become available; otherwise who could judge the accuracy of a recitation? Perhaps more important, who would care?

All this is not to detract from the feat. Learning and reciting an epic poem, such as Homer’s *Odyssey* and *Iliad*, is clearly difficult even if the singer is re-creating it: there are twenty-seven thousand lines of verse in the combined written version. Lord points out that this length is excessive, probably produced only during the special circumstances in which Homer (or some other singer) dictated the story slowly and repetitively to the person who first wrote it down. Normally the length would be varied to accommodate the whims of the audience, and no normal audience could sit through twenty-seven thousand lines. But even at one-third the size, nine thousand lines, being able to recite the poem is impressive: at one second per line, the verses would take two and one-half hours to recite. It is impressive even allowing for the fact that the poem is re-created as opposed to memorized, because neither the singer nor the audience expect word-for-word accuracy (nor would either have any way of verifying that).

Most of us do not learn epic poems. But we do make use of strong constraints that serve to simplify what must be retained in memory. Consider an example from a completely different domain: taking apart and reassembling a mechanical device.

Typical items in the home that an adventuresome person might attempt to repair include a door lock, toaster, and washing machine. The device is apt to have tens of parts. What has to be remembered to be able to put the parts together again in a proper order? Not as much as might appear from an initial analysis. In the extreme case, if there are ten parts, there are 10! (ten factorial) different ways in which to reassemble them—a little over 3.5 million alternatives.

But few of these possibilities are possible: there are numerous physical constraints on the ordering. Some pieces must be assembled before it is even possible to assemble the others. Some pieces are physically constrained from fitting into the spots reserved for others: bolts must fit into holes of an appropriate diameter and depth; nuts and washers must be paired with bolts and screws of appropriate sizes; and washers must always be put on before nuts. There are even cultural constraints: we turn screws clockwise to tighten, counterclockwise to loosen; the heads of screws tend to go on the visible part (front or top) of a piece, bolts on the less visible part (bottom, side, or interior); wood screws and machine screws look different and are inserted into different kinds of materials. In the end, the apparently large number of decisions is reduced to only a few choices that should have been learned or otherwise noted during the disassembly. The constraints by themselves are often not sufficient to determine the proper reassembly of the device—mistakes do get made—but the constraints reduce the amount that must be learned to a reasonable quantity. Constraints are powerful tools for the designer: they are examined in detail in Chapter 4.

Memory Is Knowledge in the Head

An old Arabic folk tale, "'Ali Baba and the Forty Thieves," tells how the poor woodcutter 'Ali Baba discovered the secret cave of a band of thieves. 'Ali Baba overheard the thieves entering the cave and learned the secret phrase that opened the cave: "Open Simsim." (*Simsim* means "sesame" in Persian, so many versions of the story translate the phrase as "Open Sesame.") 'Ali Baba's brother-in-law, Kasim, forced him to reveal the secret. Kasim then went to the cave.

> *When he reached the entrance of the cavern, he pronounced the words, Open Simsim!*
>
> *The door immediately opened, and when he was in, closed on him. In examining the cave he was greatly astonished to find much more riches than he had expected from 'Ali Baba's relation.*
>
> *He quickly laid at the door of the cavern as many bags of gold as his ten mules could carry, but his thoughts were now so full of the great riches he should possess, that he could not think of the necessary words to make the door open. Instead of Open Simsim! he said Open Barley! and was much amazed to find that the door remained shut. He named several sorts of grain, but still the door would not open.*
>
> *Kasim never expected such an incident, and was so alarmed at the danger he was in that the more he endeavoured to remember the word Simsim the more his memory was confounded, and he had as much forgotten it as if he had never heard it mentioned.*

Kasim never got out. The thieves returned, cut off Kasim's head, and quartered his body. (From Colum's 1953 edition of *The Arabian Nights.)*

Most of us will not get our head cut off if we fail to remember a secret code, but it can still be very hard to recall the code. It is one thing to have to memorize one or two secrets: a combination, or a password, or the secret to opening a door. But when the number of secret codes gets too large, memory fails. There seems to be a conspiracy, one calculated to destroy our sanity by overloading our memory. Many codes, such as postal codes and telephone numbers, exist primarily to make life easier for machines and their designers without any consideration of the burden placed upon people. Fortunately, technology has now permitted most of us to avoid having to remember this arbitrary knowledge but to let our technology do it for us: phone numbers, addresses and postal codes, Internet and e-mail addresses are all retrievable automatically, so we no longer have to learn them. Security codes, however, are a different matter, and in the never-ending, escalating battle between the white hats and the black, the good guys and the bad, the number of different arbitrary codes we must remember or special security devices we must carry with us continues to escalate in both number and complexity.

Many of these codes must be kept secret. There is no way that we can learn all those numbers or phrases. Quick: what magical command was Kasim trying to remember to open the cavern door?

How do most people cope? They use simple passwords. Studies show that five of the most common passwords are: "password," "123456," "12345678," "qwerty," and "abc123." All of these are clearly selected for easy remembering and typing. All are therefore easy for a thief or mischief-maker to try. Most people (including me) have a small number of passwords that they use on as many different sites as possible. Even security professionals admit to this, thereby hypocritically violating their own rules.

Many of the security requirements are unnecessary, and needlessly complex. So why are they required? There are many reasons. One is that there are real problems: criminals impersonate identities to steal people's money and possessions. People invade others' privacy, for nefarious or even harmless purposes. Professors and teachers need to safeguard examination questions and grades. For companies and nations, it is important to maintain secrets. There are lots of reasons to keep things behind locked doors or password-protected walls. The problem, however, is the lack of proper understanding of human abilities.

We do need protection, but most of the people who enforce the security requirements at schools, businesses, and government are technologists or possibly law-enforcement officials. They understand crime, but not human behavior. They believe that "strong" passwords, ones difficult to guess, are required, and that they must be changed frequently. They do not seem to recognize that we now need so many passwords—even easy ones—that it is difficult to remember which goes with which requirement. This creates a new layer of vulnerability.

The more complex the password requirements, the less secure the system. Why? Because people, unable to remember all these combinations, write them down. And then where do they store this private, valuable knowledge? In their wallet, or taped under the computer keyboard, or wherever it is easy to find, because it is so frequently needed. So a thief only has to steal the wallet or find the list and then all secrets are known. Most people are honest, concerned workers. And it is these individuals that complex security systems impede the most, preventing them from getting their work done. As a result, it is often the most dedicated employee who violates the security rules and weakens the overall system.

When I was doing the research for this chapter, I found numerous examples of secure passwords that force people to use insecure memory devices for them. One post on the "Mail Online" forum of the British *Daily Mail* newspaper described the technique:

> *When I used to work for the local government organisation we HAD TO change our Passwords every three months. To ensure I could remember it, I used to write it on a Post-It note and stick it above my desk.*

How can we remember all these secret things? Most of us can't, even with the use of mnemonics to make some sense of nonsensical material. Books and courses on improving memory can work, but the methods are laborious to learn and need continual practice to maintain. So we put the memory in the world, writing things down in books, on scraps of paper, even on the backs of our hands. But we disguise them to thwart would-be thieves. That creates another problem: How do we disguise the items, how do we hide them, and how do we remember what the disguise was or where we put it? Ah, the foibles of memory.

Where should you hide something so that nobody else will find it? In unlikely places, right? Money is hidden in the freezer; jewelry in the medicine cabinet or in shoes in the closet. The key to the front door is hidden under the mat or just below the window ledge. The car key is under the bumper. The love letters are in a flower vase. The problem is, there aren't that many unlikely places in the home. You may not remember where the love letters or keys are hidden, but your burglar will. Two psychologists who examined the issue described the problem this way:

> *There is often a logic involved in the choice of unlikely places. For example, a friend of ours was required by her insurance company to acquire a safe if she wished to insure her valuable gems. Recognizing that she might forget the combination to the safe, she thought carefully about where to keep the combination. Her solution was to write it in her personal phone directory under the letter S next to "Mr. and Mrs. Safe," as if it were a telephone number. There is a clear logic here: Store numerical information with other numerical information. She was appalled, however, when she*

> *heard a reformed burglar on a daytime television talk show say that upon encountering a safe, he always headed for the phone directory because many people keep the combination there.* (From Winograd & Soloway, 1986, "On Forgetting the Locations of Things Stored in Special Places." Reprinted with permission.)

All the arbitrary things we need to remember add up to unwitting tyranny. It is time for a revolt. But before we revolt, it is important to know the solution. As noted earlier, one of my self-imposed rules is, "Never criticize unless you have a better alternative." In this case, it is not clear what the better system might be.

Some things can only be solved by massive cultural changes, which probably means they will never be solved. For example, take the problem of identifying people by their names. People's names evolved over many thousands of years, originally simply to distinguish people within families and groups who lived together. The use of multiple names (given names and surnames) is relatively recent, and even those do not distinguish one person from all the seven billion in the world. Do we write the given name first, or the surname? It depends upon what country you are in. How many names does a person have? How many characters in a name? What characters are legitimate? For example, can a name include a digit? (I know people who have tried to use such names as "h3nry." I know of a company named "Autonom3.")

How does a name translate from one alphabet to another? Some of my Korean friends have given names that are identical when written in the Korean alphabet, Hangul, but that are different when transliterated into English.

Many people change their names when they get married or divorced, and in some cultures, when they pass significant life events. A quick search on the Internet reveals multiple questions from people in Asia who are confused about how to fill out American or European passport forms because their names don't correspond to the requirements.

And what happens when a thief steals a person's identity, masquerading as the other individual, using his or her money and credit? In the United States, these identity thieves can also apply for income tax rebates and get them, and when the legitimate taxpayers try to get their legitimate refund, they are told they already received it.

I once attended a meeting of security experts that was held at the corporate campus of Google. Google, like most corporations, is very protective of its processes and advanced research projects, so most of the buildings were locked and guarded. Attendees of the security meeting were not allowed access (except those who worked at Google, of course). Our meetings were held in a conference room in the public space of an otherwise secure building. But the toilets were all located inside a secure area. How did we manage? These world-famous, leading authorities on security figured out a solution: They found a brick and used it to prop open the door leading into the secure area. So much for security: Make something too secure, and it becomes less secure.

How do we solve these problems? How do we guarantee people's access to their own records, bank accounts, and computer systems? Almost any scheme you can imagine has already been proposed, studied, and found to have defects. Biometric markers (iris or retina patterns, fingerprints, voice recognition, body type, DNA)? All can be forged or the systems' databases manipulated. Once someone manages to fool the system, what recourse is there? It isn't possible to change biometric markers, so once they point to the wrong person, changes are extremely difficult to make.

The strength of a password is actually pretty irrelevant because most passwords are obtained through "key loggers" or are stolen. A key logger is software hidden within your computer system that records what you type and sends it to the bad guys. When computer systems are broken into, millions of passwords might get stolen, and even if they are encrypted, the bad guys can often decrypt them. In both these cases, however secure the password, the bad guys know what it is.

The safest methods require multiple identifiers, the most common schemes requiring at least two different kinds: "something you have" plus "something you know." The "something you have" is often a physical identifier, such as a card or key, perhaps even something implanted under the skin or a biometric identifier, such as fingerprints or patterns of the eye's iris. The "something you know" would be knowledge in the head, most likely something memorized. The memorized item doesn't have to be as secure as today's passwords because it wouldn't work without the "something you have." Some systems allow for a second, alerting password, so that if the bad guys try to force someone to enter a password into a system, the individual would use the alerting one, which would warn the authorities of an illegal entry.

Security poses major design issues, ones that involve complex technology as well as human behavior. There are deep, fundamental difficulties. Is there a solution? No, not yet. We will probably be stuck with these complexities for a long time.

The Structure of Memory

> *Say aloud the numbers 1, 7, 4, 2, 8. Next, without looking back, repeat them. Try again if you must, perhaps closing your eyes, the better to "hear" the sound still echoing in mental activity. Have someone read a random sentence to you. What were the words? The memory of the just present is available immediately, clear and complete, without mental effort.*
>
> *What did you eat for dinner three days ago? Now the feeling is different. It takes time to recover the answer, which is neither as clear nor as complete a remembrance as that of the just present, and the recovery is likely to require considerable mental effort. Retrieval of the past differs from retrieval of the just present. More effort is required, less clarity results. Indeed, the "past" need not be so long ago. Without looking back, what were those digits? For some people, this retrieval now takes time and effort.* (From *Learning and Memory*, Norman, 1982.)

Psychologists distinguish between two major classes of memory: short-term or working memory, and long-term memory. The two are quite different, with different implications for design.

SHORT-TERM OR WORKING MEMORY

Short-term or working memory (STM) retains the most recent experiences or material that is currently being thought about. It is the memory of the just present. Information is retained automatically and retrieved without effort; but the amount of information that can be retained this way is severely limited. Something like five to seven items is the limit of STM, with the number going to ten or twelve if the material is continually repeated, what psychologists call "rehearsing."

Multiply 27 times 293 in your head. If you try to do it the same way you would with paper and pencil, you will almost definitely be unable to hold all the digits and intervening answers within STM. You will fail. The traditional method of multiplying is optimized for paper and pencil. There is no need to minimize the burden on working memory because the numbers written on the paper serve this function (knowledge in the world), so the burden on STM, on knowledge in the head, is quite limited. There are ways of doing mental multiplication, but the methods are quite different from those using paper and pencil and require considerable training and practice.

Short-term memory is invaluable in the performance of everyday tasks, in letting us remember words, names, phrases, and parts of tasks: hence its alternative name, working memory. But the material being maintained in STM is quite fragile. Get distracted by some other activity and, poof, the stuff in STM disappears. It is capable of holding a postal code or telephone number from the time you look it up until the time it is used—as long as no distractions occur. Nine- or ten-digit numbers give trouble, and when the number starts to exceed that—don't bother. Write it down. Or divide the number into several shorter segments, transforming the long number into meaningful chunks.

Memory experts use special techniques, called *mnemonics*, to remember amazingly large amounts of material, often after only a single exposure. One method is to transform the digits into meaningful segments (one famous study showed how an athlete thought of digit sequences as running times, and after refining the method over a long period, could learn incredibly long sequences at one glance). One traditional method used to encode long sequences of digits is to first transform each digit into a consonant, then transform the consonant sequence into a memorable phrase. A standard table of conversions of digits to consonants has been around for hundreds of years, cleverly designed to be easy to learn because the consonants can be derived from the shape of the digits. Thus, "1" is translated into "t" (or the similar-sounding "d"), "2" becomes "n," "3" becomes "m," "4" is "r," and "5" becomes "L" (as in the Roman numeral for 50). The full table and the mnemonics for learning the pairings are readily found on the Internet by searching for "number-consonant mnemonic."

Using the number-consonant transformation, the string 4194780135092770 translates into the letters *rtbrkfstmlspncks*, which in turn may become, “A hearty breakfast meal has pancakes.” Most people are not experts at retaining long arbitrary strings of anything, so although it is interesting to observe memory wizards, it would be wrong to design systems that assumed this level of proficiency.

The capacity of STM is surprisingly difficult to measure, because how much can be retained depends upon the familiarity of the material. Retention, moreover, seems to be of meaningful items, rather than of some simpler measure such as seconds or individual sounds or letters. Retention is affected by both time and the number of items. The number of items is more important than time, with each new item decreasing the likelihood of remembering all of the preceding items. The capacity is items because people can remember roughly the same number of digits and words, and almost the same number of simple three- to five-word phrases. How can this be? I suspect that STM holds something akin to a pointer to an already encoded item in long-term memory, which means the memory capacity is the number of pointers it can keep. This would account for the fact that the length or complexity of the item has little impact—simply the number of items. It doesn’t neatly account for the fact that we make acoustical errors in STM, unless the pointers are held in a kind of acoustical memory. This remains an open topic for scientific exploration.

The traditional measures of STM capacity range from five to seven, but from a practical point of view, it is best to think of it as holding only three to five items. Does that seem too small a number? Well, when you meet a new person, do you always remember his or her name? When you have to dial a phone number, do you have to look at it several times while entering the digits? Even minor distractions can wipe out the stuff we are trying to hold on to in STM.

What are the design implications? Don’t count on much being retained in STM. Computer systems often enhance people’s frustration when things go wrong by presenting critical information in a message that then disappears from the display just when the person wishes to make use of the information. So how can people remember the critical information? I am not surprised when people hit, kick, or otherwise attack their computers.

I have seen nurses write down critical medical information about their patients on their hands because the critical information would disappear if the nurse was distracted for a moment by someone asking a question. The electronic medical records systems automatically log out users when the system does not appear to be in use. Why the automatic logouts? To protect patient privacy. The cause may be well motivated, but the action poses severe challenges to nurses who are continually being interrupted in their work by physicians, co-workers, or patient requests. While they are attending to the interruption, the system logs them out, so they have to start over again. No wonder these nurses wrote down the knowledge, although this then negated much of the value of the computer system in minimizing handwriting errors. But what else were they to do? How else to get at the critical information? They couldn't remember it all: that's why they had computers.

The limits on our short-term memory systems caused by interfering tasks can be mitigated by several techniques. One is through the use of multiple sensory modalities. Visual information does not much interfere with auditory, actions do not interfere much with either auditory or written material. Haptics (touch) is also minimally interfering. To maximize efficiency of working memory it is best to present different information over different modalities: sight, sound, touch (haptics), hearing, spatial location, and gestures. Automobiles should use auditory presentation of driving instructions and haptic vibration of the appropriate side of the driver's seat or steering wheel to warn when drivers leave their lanes, or when there are other vehicles to the left or right, so as not to interfere with the visual processing of driving information. Driving is primarily visual, so the use of auditory and haptic modalities minimizes interference with the visual task.

LONG-TERM MEMORY

Long-term memory (LTM) is memory for the past. As a rule, it takes time for information to get into LTM and time and effort to get it out again. Sleep seems to play an important role in strengthening the memories of each day's experiences. Note that we do not remember our experiences as an exact recording; rather, as bits and pieces that are reconstructed and interpreted each time we recover the memories, which means they are subject to all the distortions and changes that the human explanatory mechanism imposes upon life. How well we can ever recover experiences and knowledge from LTM is highly dependent upon how the material was interpreted in the first place. What is stored in LTM under one interpretation probably cannot be found later on when sought under some other interpretation. As for how large the memory is, nobody really knows: giga- or tera-items. We don't even know what kinds of units should be used. Whatever the size, it is so large as not to impose any practical limit.

The role of sleep in the strengthening of LTM is still not well understood, but there are numerous papers investigating the topic. One possible mechanism is that of rehearsal. It has long been known that rehearsal of material—mentally reviewing it while still active in working memory (STM)—is an important component of the formation of long-term memory traces. "Whatever makes you rehearse during sleep is going to determine what you remember later, and conversely, what you're going to forget," said Professor Ken Paller of Northwestern University, one of the authors of a recent study on the topic (Oudiette, Antony, Creery, and Paller, 2013). But although rehearsal in sleep strengthens memories, it might also falsify them: "Memories in our brain are changing all of the time. Sometimes you improve memory storage by rehearsing all the details, so maybe later you remember better—or maybe worse if you've embellished too much."

Remember how you answered this question from Chapter 2?

> *In the house you lived in three houses ago, as you entered the front door, was the doorknob on the left or right?*

For most people, the question requires considerable effort just to recall which house is involved, plus one of the special techniques described in Chapter 2 for putting yourself back at the scene and reconstructing the answer. This is an example of procedural memory, a memory for how we do things, as opposed to declarative memory, the memory for factual information. In both cases, it can take considerable time and effort to get to the answer. Moreover, the answer is not directly retrieved in a manner analogous to the way we read answers from books or websites. The answer is a reconstruction of the knowledge, so it is subject to biases and distortions. Knowledge in memory is meaningful, and at the time of retrieval, a person might subject it to a different meaningful interpretation than is wholly accurate.

A major difficulty with LTM is in organization. How do we find the things we are trying to remember? Most people have had the "tip of the tongue" experience when trying to remember a name or word: there is a feeling of knowing, but the knowledge is not consciously available. Sometime later, when engaged in some other, different activity, the name may suddenly pop into the conscious mind. The way by which people retrieve the needed knowledge is still unknown, but probably involves some form of pattern-matching mechanism coupled with a confirmatory process that checks for consistency with the required knowledge. This is why when you search for a name but continually retrieve the wrong name, you know it is wrong. Because this false retrieval impedes the correct retrieval, you have to turn to some other activity to allow the subconscious memory retrieval process to reset itself.

Because retrieval is a reconstructive process, it can be erroneous. We may reconstruct events the way we would prefer to remember them, rather than the way we experienced them. It is relatively easy to bias people so that they form false memories, "remembering" events in their lives with great clarity, even though they never occurred. This is one reason that eyewitness testimony in courts of law is so problematic: eyewitnesses are notoriously unreliable. A huge number of psychological experiments show how easy it is to implant false memories into people's minds so convincingly that people refuse to admit that the memory is of an event that never happened.

Knowledge in the head is actually knowledge in memory: internal knowledge. If we examine how people use their memories and how they retrieve knowledge, we discover a number of categories. Two are important for us now:

1. **Memory for arbitrary things.** The items to be retained seem arbitrary, with no meaning and no particular relationship to one another or to things already known.
2. **Memory for meaningful things.** The items to be retained form meaningful relationships with themselves or with other things already known.

MEMORY FOR ARBITRARY AND MEANINGFUL THINGS

Arbitrary knowledge can be classified as the simple remembering of things that have no underlying meaning or structure. A good example is the memory of the letters of the alphabet and their ordering, the names of people, and foreign vocabulary, where there appears to be no obvious structure to the material. This also applies to the learning of the arbitrary key sequences, commands, gestures, and procedures of much of our modern technology: This is rote learning, the bane of modern existence.

Some things do require rote learning: the letters of the alphabet, for example, but even here we add structure to the otherwise meaningless list of words, turning the alphabet into a song, using the natural constraints of rhyme and rhythm to create some structure.

Rote learning creates problems. First, because what is being learned is arbitrary, the learning is difficult: it can take considerable time and effort. Second, when a problem arises, the memorized sequence of actions gives no hint of what has gone wrong, no suggestion of what might be done to fix the problem. Although some things are appropriate to learn by rote, most are not. Alas, it is still the dominant method of instruction in many school systems, and even for much adult training. This is how some people are taught to use computers, or to cook. It is how we have to learn to use some of the new (poorly designed) gadgets of our technology.

We learn arbitrary associations or sequences by artificially providing structure. Most books and courses on methods for improving memory (mnemonics) use a variety of standard methods for providing structure, even for things that might appear completely arbitrary, such as grocery lists, or matching the names of people to their appearance. As we saw in the discussion of these methods for STM, even strings of digits can be remembered if they can be associated with meaningful structures. People who have not received this training or who have not invented some methods themselves often try to manufacture some artificial structure, but these are often rather unsatisfactory, which is why the learning is so bad.

Most things in the world have a sensible structure, which tremendously simplifies the memory task. When things make sense, they correspond to knowledge that we already have, so the new material can be understood, interpreted, and integrated with previously acquired material. Now we can use rules and constraints to help understand what things go together. Meaningful structure can organize apparent chaos and arbitrariness.

Remember the discussion of conceptual models in Chapter 1? Part of the power of a good conceptual model lies in its ability to provide meaning to things. Let’s look at an example to show how a meaningful interpretation transforms an apparently arbitrary task into a natural one. Note that the appropriate interpretation may not at first be obvious; it, too, is knowledge and has to be discovered.

A Japanese colleague, Professor Yutaka Sayeki of the University of Tokyo, had difficulty remembering how to use the turn signal switch on his motorcycle's left handlebar. Moving the switch forward signaled a right turn; backward, a left turn. The meaning of the switch was clear and unambiguous, but the direction in which it should be moved was not. Sayeki kept thinking that because the switch was on the left handlebar, pushing it forward should signal a left turn. That is, he was trying to map the action "push the left switch forward" to the intention "turn left," which was wrong. As a result, he had trouble remembering which switch direction should be used for which turning direction. Most motorcycles have the turn-signal switch mounted differently, rotated 90 degrees, so that moving it left signals a left turn; moving it right, a right turn. This mapping is easy to learn (it is an example of a natural mapping, discussed at the end of this chapter). But the turn switch on Sayeki's motorcycle moved forward and back, not left and right. How could he learn it?

Sayeki solved the problem by reinterpreting the action. Consider the way the handlebars of the motorcycle turn. For a left turn, the left handlebar moves backward. For a right turn, the left handlebar moves forward. The required switch movements exactly paralleled the handlebar movements. If the task is conceptualized as signaling the direction of motion of the handlebars rather than the direction of the motorcycle, the switch motion can be seen to mimic the desired motion; finally we have a natural mapping.

When the motion of the switch seemed arbitrary, it was difficult to remember. Once Professor Sayeki had invented a meaningful relationship, he found it easy to remember the proper switch operation. (Experienced riders will point out that this conceptual model is wrong: to turn a bike, one first steers in the opposite direction of the turn. This is discussed as Example 3 in the next section, "Approximate Models.")

The design implications are clear: provide meaningful structures. Perhaps a better way is to make memory unnecessary: put the required information in the world. This is the power of the traditional graphical user interface with its old-fashioned menu structure. When in doubt, one could always examine all the menu items until the desired one was found. Even systems that do not use menus need to provide some structure: appropriate constraints and forcing functions, natural good mapping, and all the tools of feedforward and feedback. The most effective way of helping people remember is to make it unnecessary.

Approximate Models: Memory in the Real World

Conscious thinking takes time and mental resources. Well-learned skills bypass the need for conscious oversight and control: conscious control is only required for initial learning and for dealing with unexpected situations. Continual practice automates the action cycle, minimizing the amount of conscious thinking and problem-solving required to act. Most expert, skilled behavior works this way, whether it is playing tennis or a musical instrument, or doing mathematics and science. Experts minimize the need for conscious reasoning. Philosopher and mathematician Alfred North Whitehead stated this principle over a century ago:

> *It is a profoundly erroneous truism, repeated by all copy-books and by eminent people when they are making speeches, that we should cultivate the habit of thinking of what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them.* (Alfred North Whitehead, 1911.)

One way to simplify thought is to use simplified models, approximations to the true underlying state of affairs. Science deals in truth, practice deals with approximations. Practitioners don't need truth: they need results relatively quickly that, although inaccurate, are "good enough" for the purpose to which they will be applied. Consider these examples:

EXAMPLE 1: CONVERTING TEMPERATURES BETWEEN FAHRENHEIT AND CELSIUS

It is now 55°F outside my home in California. What temperature is it in Celsius? Quick, do it in your head without using any technology: What is the answer?

I am sure all of you remember the conversion equation:

$$°C = (°F–32) \times 5 / 9$$

Plug in 55 for °F, and ºC = (55–32) × 5 / 9 = 12.8°. But most people can't do this without pencil and paper because there are too many intermediate numbers to maintain in STM.

Want a simpler way? Try this approximation—you can do it in your head, there is no need for paper or pencil:

$$°C = (°F–30) / 2$$

Plug in 55 for °F, and ºC = (55–30) / 2 = 12.5º. Is the equation an exact conversion? No, but the approximate answer of 12.5 is close enough to the correct value of 12.8. After all, I simply wanted to know whether I should wear a sweater. Anything within 5ºF of the real value would work for this purpose.

Approximate answers are often good enough, even if technically wrong. This simple approximation method for temperature conversion is "good enough" for temperatures in the normal range of interior and outside temperatures: it is within 3ºF (or 1.7ºC) in the range of –5º to 25ºC (20º to 80ºF). It gets further off at lower or higher temperatures, but for everyday use, it is wonderful. Approximations are good enough for practical use.

EXAMPLE 2: A MODEL OF SHORT-TERM MEMORY

Here is an approximate model for STM:

> *There are five memory slots in short-term memory. Each time a new item is added, it occupies a slot, knocking out whatever was there beforehand.*

Is this model true? No, not a single memory researcher in the entire world believes this to be an accurate model of STM. But it is good enough for applications. Make use of this model, and your designs will be more usable.

EXAMPLE 3: STEERING A MOTORCYCLE

In the preceding section, we learned how Professor Sayeki mapped the turning directions of his motorcycle to his turn signals, enabling him to remember their correct usage. But there, I also pointed out that the conceptual model was wrong.

Why is the conceptual model for steering a motorcycle useful even though it is wrong? Steering a motorcycle is counterintuitive: to turn to the left, the handlebars must first be turned to the right. This is called countersteering, and it violates most people's conceptual models. Why is this true? Shouldn't we rotate the handlebars left to turn the bike left? The most important component of turning a two-wheeled vehicle is lean: when the bike is turning left, the rider is leaning to the left. Countersteering causes the rider to lean properly: when the handlebars are turned to the right, the resulting forces upon the rider cause the body to lean left. This weight shift then causes the bike to turn left.

Experienced riders often do the correct operations subconsciously, unaware that they start a turn by rotating the handlebars opposite from the intended direction, thus violating their own conceptual models. Motorcycle training courses have to conduct special exercises to convince riders that this is what they are doing.

You can test this counterintuitive concept on a bicycle or motorcycle by getting up to a comfortable speed, placing the palm of the hand on the end of the left handlebar, and gently pushing it forward. The handlebars and front wheel will turn to the right and the body will lean to the left, resulting in the bike—and the handlebars— turning to the left.

Professor Sayeki was fully aware of this contradiction between his mental scheme and reality, but he wanted his memory aid to match his conceptual model. Conceptual models are powerful explanatory devices, useful in a variety of circumstances. They do not have to be accurate as long as they lead to the correct behavior in the desired situation.

EXAMPLE 4: "GOOD ENOUGH" ARITHMETIC

Most of us can't multiply two large numbers in our head: we forget where we are along the way. Memory experts can multiply two large numbers quickly and effortlessly in their heads, amazing audiences with their skills. Moreover, the numbers come out left to right, the way we use them, not right to left, as we write them while laboriously using pencil and paper to compute the answers. These experts use special techniques that minimize the load on working memory, but they do so at the cost of having to learn numerous special methods for different ranges and forms of problems.

Isn't this something we should all learn? Why aren't school systems teaching this? My answer is simple: Why bother? I can estimate the answer in my head with reasonable accuracy, often good enough for the purpose. When I need precision and accuracy, well, that's what calculators are for.

Remember my earlier example, to multiply 27 times 293 in your head? Why would anyone need to know the precise answer? an approximate answer is good enough, and pretty easy to get. Change 27 to 30, and 293 to 300: 30 × 300 = 9,000 (3 × 3 = 9, and add back the three zeros). The accurate answer is 7,911, so the estimate of 9,000 is only 14 percent too large. In many instances, this is good enough. Want a bit more accuracy? We changed 27 to 30 to make the multiplication easier. That's 3 too large. So subtract 3 × 300 from the answer (9,000 – 900). Now we get 8,100, which is accurate within 2 percent.

It is rare that we need to know the answers to complex arithmetic problems with great precision: almost always, a rough estimate is good enough. When precision is required, use a calculator. That's what machines are good for: providing great precision. For most purposes, estimates are good enough. Machines should focus on solving arithmetic problems. People should focus on higher-level issues, such as the reason the answer was needed.

Unless it is your ambition to become a nightclub performer and amaze people with great skills of memory, here is a simpler way to dramatically enhance both memory and accuracy: write things down. Writing is a powerful technology: why not use it? Use a pad of paper, or the back of your hand. Write it or type it. Use a phone or a computer. Dictate it. This is what technology is for.

The unaided mind is surprisingly limited. It is things that make us smart. Take advantage of them.

SCIENTIFIC THEORY VERSUS EVERYDAY PRACTICE

Science strives for truth. As a result, scientists are always debating, arguing, and disagreeing with one another. The scientific method is one of debate and conflict. Only ideas that have passed through the critical examination of multiple other scientists survive. This continual disagreement often seems strange to the nonscientist, for it appears that scientists don't know anything. Select almost any topic, and you will discover that scientists who work in that area are continually disagreeing.

But the disagreements are illusory. That is, most scientists usually agree about the broad details: their disagreements are often about tiny details that are important for distinguishing between two competing theories, but that might have very little impact in the real world of practice and applications.

In the real, practical world, we don't need absolute truth: approximate models work just fine. Professor Sayeki's simplified conceptual model of steering his motorcycle enabled him to remember which way to move the switches for his turn signals; the simplified equation for temperature conversion and the simplified model of approximate arithmetic enabled "good enough" answers in the head. The simplified model of STM provides useful design guidance, even if it is scientifically wrong. Each of these approximations is wrong, yet all are valuable in minimizing thought, resulting in quick, easy results whose accuracy is "good enough."

Knowledge in the Head

Knowledge in the world, external knowledge, is a valuable tool for remembering, but only if it is available at the right place, at the right time, in the appropriate situation. Otherwise, we must use knowledge in the head, in the mind. A folk saying captures this situation well: "Out of sight, out of mind." Effective memory uses all the clues available: knowledge in the world and in the head, combining world and mind. We have already seen how the combination allows us to function quite well in the world even though either source of knowledge, by itself, is insufficient.

HOW PILOTS REMEMBER WHAT AIR-TRAFFIC CONTROL TELLS THEM

Airplane pilots have to listen to commands from air-traffic control delivered at a rapid pace, and then respond accurately. Their lives depend upon being able to follow the instructions accurately. One website, discussing the problem, gave this example of instructions to a pilot about to take off for a flight:

> *Frasca 141, cleared to Mesquite airport, via turn left heading 090, radar vectors to Mesquite airport. Climb and maintain 2,000. Expect 3,000 10 minutes after departure. Departure frequency 124.3, squawk 5270.*
>
> (Typical Air traffic control sequence, usually spoken extremely rapidly. Text from "ATC Phraseology," on numerous websites, with no credit for originator.)

"How can we remember all that," asked one novice pilot, "when we are trying to focus on taking off?" Good question. Taking off is a busy, dangerous procedure with a lot going on, both inside and outside the airplane. How do pilots remember? Do they have superior memories?

Pilots use three major techniques:

1. They write down the critical information.
2. They enter it into their equipment as it is told to them, so minimal memory is required.
3. They remember some of it as meaningful phrases.

Although to the outside observer, all the instructions and numbers seem random and confusing, to the pilots they are familiar names, familiar numbers. As one respondent pointed out, those are common numbers and a familiar pattern for a takeoff. “Frasca 141” is the name of the airplane, announcing the intended recipient of these instructions. The first critical item to remember is to turn left to a compass direction of 090, then climb to an altitude of 2,000 feet. Write those two numbers down. Enter the radio frequency 124.3 into the radio as you hear it—but most of the time this frequency is known in advance, so the radio is probably already set to it. All you have to do is look at it and see that it is set properly. Similarly, setting the “squawk box to 5270” is the special code the airplane sends whenever it is hit by a radar signal, identifying the airplane to the air-traffic controllers. Write it down, or set it into the equipment as it is being said. As for the one remaining item, “Expect 3,000 10 minutes after departure,” nothing need be done. This is just reassurance that in ten minutes, Frasca 141 will probably be advised to climb to 3,000 feet, but if so, there will be a new command to do so.

How do pilots remember? They transform the new knowledge they have just received into memory in the world, sometimes by writing, sometimes by using the airplane’s equipment.

The design implication? The easier it is to enter the information into the relevant equipment as it is heard, the less chance of memory error. The air-traffic control system is evolving to help. The instructions from the air-traffic controllers will be sent digitally, so that they can remain displayed on a screen as long as the pilot wishes. The digital transmission also makes it easy for automated equipment to set itself to the correct parameters. Digital transmission of the controller’s commands has some disadvantages, however. Other aircraft will not hear the commands, which reduces pilot awareness of what all the airplanes in the vicinity are going to do. Researchers in air-traffic control and aviation safety are looking into these issues. Yes, it’s a design issue.

REMINDING: PROSPECTIVE MEMORY

The phrases *prospective memory* or *memory for the future* might sound counterintuitive, or perhaps like the title of a science-fiction novel, but to memory researchers, the first phrase simply denotes the task of remembering to do some activity at a future time. The second phrase denotes planning abilities, the ability to imagine future scenarios. Both are closely related.

Consider reminding. Suppose you have promised to meet some friends at a local café on Wednesday at three thirty in the afternoon. The knowledge is in your head, but how are you going to remember it at the proper time? You need to be reminded. This is a clear instance of prospective memory, but your ability to provide the required cues involves some aspect of memory for the future as well. Where will you be Wednesday just before the planned meeting? What can you think of now that will help you remember then?

There are many strategies for reminding. One is simply to keep the knowledge in your head, trusting yourself to recall it at the critical time. If the event is important enough, you will have no problem remembering it. It would be quite strange to have to set a calendar alert to remind yourself, "Getting married at 3 PM."

Relying upon memory in the head is not a good technique for commonplace events. Ever forget a meeting with friends? It happens a lot. Not only that, but even if you might remember the appointment, will you remember all the details, such as that you intended to loan a book to one of them? Going shopping, you may remember to stop at the store on the way home, but will you remember all the items you were supposed to buy?

If the event is not personally important and several days away, it is wise to transfer some of the burden to the world: notes, calendar reminders, special cell phone or computer reminding services. You can ask friends to remind you. Those of us with assistants put the burden on them. They, in turn, write notes, enter events on calendars, or set alarms on their computer systems.

Why burden other people when we can put the burden on the thing itself? Do I want to remember to take a book to a colleague? I put the book someplace where I cannot fail to see it when I leave the house. A good spot is against the front door so that I can't leave without tripping over it. Or I can put my car keys on it, so when I leave, I am reminded. Even if I forget, I can't drive away without the keys. (Better yet, put the keys under the book, else I might still forget the book.)

There are two different aspects to a reminder: the signal and the message. Just as in doing an action we can distinguish between knowing *what* can be done and knowing *how* to do it, in reminding we must distinguish between the *signal*—knowing that something is to be remembered, and the *message*—remembering the information itself. Most popular reminding methods typically provide only one or the other of these two critical aspects. The famous "tie a string around your finger" reminder provides only the signal. It gives no hint of what is to be remembered. Writing a note to yourself provides only the message; it doesn't remind you ever to look at it. The ideal reminder has to have both components: the signal that something is to be remembered, and then the message of what it is.

The signal that something is to be remembered can be a sufficient memory cue if it occurs at the correct time and place. Being reminded too early or too late is just as useless as having no reminder. But if the reminder comes at the correct time or location, the environmental cue can suffice to provide enough knowledge to aid retrieval of the to-be-remembered item. Time-based reminders can be effective: the *bing* of my cell phone reminds me of the next appointment. Location-based reminders can be effective in giving the cue at the precise place where it will be needed. All the knowledge needed can reside in the world, in our technology.

The need for timely reminders has created loads of products that make it easier to put the knowledge in the world—timers, diaries, calendars. The need for electronic reminders is well known, as the proliferation of apps for smart phones, tablets, and other portable devices attests. Yet surprisingly in this era of screen-based devices, paper tools are still enormously popular and effective, as the number of paper-based diaries and reminders indicates.

The sheer number of different reminder methods also indicates that there is indeed a great need for assistance in remembering, but that none of the many schemes and devices is completely satisfactory. After all, if any one of them was, then we wouldn't need so many. The less effective ones would disappear and new schemes would not continually be invented.

The Tradeoff Between Knowledge in the World and in the Head

Knowledge in the world and knowledge in the head are both essential in our daily functioning. But to some extent we can choose to lean more heavily on one or the other. That choice requires a tradeoff—gaining the advantages of knowledge in the world means losing the advantages of knowledge in the head (Table 3.1).

Knowledge in the world acts as its own reminder. It can help us recover structures that we otherwise would forget. Knowledge in the head is efficient: no search and interpretation of the environment is required. The tradeoff is that to use our knowledge in the head, we have to be able to store and retrieve it, which might require considerable amounts of learning. Knowledge in the world requires no learning, but can be more difficult to use. And it relies heavily upon the continued physical presence of the knowledge; change the environment and the knowledge might be lost. Performance relies upon the physical stability of the task environment.

TABLE 3.1. Tradeoffs Between Knowledge in the World and in the Head

Knowledge in the World	Knowledge in the Head
Information is readily and easily available whenever perceivable.	Material in working memory is readily available. Otherwise considerable search and effort may be required.

Interpretation substitutes for learning. How easy it is to interpret knowledge in the world depends upon the skill of the designer.	Requires learning, which can be considerable. Learning is made easier if there is meaning or structure to the material or if there is a good conceptual model.
Slowed by the need to find and interpret the knowledge.	Can be efficient, especially if so well-learned that it is automated.
Ease of use at first encounter is high.	Ease of use at first encounter is low.
Can be ugly and inelegant, especially if there is a need to maintain a lot of knowledge. This can lead to clutter. Here is where the skills of the graphics and industrial designer play major roles.	Nothing needs to be visible, which gives more freedom to the designer. This leads to cleaner, more pleasing appearance—at the cost of ease of use at first encounter, learning, and remembering.

As we just discussed, reminders provide a good example of the relative tradeoffs between knowledge in the world versus in the head. Knowledge in the world is accessible. It is self-reminding. It is always there, waiting to be seen, waiting to be used. That is why we structure our offices and our places of work so carefully. We put piles of papers where they can be seen, or if we like a clean desk, we put them in standardized locations and teach ourselves (knowledge in the head) to look in these standard places routinely. We use clocks and calendars and notes. Knowledge in the mind is ephemeral: here now, gone later. We can't count on something being present in mind at any particular time, unless it is triggered by some external event or unless we deliberately keep it in mind through constant repetition (which then prevents us from having other conscious thoughts). Out of sight, out of mind.

As we move away from many physical aids, such as printed books and magazines, paper notes, and calendars, much of what we use today as knowledge in the world will become invisible. Yes, it will all be available on display screens, but unless the screens always show this material, we will have added to the burden of memory in the head. We may not have to remember all the details of the information stored away for us, but we will have to remember that it is there, that it needs to be redisplayed at the appropriate time for use or for reminding.

Memory in Multiple Heads, Multiple Devices

If knowledge and structure in the world can combine with knowledge in the head to enhance memory performance, why not use the knowledge in multiple heads, or in multiple devices?

Most of us have experienced the power of multiple minds in remembering things. You are with a group of friends trying to remember the name of a movie, or perhaps a restaurant, and failing. But others try to help. The conversation goes something like this:

"That new place where they grill meat"

"Oh, the Korean barbecue on Fifth Street?"

"No, not Korean, South American, um,"

"Oh, yeah, Brazilian, it's what's its name?"

"Yes, that's the one!"

"Pampas something."

"Yes, Pampas Chewy. Um, Churry, um,"

"Churrascaria. Pampas Churrascaria."

How many people are involved? It could be any number, but the point is that each adds their bit of knowledge, slowly constraining the choices, recalling something that no single one of them could have done alone. Daniel Wegner, a Harvard professor of psychology, has called this "transactive memory."

Of course, we often turn to technological aids to answer our questions, reaching for our smart devices to search our electronic resources and the Internet. When we expand from seeking aids from other people to seeking aids from our technologies, which Wegner labels as "cybermind," the principle is basically the same. The cybermind doesn't always produce the answer, but it can produce sufficient clues so that we can generate the answer. Even where the technology produces the answer, it is often buried in a list of potential answers, so we have to use our own knowledge— or the knowledge of our friends—to determine which of the potential items is the correct one.

What happens when we rely too much upon external knowledge, be it knowledge in the world, knowledge of friends, or knowledge provided by our technology? On the one hand, there no such thing as "too much." The more we learn to use these resources, the better our performance. External knowledge is a powerful tool for enhanced intelligence. On the other hand, external knowledge is often erroneous: witness the difficulties of trusting online sources and the controversies that arise over Wikipedia entries. It doesn't matter where our knowledge comes from. What matters is the quality of the end result.

In an earlier book, *Things That Make Us Smart*, I argued that it is this combination of technology and people that creates super-powerful beings. Technology does not make us smarter. People do not make technology smart. It is the combination of the two, the person plus the artifact, that is smart. Together, with our tools, we are a powerful combination. On the other hand, if we are suddenly without these external devices, then we don't do very well. In many ways, we do become less smart.

Take away their calculator, and many people cannot do arithmetic. Take away a navigation system, and people can no longer get around, even in their own cities. Take away a phone's or computer's address book, and people can no longer reach their friends (in my case, I can no longer remember my own phone number). Without a keyboard, I can't write. Without a spelling corrector, I can't spell.

What does all of this mean? Is this bad or good? It is not a new phenomenon. Take away our gas supply and electrical service and we might starve. Take away our housing and clothes and we might freeze. We rely on commercial stores, transportation, and government services to provide us with the essentials for living. Is this bad?

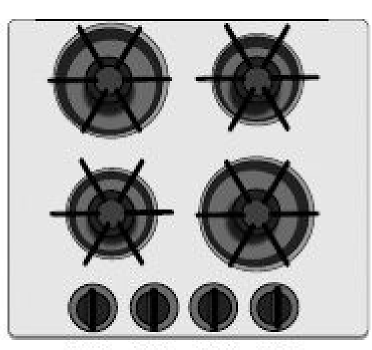
The partnership of technology and people makes us smarter, stronger, and better able to live in the modern world. We have become reliant on the technology and we can no longer function without it. The dependence is even stronger today than ever before, including mechanical, physical things such as housing, clothing, heating, food preparation and storage, and transportation. Now this range of dependencies is extended to information services as well: communication, news, entertainment, education, and social interaction. When things work, we are informed, comfortable, and effective. When things break, we may no longer be able to function. This dependence upon technology is very old, but every decade, the impact covers more and more activities.

Natural Mapping

Mapping, a topic from Chapter 1, provides a good example of the power of combining knowledge in the world with that in the head. Did you ever turn the wrong burner of a stove on or off? You would think that doing it correctly would be an easy task. A simple control turns the burner on, controls the temperature, and allows the burner to be turned off. In fact, the task appears to be so simple that when people do it wrong, which happens more frequently than you might have thought, they blame themselves: "How could I be so stupid as to do this simple task wrong?" they think to themselves. Well, it isn't so simple, and it is not their fault: even as simple a device as the everyday kitchen stove is frequently badly designed, in a way that guarantees the errors.

Most stoves have only four burners and four controls in one-to-one correspondence. Why is it so hard to remember four things? In principle, it should be easy to remember the relationship between the controls and the burners. In practice, however, it is almost impossible. Why? Because of the poor mappings between the controls and the burners. Look at Figure 3.2, which depicts four possible mappings between the four burners and controls. Figures 3.2A and B show how not to map one dimension onto two. Figures 3.2C and D show two ways of doing it properly: arrange the controls in two dimensions (C) or stagger the burners (D) so they can be ordered left to right.

A.



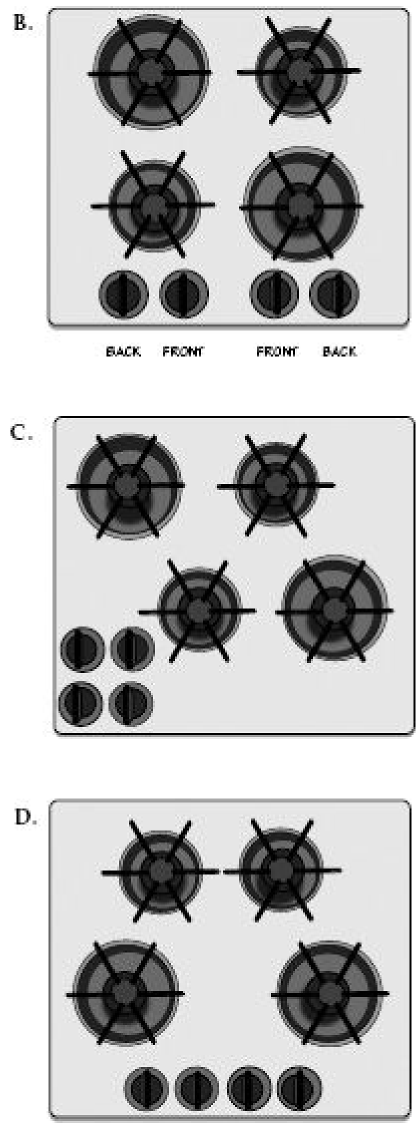


FIGURE 3.2. Mappings of Stove Controls with Burners. With the traditional arrangement of stove burners shown in Figures A and B, the burners are arranged in a rectangle and the controls in a linear line. Usually there is a partial natural mapping, with the left two controls operating the left burners and the right two controls operating the right burners. Even so, there are four possible mappings of controls to burners, all four of which are used on commercial stoves. The only way to know which control works which burner is to read the labels. But if the controls were also in a rectangle (Figure C) or the burners staggered (Figure D), no labels would be needed. Learning would be easy; errors would be reduced.

To make matters worse, stove manufacturers cannot agree upon what the mapping should be. If all stoves used the same arrangement of controls, even if it is unnatural, everyone could learn it once and forever after get things right. As the legend of Figure 3.2 points out, even if the stove manufacturer is nice enough to ensure that each pair of controls operates the pair of burners on its side, there are still four possible mappings. All four are in common use. Some stoves arrange the controls in a vertical line, giving even more possible mappings. Every stove seems to be different. Even different stoves from the same manufacturer differ. No wonder people have trouble, leading their food to go uncooked, and in the worst cases, leading to fire.

Natural mappings are those where the relationship between the controls and the object to be controlled (the burners, in this case) is obvious. Depending upon circumstances, natural mappings will employ spatial cues. Here are three levels of mapping, arranged in decreasing effectiveness as memory aids:

- **Best mapping:** Controls are mounted directly on the item to be controlled.
- **Second-best mapping:** Controls are as close as possible to the object to be controlled.
- **Third-best mapping:** Controls are arranged in the same spatial configuration as the objects to be controlled.

In the ideal and second-best cases, the mappings are indeed clear and unambiguous.

Want excellent examples of natural mapping? Consider gesture-controlled faucets, soap dispensers, and hand dryers. Put your hands under the faucet or soap dispenser and the water or soap appears. Wave your hand in front of the paper towel dispenser and out pops a new towel, or in the case of blower-controlled hand dryers, simply put your hands beneath or into the dryer and the drying air turns on. Mind you, although the mappings of these devices are appropriate, they do have problems. First, they often lack signifiers, hence they lack discoverability. The controls are often invisible, so we sometimes put our hands under faucets expecting to receive water, but wait in vain: these are mechanical faucets that require handle turning. Or the water turns on and then stops, so we wave our hands up and down, hoping to find the precise location where the water turns on. When I wave my hand in front of the towel dispenser but get no towel, I do not know whether this means the dispenser is broken or out of towels; or that I did the waving wrong, or in the wrong place; or that maybe this doesn't work by gesture, but I must push, pull, or turn something. The lack of signifiers is a real drawback. These devices aren't perfect, but at least they got the mapping right.

In the case of stove controls, it is obviously not possible to put the controls directly on the burners. In most cases, it is also dangerous to put the controls adjacent to the burners, not only for fear of burning the person using the stove, but also because it would interfere with the placement of cooking utensils. Stove controls are usually situated on the side, back, or front panel of the stove, in which case they ought to be arranged in spatial harmony with the burners, as in Figures 3.2 C and D.

With a good natural mapping, the relationship of the controls to the burner is completely contained in the world; the load on human memory is much reduced. With a bad mapping, however, a burden is placed upon memory, leading to more mental effort and a higher chance of error. Without a good mapping, people new to the stove cannot readily determine which burner goes with which control and even frequent users will still occasionally err.

Why do stove designers insist on arranging the burners in a two-dimensional rectangular pattern, and the controls in a one-dimensional row? We have known for roughly a century just how bad such an arrangement is. Sometimes the stove comes with clever little diagrams to indicate which control works which burner. Sometimes there are labels. But the proper natural mapping requires no diagrams, no labels, and no instructions.

The irony about stove design is that it isn't hard to do right. Textbooks of ergonomics, human factors, psychology, and industrial engineering have been demonstrating both the problems and the solutions for over fifty years. Some stove manufacturers do use good designs. Oddly, sometimes the best and the worst designs are manufactured by the same companies and are illustrated side by side in their catalogs. Why do users still purchase stoves that cause so much trouble? Why not revolt and refuse to buy them unless the controls have an intelligent relationship to the burners?

The problem of the stovetop may seem trivial, but similar mapping problems exist in many situations, including commercial and industrial settings, where selecting the wrong button, dial, or lever can lead to major economic impact or even fatalities.

In industrial settings good mapping is of special importance, whether it is a remotely piloted airplane, a large building crane where the operator is at a distance from the objects being manipulated, or even in an automobile where the driver might wish to control temperature or windows while driving at high speeds or in crowded streets. In these cases, the best controls usually are spatial mappings of the controls to the items being controlled. We see this done properly in most automobiles where the driver can operate the windows through switches that are arranged in spatial correspondence to the windows.

Usability is not often thought about during the purchasing process. Unless you actually test a number of units in a realistic environment, doing typical tasks, you are not likely to notice the ease or difficulty of use. If you just look at something, it appears straightforward enough, and the array of wonderful features seems to be a virtue. You may not realize that you won't be able to figure out how to use those features. I urge you to test products before you buy them. Before purchasing a new stovetop, pretend you are cooking a meal. Do it right there in the store. Do not be afraid to make mistakes or ask stupid questions. Remember, any problems you have are probably the design's fault, not yours.

A major obstacle is that often the purchaser is not the user. Appliances may be in a home when people move in. In the office, the purchasing department orders equipment based upon such factors as price, relationships with the supplier, and perhaps reliability: usability is seldom considered. Finally, even when the purchaser is the end user, it is sometimes necessary to trade off one desirable feature for an undesirable one. In the case of my family's stove, we did not like the arrangement of controls, but we bought the stove anyway: we traded off the layout of the burner controls for another design feature that was more important to us and available only from one manufacturer. But why should we have to make a tradeoff? It wouldn't be hard for all stove manufacturers to use natural mappings, or at the least, to standardize their mappings.

Culture and Design: Natural Mappings Can Vary with Culture

I was in Asia, giving a talk. My computer was connected to a projector and I was given a remote controller for advancing through the illustrations for my talk. This one had two buttons, one above the other. The title was already displayed on the screen, so when I started, all I had to do was to advance to the first photograph in my presentation, but when I pushed the upper button, to my amazement I went backward through my illustrations, not forward.

"How could this happen?" I wondered. To me, top means forward; bottom, backward. The mapping is clear and obvious. If the buttons had been side by side, then the control would have been ambiguous: which comes first, right or left? This controller appeared to use an appropriate mapping of top and bottom. Why was it working backward? Was this yet another example of poor design?

I decided to ask the audience. I showed them the controller and asked: "To get to my next picture, which button should I push, the top or the bottom?" To my great surprise, the audience was split in their responses. Many thought that it should be the top button, just as I had thought. But a large number thought it should be the bottom.

What's the correct answer? I decided to ask this question to my audiences around the world. I discovered that they, too, were split in their opinions: some people firmly believe that it is the top button and some, just as firmly, believe it is the bottom button. Everyone is surprised to learn that someone else might think differently.

I was puzzled until I realized that this was a point-of-view problem, very similar to the way different cultures view time. In some cultures, time is represented mentally as if it were a road stretching out ahead of the person. As a person moves through time, the person moves forward along the time line. Other cultures use the same representation, except now it is the person who is fixed and it is time that moves: an event in the future moves toward the person.

This is precisely what was happening with the controller. Yes, the top button does cause something to move forward, but the question is, what is moving? Some people thought that the person would move through the images, other people thought the images would move. People who thought that they moved through the images wanted the top button to indicate the next one. People who thought it was the illustrations that moved would get to the next image by pushing the bottom button, causing the images to move toward them.

Some cultures represent the time line vertically: up for the future, down for the past. Other cultures have rather different views. For example, does the future lie ahead or behind? To most of us, the question makes no sense: of course, the future lies ahead—the past is behind us. We speak this way, discussing the "arrival" of the future; we are pleased that many unfortunate events of the past have been "left behind."

But why couldn't the past be in front of us and the future behind? Does that sound strange? Why? We can see what is in front of us, but not what is behind, just as we can remember what happened in the past, but we can't remember the future. Not only that, but we can remember recent events much more clearly than long-past events, captured neatly by the visual metaphor in which the past lines up before us, the most recent events being the closest so that they are clearly perceived (remembered), with long-past events far in the distance, remembered and perceived with difficulty. Still sound weird? This is how the South American Indian group, the Aymara, represent time. When they speak of the future, they use the phrase *back days* and often gesture behind them. Think about it: it is a perfectly logical way to view the world.

If time is displayed along a horizontal line, does it go from left to right or right to left? Either answer is correct because the choice is arbitrary, just as the choice of whether text should be strung along the page from left to right or right to left is arbitrary. The choice of text direction also corresponds to people's preference for time direction. People whose native language is Arabic or Hebrew prefer time to flow from right to left (the future being toward the left), whereas those who use a left-to-right writing system have time flowing in the same direction, so the future is to the right.

But wait: I'm not finished. Is the time line relative to the person or relative to the environment? In some Australian Aborigine societies, time moves relative to the environment based on the direction in which the sun rises and sets. Give people from this community a set of photographs structured in time (for example, photographs of a person at different ages or a child eating some food) and ask them to order the photographs in time. People from technological cultures would order the pictures from left to right, most recent photo to the right or left, depending upon how their printed language was written. But people from these Australian communities would order them east to west, most recent to the west. If the person were facing south, the photo would be ordered left to right. If the person were facing north, the photos would be ordered right to left. If the person were facing west, the photos would be ordered along a vertical line extending from the body outward, outwards being the most recent. And, of course, were the person facing east, the photos would also be on a line extending out from the body, but with the most recent photo closest to the body.

The choice of metaphor dictates the proper design for interaction. Similar issues show up in other domains. Consider the standard problem of scrolling the text in a computer display. Should the scrolling control move the text or the window? This was a fierce debate in the early years of display terminals, long before the development of modern computer systems. Eventually, there was mutual agreement that the cursor arrow keys—and then, later on, the mouse—would follow the moving window metaphor. Move the window down to see more text at the bottom of the screen. What this meant in practice is that to see more text at the bottom of the screen, move the mouse down, which moves the window down, so that the text moves up: the mouse and the text move in opposite directions. With the moving text metaphor, the mouse and the text move in the same directions: move the mouse up and the text moves up. For over two decades, everyone moved the scrollbars and mouse down in order to make the text move up.

But then smart displays with touch-operated screens arrived. Now it was only natural to touch the text with the fingers and move it up, down, right, or left directly: the text moved in the same direction as the fingers. The moving text metaphor became prevalent. In fact, it was no longer thought of as a metaphor: it was real. But as people switched back and forth between traditional computer systems that used the moving window metaphor and touch-screen systems that used the moving text model, confusion reigned. As a result, one major manufacturer of both computers and smart screens, Apple, switched everything to the moving text model, but no other company followed Apple's lead. As I write this, the confusion still exists. How will it end? I predict the demise of the moving window metaphor: touch-screens and control pads will dominate, which will cause the moving text model to take over. All systems will move the hands or controls in the same direction as they wish the screen images to move. Predicting technology is relatively easy compared to predictions of human behavior, or in this case, the adoption of societal conventions. Will this prediction be true? You will be able to judge for yourself.

Similar issues occurred in aviation with the pilot's attitude indicator, the display that indicates the airplane's orientation (roll or bank and pitch). The instrument shows a horizontal line to indicate the horizon with a silhouette of an airplane seen from behind. If the wings are level and on a line with the horizon, the airplane is flying in level flight. Suppose the airplane turns to the left, so it banks (tilts) left. What should the display look like? Should it show a left-tilting airplane against a fixed horizon, or a fixed airplane against a right-tilting horizon? The first is correct from the viewpoint of someone watching the airplane from behind, where the horizon is always horizontal: this type of display is called *outside-in*. The second is correct from the viewpoint of the pilot, where the airplane is always stable and fixed in position, so that when the airplane banks, the horizon tilts: this type of display is called *inside-out*.

In all these cases, every point of view is correct. It all depends upon what you consider to be moving. What does all this mean for design? What is natural depends upon point of view, the choice of metaphor, and therefore, the culture. The design difficulties occur when there is a switch in metaphors. Airplane pilots have to undergo training and testing before they are allowed to switch from one set of instruments (those with an outside-in metaphor, for example) to the other (those with the inside-out metaphor). When countries decided to switch which side of the road cars would drive on, the temporary confusion that resulted was dangerous. (Most places that switched moved from left-side driving to right-side, but a few, notably Okinawa, Samoa, and East Timor, switched from right to left.) In all these cases of convention switches, people eventually adjusted. It is possible to break convention and switch metaphors, but expect a period of confusion until people adapt to the new system.