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MEDIA AS LIVED ENVIRONMENTS: THE ECOLOGICAL PSYCHOLOGY OF EDUCATIONAL TECHNOLOGY

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We live in an era when everyday activities are shaped by environments that are not only *artificial*—almost half of humanity lives in cities—but also *mediated*. Emotional and cognitive activities in all levels and segments of society are increasingly vested in information-rich venues supported by television, radio, telephone, and computer networks. Even in very remote areas, hunters and farmers watch satellite broadcasts and play battery-operated video games. And in the depths of the Amazon River basin, tribes use tiny video cameras to document territorial encroachments and destruction of rain forest habitat.

10.1 OVERVIEW

This chapter explores the metaphor of media as lived environments. A *medium* can be considered an environment to the extent that it supports both the perception of opportunities for acting and some *means* for acting. This environmental metaphor can help us understand how media users exercise their powers of perception, mobility, and agency within the constraints imposed by particular media technologies and within the conventions established by various media cultures.

The ergonomic utility of many media environments is based on metaphors and mechanics that invite users to participate in worlds populated by semiautonomous objects and agents—ranging from buttons and windows to sprites and computer personas. Attempts to model user engagement with these worlds as the processing of symbols, messages, and discourse are limited because the channel-communications metaphor fails to specify many of the modalities by which humans interact with situations. These modalities include locating, tracking, identifying, grasping, moving, and modifying objects. There is a profound, but not always obvious, difference between receiving communication and acquiring information through these interactive modalities.

Much of the philosophy and neuropsychology of the last century concerned explanations of the mechanisms by which organisms create and store information about their external environment and their relationship to that environment. These explanations have generated a superabundance of terminology for describing internal representations including *memory, stimulus-response mechanisms, neural networks, productions, associations, propositions, scripts, schemata, mental images and models,* and *engrams*.

For simplicity's sake, we will often use a single acronym, *MIROS,* to stand for all such *Mental-Internal Representations of Situations.*[1] Much of the discussion in this chapter assumes that MIROS are incomplete—functioning as complements to rather than substitutes for the external representation of situations provided by media and by realia,[2] that is, real things. The metaphor of media as environments helps us reconsider tradeoffs between the "cost" of (a) *external* storing and processing of information via realia and media and the "cost" of (b) *internal-mental* storing and processing of information.

Investment of organic resources in improved perceptual capacities, whether acquired through learning or by natural selection, offers an important alternative to construction of more complete MIROS. Improved perception allows organisms to more effectively use information reflected in the structure of the environment, information maintained at no biological "cost" to the organism. The tradeoff between internal and external storage and processing provides a basis for coordinating media with MIROS so that they "share the work" of representing situations.

This chapter also seeks to link paradigms of ecological psychologists with the concerns of researchers, designers, and developers who are responsible for understanding and improving the person–environment fit. It examines ways ecological psychology might inform the design of products and systems that are efficient in promoting wise use of human cognitive resources yet humane in enabling authentic modes of being.

Theories that treat media as mere conveyances of symbols and messages often neglect the differences in actions enabled by media, MIROS, and realia. The pages of a book on human anatomy, for example, afford examination of structures of the human body as does a film of an autopsy. However, each of these media offers different possibilities for exploratory action. The anatomy book affords systematic surveys of body structure through layouts and cross sections, while the film affords observation of the mechanics of the dissection process.

The advantages of storage and transmission provided by media technologies should be weighed against possible loss in representational fidelity. Older technologies such as print and film employ well-established conventions that help users to reconstitute missing circumstances and perspectives. Prominent among these conventions are the captions and narratives that accompany two-dimensional (2-D) pictures that guide viewers in constructing the MIROS required for interpretation and understanding. These conventions help us understand how perception in mediated environments can substitute for actions that might have been available to hypothetical observers of or participants in the represented situation.

The actions afforded by media are rarely the same as those afforded by imaginary or real environments represented by these media. Media technologies can partially overcome dislocations in time and space by storing and transferring information. Opportunities for perceiving and acting on media, however, are rarely identical to the opportunities for perceiving and acting on corresponding realia or MIROS.

Emerging technologies challenge us to rethink conventional ideas about learning from and with media by reminding us that we humans are embodied beings with a long heritage of interactions in complex spatiotemporal and quasi-social environments—a heritage much older than our use of symbols and language. Like other organisms whose capabilities are shaped by niche or occupation, our modes of perception are adapted to opportunities for action in the environment. The conclusion of this chapter examines problems that can result when media technologies so degrade opportunities for integrating action with perception that users face a restricted range of options for moral thought and behavior.

10.2 BACKGROUND

Many important issues in ecological psychology were first identified by J. J. Gibson, a perceptual psychologist whose powerful, incomplete, and often misunderstood ideas have played a seminal role in technologies for simulating navigable environments. Although we do not entirely agree with Gibson's theories, which were still evolving when he died in 1979, his work serves as a useful organizing framework for examining the implications of ecological psychology for media design and research.

We provide here a list of phenomena that Gibson identified in personal notes as critical to the future of ecological psychology (J. J. Gibson, 1971/1982, p. 394).

1. Perceiving environmental layout (inseparable from the problem of the ego and its locomotion)
2. Perceiving objects of the environment including their texture, color, shape, and their affordances
3. Perceiving events and their affordances
4. Perceiving other animals and persons ("together with what they persistently afford and what they momentarily do")
5. Perceiving expressive responses of other persons
6. Perceiving communication or speech

   Also,
7. Knowledge mediated by artificial displays, images, pictures, and writing
8. Thought as mediated by symbols
9. Attending to sensations
10. Attending to structure of experience (aesthetics)
11. Cultivating cognitive maps by traveling and sightseeing

According to Gibson (1971/1982), everyday living depends on *direct perception,* perception that is independent of internal propositional or associational representations—perception that guides actions intuitively and automatically. Direct perception,

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[1] A situation can be defined as a structured relation between one or more objects. A MIROS is a mental representation of such a structured relationship. If perception is understood to be *acquisition of information* about the environment, percepts are not considered to be MIROS.

[2] *Realia* (Latin, *ralis,* relating to real things): (a) objects that may be used as teaching aids but were not made for the purpose; and (b) real things, actual facts, especially as distinct from theories about them (1987 *Compact Edition of the Oxford English Dictionary, Volume III Supplement*). Oxford: Oxford University Press.

for example, guides drivers as they respond to subtle changes in their relationship to roadway centerlines. Direct perception adjusts the movements required to bring cup to lip, and guides the manipulation of tools such as pencils, toothbrushes, and scalpels. Direct perception is often tightly linked in real time with ongoing action. "The child who sees directly whether or not he can jump a ditch is aware of something more basic than is the child who has learned to say how wide it is in feet or meters" (J. J. Gibson, 1977/1982, p. 251).

Perhaps the most widely adopted of Gibson's (1979) contributions to the descriptive language of ecological psychology are his concepts of *affordances* (roughly, opportunities for action) and *effectivities* (roughly, capabilities for action). Natural selection gradually tunes a species' effectivities to the affordances associated with its niche or "occupation." Thus are teeth and jaws the effectivities that permit killer whales to exploit the "grab-ability" of seals. Thus are wings the effectivities that allow birds to exploit the flow of air.

In contrast to direct perception, *indirect perception* operates on intermediaries, such as signs, symbols, words, and propositions, that inform an organism about its environment via indexical bonds (Nichols, 1991). Following verbal directions to locate a hidden object is a good example of indirect perception. Indirect perception permits, even promotes, reflection and deliberation.

Gibson acknowledged the importance of intermediaries such as symbols and language-based propositions to human thought. However, he was skeptical about claims that general cognitive processes could be modeled in terms of such intermediaries. He argued that models relying excessively on internal manipulation of symbols and propositions would inevitably neglect critical relationships between perceiving and acting.

Every media technology from book, to video, to computer simulation, imposes profound constraints on representation or description of real or imaginary world and requires tradeoffs as to which aspects of a world will be represented. Even museums, as repositories of "unmediated" authentic artifacts and specimens, must work within the technical limitations of display technologies that favor some modalities of perception over others—looking in lieu of touching, for instance.

Although Gibson (1977/1982) did not develop a complete theory of *mediated* perceiving—that is, perceiving through intermediaries such as pictures and text—he posited that such intermediaries are effective because they are "tools for perceiving by analogy with tools for performing" (p. 290). Careful appraisal of this idea reminds us that in the Gibsonian worldview, everyday perceiving cannot be separated from acting. Therefore, there is no contradiction in the assertion that "tools for perceiving" might serve as analogs for action. Static media such as text, diagrams, pictures, and photos have traditionally achieved many of their most important informative effects by substituting acts of perception for acts of exploration.

THE MISSION MUSEUM: NAVIGATIONAL SHORT CUTS AND ANALOGS FOR ACTION

Almost every fourth grader in California's public schools learns about the chain of late 18th century Franciscan missions that inaugurated the Spanish colonial era in California. A CD-ROM product now makes the mission at La Purísima, Lompoc, more accessible. *The Mystery of the Mission Museum* (Hoffman, et al., 2002) offer a through-the-screen virtual reality model coordinated with curriculum materials that challenge students to become "museum guides" by researching, developing, and giving presentations using the virtual mission environment.

The virtual mission encompasses 176 photographically generated 360-degree "panoramas"—scrollable views of interior and exterior spaces. Users move from one panorama to another by clicking on doors and passageways. Like their colleagues at other museums, curators at the La Purísima mission populated their museum with realia—authentic artifacts of mission life. To represent these artifacts virtually, Mission Museum designers embedded within the various panoramas over 50 virtual objects ranging from kitchen utensils to weapons.

FIGURE 10.1. Sample screens from the Mystery of the Mission Museum software. Interactive maps (lower left corner insets, and top screen) afford faster movement across longer distances. Users click in panoramas to view 60 short videos, featuring costumed docents demonstrating mission crafts or telling life stories. Users can also manipulate virtual objects. In the Cuartel (bottom), for example, they can open and close the stocks (second from bottom) by dragging the computer mouse along a top-to-bottom axis. For more information, see http://mystery.sdsu.edu

In many virtual environments, designers provide some degree of manipulability of virtual objects by creating computer-generated 3-D graphic objects that can be rotated for inspection. However, capturing La Purísima objects from every viewpoint would have been complex and costly.

Making the virtual objects "rotate-able" would have wasted production resources on representation of spatial features with dubious educational relevance, such as the back of a storage chest, the bottom of an ox cart, or the entire circumference of a bell. More importantly, such a strategy would have focused user attention on spatial and physical properties of artifacts at the expense of anthropologically significant affordance properties related to the way real people might have used the artifacts to accomplish their goals.

The designers therefore decided to simulate affordance properties that were especially characteristic of each object as mission inhabitants might use it. The limited affordance properties of the through-the-screen system, which assumed users would employ a standard computer mouse, led designers to a solution in which users employ mouse actions roughly analogous to actions real people at the real museum would use to manipulate "real things." Thus, in the finished version of the virtual museum, students can "operate" a spinning wheel by clicking on ("grasping") the wheel and moving the mouse in a circular fashion. (Some objects, such as bells, also respond with sounds when manipulated.) By means of similar analogs for action, olive-mill and wheat-mill donkeys are lead-able; the mission's cannon is point-able and shoot-able; and the mission bell rope is pull-able. In small-scale usability testing, McKean, Allen, and Hoffman (1999) found that fourth-grade boys manipulated these virtual artifacts more frequently than did their female counterparts. However, videotapes of the students suggested that girls were more likely to discuss the social significance of the artifacts.

Another kind of trade-off confronted *Mission Museum* designers as they created affordances for macro- and micronavigation. Traversing the real La Purísima requires more than a few minutes, even at a brisk walk, and reaching some locations requires diligent wayfinding through hallways, corridors, and rooms. Initially the designers had planned to require node-by-node navigation as a means of representing the scale and complexity of the real mission. However, early usability testing revealed that users found this requirement tedious and frustrating. Moving in the most direct line from one end to the other of the main building complex alone takes 26 mouse clicks.

On reflection it became clear to the designers that the initial approach sacrificed educational utility to a more literal notion of spatial authenticity. As a result, they provided a high-level map to afford "jumps" among a dozen major areas, each represented by a local map. This approach essentially collapsed the space–time affordance structures of the real museum while preserving the potential value associated with direct navigation of specific environs such as rooms, shops, and courtyards.

10.3 NATURAL AND CULTURAL DYNAMICS OF INFORMATION AND MEDIA TECHNOLOGIES

What distinguishes contemporary humans from our pre-ice age ancestors is that our adaptations are primarily cultural. The human evolutionary clock may have slowed for the moment in some respects because we accommodate some "natural selection pressure" technically and socially rather than biologically.

Donald's (1991) reconstruction of the origins of the modern mind claims that the unfolding drama of our distinctly human cognitive capacity has been characterized primarily by increasing externalization of information—first as gestures and "rudimentary songs," later as high-speed articulate speech, and eventually as visual markings that enabled storage of information in stable nonbiological systems.

Norman (1993) succinctly captures this theme of information externalization in the title of his trade book, *Things that Make Us Smart*. He argues that the hallmark of human cognition lies not so much in our ability to reason or remember, but rather in our ability to construct external cognitive artifacts and to use these artifacts to compensate for the limitations of our working and long-term memories. Norman defines cognitive artifacts as artificial devices designed to maintain, display, or operate upon information in order to serve representational functions.

As Greeno (1991) claims, "a significant part of what we call 'memory' involves information that is in situations . . . rather than just in the minds of the behaving individual" (p. 265). Indeed, a sizable body of literature describes some profound limitations of internal representations (or in our terms, MIROS) and suggests that without the support of external devices or representations, MIROS are typically simplistic, incomplete, fragmentary, unstable, difficult to run or manipulate, lacking firm boundaries, easily confused with one another, and generally unscientific. See, for example, Carroll and Olson, 1988; Craik, 1943; di Sessa, 1983, 1988; D. Gentner and D. R. Gentner, 1983; D. Gentner and Stevens, 1983; Greeno, 1989; Johnson-Laird, 1983; Larkin and Simon, 1987; Lave, 1988; Payne, 1992; Rouse and Morris, 1986; Wood, Bruner, and Ross, 1976; and Young, 1983.

10.3.1 Thermodynamic Efficiency of Externalization

The scope and complexity of MIROS are constrained by the thermodynamics of information storage and processing in biological systems. Seemingly lost in three decades of discussion on the problems of internal representation is Hawkins' (1964) insight that *external* representations can confer gains in thermodynamic efficiency.

Hawkins suggested that the capacity to learn evolved when nervous systems made it possible for organisms to store information outside the structure of the cell nucleus proper. Resulting increases in capacity and flexibility meant that a species' genome was no longer the only repository for survival-enhancing information.

Hawkins argued that the first law of thermodynamics, conservation of energy, established conditions that favor development of higher levels of cognition in animal species. He based this line of argument partly on the work of Shannon and Weaver (1949), the mathematicians who applied thermodynamic analysis to technical problems such as the coding and transmission of messages over channels, maximum rate of signal transmission over given channels, and effects of noise.

Hawkins (1964) reasoned further from Shannon and Weaver's (1949) theoretical treatment of information that learning, whether the system that learns be machine or human, confers its benefits through increased thermodynamic efficiency. He considers two simple learning mechanisms: conditioned reflexes and network switches. In both of these mechanisms, the essential thermodynamic condition is the availability of free energy to reduce entropy and increase order. A network of switches can transmit flows of energy much larger than incoming signals that direct switching operations. "Through reinforcement and inhibition, relatively simple stimuli come to release complex responses adapted to the character and behavior of the environment" (p. 273). In both these cases, the patterning found in the operation of the switches and complex responses represents, vis-à-vis the environment, lowered entropy of arrangement.

Externalization of information beyond the limits of cell nuclei and the appearance of simple learning mechanisms referred to by Hawkins (1964) are only the first of many strategies life has evolved for increasing thermodynamic efficiency. Even greater gains accrue if an organism can off-load the work of information storage and processing to the external environment itself and thus reduce biological costs associated with maintaining and processing that information in neural networks. "Investment" of organic resources in improved perception, whether acquired by learning or by natural selection, is an important alternative to construction of more complete MIROS.

Improved perception allows organisms to more effectively use information reflected in the structure of the environment, information maintained at no biological "cost" to the organism. Environments rich in information related to the needs, goals, or intentions of an organism favor development of enhanced perception. Environments lacking such information favor development of enhanced MIROS.

This tradeoff between internal and external storage and processing provides a basis for coordinating media with MIROS so that they "share the work" of representing situations. All things being equal, we might expect investment of organic resources in improved capabilities of perception to be a more effective strategy for organisms than construction of elaborate MIROS. Regardless of whether such capabilities are acquired through learning or natural selection, improved perception allows organisms to more effectively exploit information reflected in the structure of the environment—information that is maintained with no direct biological "cost" to the organism.

Yet all things are not equal: A number of factors determine how biological resources are divided between perceptual capabilities and MIROS. These factors include the niche or occupation of the organism; the availability in the environment of information related to the niche; the biological "costs" of action requisite to information acquisition; the costs of developing and maintaining perceptual organs; and the costs of developing and maintaining the MIROS. Also, when the organism's acquisition of information involves exploring or investigating, there is a "cost" of opportunities forgone: Moving or adjusting sensory organs to favor selection of information from one sector of the environment may preclude, for some time, selection of information from other sectors.

Consider in the following scenario how these factors operate at the extremes to favor development of, respectively, perception and MIROS in two hypothetical groups of people concerned with navigation in a high-security office building.

The first group are ordinary workers who move into a building and after a short time are able to navigate effectively using an environment rich in information such as signage, landmarks, changes in color schemes, and the like. If the building is well designed, it is unlikely the workers will invest much mental effort in remembering the actual details of the spatial layout. "Why bother," they might say. "It's obvious: You just keep going until you find a familiar landmark or sign and then you make your next move. We don't need a mental model because we can see where to go." Norman and Rumelhart (1975) have demonstrated that living in buildings for many months is no guarantee that inhabitants will be able to draw realistic floor plans. In fact, such residents often make gross errors in their representation of environmental layouts—incorrectly locating the position of doors, furniture, and balconies.

Now, suppose a second group, more nefarious and transient, is hired to steal company secrets in the same building during the dead of night when visual information about the environment is not so easily obtained. Each use of flashlights by these commandos would entail risk of discovery (a kind of cost) and each act of exploration or orientation would increase the possibility of being caught. In preparing for their raid, therefore, the commandos might be willing to spend a great deal of time developing a mental model of the layout of a building they may only raid once. "Sure," they might say, "we have to invest a lot of mental resources to memorize floor plans, but it's an investment that pays off in saved time and reduced risk."

Unfortunately, explanatory models in the cognitive sciences still tend to favor notions of mental models as complete representations of the external environment rather than as elements in a distributed information system in which the brain is only one component with representational capacities. As Zhang and Norman (1994) suggest, traditional approaches assume that cognitive processes are exclusively internal and that external representations of information are merely peripheral to internal processing (e.g., numerals are memory aids for calculation and letters represent utterances). They argue that these explanatory models fail to acknowledge external representations in their own right and therefore rely on postulations of complicated internal representations to account for complexity of behavior when much of this behavior merely reflects the complexity of the environment itself.

10.3.2 Coupling and Information Transfer

According to ecological psychologists, perception cannot be separated from action; perceiving involves selecting and attending to some sources of information at the expense of others. Human eyes, for instance, constantly flick across the visual field in rapid eye movements called saccades. Natural interaction with environments cannot be easily modeled in terms of communications channels because such environments typically contain numerous independent sources of information.

Organisms attend to these sources selectively depending on the relevance of the information to their needs and intentions. To stretch a communications metaphor that already seems inadequate, organisms constantly "switch channels." Moreover, most organisms employ networks of sensors in multiple sense modalities and actively manipulate their sensor arrays. It is unclear how we should think of such networks in a way that would be consistent with Shannon and Weaver's (1949) rigorous technical meaning for *channel* in which they model information flow as a single stream of serial bits.

According to Gibson's paradigm (1979), information contained in situations is actively selected or "picked up" rather than passively "filtered" as suggested by some metaphors associated with popular models of memory and perception. In a thermodynamic context, selective perception of the environment confers benefits similar to the switching mechanisms of learning described by Hawkins (1964): Organisms often expend small amounts of energy attending to aspects of the environment that might yield large returns.

Hawkins (1964) extends another Shannon and Weaver (1949) insight by noting that some kind of coupling is a necessary condition for duplication or transmission of patterns. He notes that the idea of coupling—widely misinterpreted by communications and media theorists to mean mechanical, deterministic coupling—was used by Shannon and Weaver to refer to thermodynamic (probabilistic, stochastic) coupling. Thermodynamic coupling is a many-to-many form of linkage. It is a concept of coupling that accounts for possible gains in efficiency and preserves the ancient Greek sense of information as transference of form (*in* + *formatio*).

Hawkins (1964) argues that human influence on the environment is primarily thermodynamic. Humans exert this influence through subtle changes in the structure of the environment that cause natural processes to flow in new ways. Competent use of this influence requires detecting invariant patterns in the environment so that attention and intention can be directed toward those aspects of the environment that *do* vary or that can be influenced. As Maturana (1978) notes, conceptualizing information as a continuous interactive transformation of pattern or form implies that learning is not merely the collection of photograph-like representations but involves continuous change in the nervous system's capacity to synthesize patterns of interaction with the environment when certain previously encountered situations reoccur. In other words, learning is more usefully described as the development of representations about how to interact with the environment than the retention of models of the environment itself.

Such learning represents a lowered state of entropy—that is, a greater orderliness of arrangement. Chaotic or arbitrary aspects of an organism's activity are ameliorated by attention and intention directed toward aspects of the environment related to survival in the organism's ecological niche. The orderliness and organization of behavior that results from niche-related attention and intention can be characterized as *intelligence,* which is thermodynamically efficient because it "leverages" the expenditure of small amounts of biological energy (Gibbs Free Energy) to guide much larger flows of energy in the external environment. Media users, for example, benefit from this thermodynamic leverage when they expend modest attentional resources to acquire information about how to control large amounts of energy. A speculator who makes a quick killing on Wall Street after reading a stock quote is making thermodynamically efficient use of media technology.

The use of media to extend human cognitive capacities reflects long-term biological and cultural trends toward increasing externalization of information storage and processing. Externalization increases the individual's thermodynamic efficiency. It reduces organic "costs" of cognitive processing by distributing the "work" of representing situations between individuals and their cognitive artifacts. Indeed, one way to define higher order learning is by the degree to which it permits individuals to benefit from externalization of information storage and processing. This can be conceptualized as *literacy* or more generally, we propose, as *mediacy*. Both literacy and mediacy are qualities of intelligence manifested by the facility with which an individual is capable of perceiving and acting on mediated information. Bruner and Olson (1977–78) invoke this concept of mediacy succinctly when they define intelligence as "skill in a medium."

10.3.3 Simplicity and Complexity

Ecology in general attempts to explain how matter and energy are transferred and organized within biological communities. Since transfer and organization of matter and energy are ultimately governed by thermodynamics rather than by processes that are solely mechanical, ecological sciences eschew purely deterministic explanation (one-to-one, reversible couplings) in favor of stochastic, probabilistic explanation (many-to-many, nonreversible couplings). Stochastic description and analysis is based on information transfer and formalized by measures of *entropy* or, organized complexity. Information is thought of essentially as a measure of *level of organization* or relatedness. Entropy can also be thought of as a measure of *degrees of freedom* (Gatlin, 1972; von Bertalanffy, 1967) or *opportunities for action*. From this perspective, complex systems offer more freedom of action than simple systems because complex systems are more highly organized, with more and higher level relations.

Complex biosystems encompass more species and support longer food chains than simple biosystems. For example, a rain forest affords more freedom of action, more opportunities to hunt and gather than does arctic tundra. Cities offer more opportunities for human action—different types of work, recreation, and socializing—than, say, a large cattle ranch. Extremely simple systems may offer no opportunities for action because (a) there is no organization—all is chance and chaos, or (b) organization is rigid—all relations are already absolutely determined. For instance, a square mile of ocean surface is simple and chaotic, whereas a square mile of sheer granite cliff is simple and rigid.

10.3.4 A Multiplicity of Media

Amidst dramatic changes enabled by convergent computing and telecommunications technologies, concepts associated with the word *media* have shifted fundamentally. Many connotations of this term originated in the late 19th century when leaders of publishing and advertising industries became concerned with large scale dissemination of commercial information. In the latter half of the 20th century, the term *medium* was applied variously to:

- storage surfaces such as tapes, discs, and papers;
- technologies for receiving, recording, copying, or playing messages;
- human communication modalities such as text, diagrams, photos, speech, or music;
- physical and electronic infrastructures such as broadcast networks or cyberspace; and
- cultures of creation and use such as sports media, edutainment, the paparazzi, and "cyburbia" (Allen, 1991, p. 53).

These forms of usage are broadly consistent with a more general concept of a medium as "a substance through which something is carried or transmitted" (*MSN Encarta*, 2002). This notion of transmission underlies technical use and popular imagination of media as channels for sending and receiving messages.

Transmission was also implicit in the metaphors of cognitivists in the 1970s and 1980s that characterized human cognition as information processing in which symbols flow through registers and processing modules in a progression of transformations akin to serial computation. Common extensions of this metaphor led many to believe that the way humans (should) work with computers is to "communicate" with them through symbols and language-based discourse including verbal commands.

We have grounded this chapter in a different paradigm that conceptualizes a medium as "a substance or the environment in which an organism naturally lives or grows" (*MSN Encarta*, 2002). Applying this metaphor to human affairs seems particularly relevant in an era when electronic information pervades virtually every aspect of everyday life. Our perceptions of the planet earth are influenced by world-wide "supermedia" events (Real, 1989) even as we are surrounded by "info-cocoons" patched together from components such as facsimile machines, computers, copiers, cellular phones, radios, TVs, and video games. Public awareness of virtual realities and other immersive environments grew steadily in the 1990s as these technologies were popularized in films and amusement parks, and as they were more widely used in architecture, medicine, aviation, and other disciplines.

However, the notion of media as channels for transmitting information is limited because it tends to ignore many of the modalities of perception and action that people use when interacting with contemporary computer-based media. Attempts to model as "communication" user interactions with graphical user interfaces such as those associated with Macintosh or Windows operating systems seem particularly dubious to us. When a user drags a folder to a trashcan icon, does the user intend to "communicate" with the computer? Possibly. When the trash can icon puffs up after receiving the file, does the user interpret this as evidence of the trashcan's intention to communicate? Possibly.

Yet, under normal circumstances, one does not interpret the act of tossing an actual file into a *real* trashcan as an act of communication but rather as an act of disposition. Similarly, a file in a real trashcan is not normally interpreted by the tosser as an effort on the part of the trashcan to communicate its status as "containing something." What is the difference between virtual file tossing and real file tossing? To computer users, both virtual and real trashcans share certain analogous functional properties: From the user's point of view, trashcans are not receivers of messages, but receivers of unwanted objects.

GUIs and similar environments also challenge conventional notions of symbols. In conventional usage, the meaning of a symbol is determined by its referents—that is, a symbol refers to a set of objects or events, but is not in and of itself the means for initiating events. For example, letters refer to sounds and numerals refer to quantities. In arranging letters to spell a word, however, one is not voicing actual sounds; in arranging numerals to represent a mathematical operation, one is not manipulating actual quantities of objects.

The dispositional properties of computer icons and tools set them apart from conventional symbols because icons and tools afford opportunities for direct action. Double-clicking on a selected file icon does not merely *symbolize* the action of opening the selected file. Rather, it *is* the action of opening the file. The double-click action causes the operating system to execute the code associated with the selected icon. Clicking on a selected file does not symbolize file opening anymore than toggling a light switch symbolizes light bulb activation.

However useful engineers may find the communications metaphor in rationalizing the logic of information flows in hardware and software subsystems, questions about the research and design of contemporary user interfaces center on object perception and manipulation partly because perception and manipulation of objects invoke powerful cognitive abilities that are also used in many everyday activities: locating, tracking, and identifying objects; grasping and moving them; altering the properties of the objects; or "switching" them from one modality to another.

The means by which users carry out such activities in a GUI are often partially or completely removed from language-based communication: Pointing, dragging, and pushing allow users to perceive and to continuously adjust virtual tools or other devices without using propositions or commands such as "Erase selected file." Ecological psychologists recognize that, in spite of their apparent modernity, such activities represent very ancient modes of unified action–perception employed by many organisms: Every predator worthy of the name must be able to locate, track, identify, grasp, move, and modify objects. The cognitive faculties used by an artist who cuts objects from a complex computer-based drawing and saves them in her electronic library have much in common with the faculties employed by a wolf who snatches white rabbits from a snow field and buries them until spring.

Developers of computer-based environments of all types, especially interactive multimedia, increasingly rely on object-oriented design and programming (Martin, 1993). Object technologies challenge the media-as-channels and "media-as-conveyors" (R. E. Clark, 1983) metaphors because the objects—files and segments of code—contain instruction sets that enable the objects to assume varying degrees of behavioral autonomy.

Contemporary, object-oriented regimes for interface design result in complex communities of semi-autonomous entities—windows, buttons, "hot spots," and other objects—that exchange messages with each other, usually by means that are invisible to the user. Thus, the user is in a very real sense only one of many agents who populate and codetermine events in cyberspace. Increasingly, human computer users are not the only senders and receivers of messages; they are participants in arenas that have been likened to theaters (Laurel, 1986), and living communities ("vivaria"; Kay, cited in Rheingold, 1991, p. 316).

10.3.5 Integrated Perception and Action

> Perceiving is an achievement of the individual, not an appearance in the theater of his consciousness. It is a keeping-in-touch with the world, an experiencing of things, rather than a having of experiences. It involves awareness-of instead of just awareness. It may be awareness of something in the environment or something in the observer or both at once, but there is no content of awareness independent of that of which one is aware. This is close to the act psychology of the nineteenth century except that perception is not a mental act. Neither is it a bodily act. Perceiving is a psychosomatic act, not of the mind or of the body, but of a living observer. (J. J. Gibson, 1979, p. 239)

Dominated by information processing theories, perceptual psychology in the mid and late 20th century emphasized research paradigms that constrained action and isolated sensation from attention and intention. This predilection for ignoring codeterminant relations between perception and action resulted in a relatively weak foundation for design of media products and a limited basis for understanding many traditional media forms.

Ulric Neisser's (1976) perceptual cycle—which acknowledges the influence of both J. J. Gibson and his spouse, developmental psychologist Eleanor Gibson—served as an early framework for examining the relationship between action and perception. Neisser (1976) was concerned with the inability of information processing models to explain phenomena associated with attention, unit formation, meaning, coherence, veridicality, and perceptual development.

Information processing models of the 1970s typically represented sensory organs as fixed and passive arrays of receptors. Neisser asked how then would such models explain why different people attend to different aspects of the same situation? How would information processing models help explain why even infants attend to objects in ways that suggest the brain can easily assign to *things* stimuli obtained through distinct sensory modalities? How would information processing models explain the remarkable ability of the brain to respond to scenes as if they were stable and coherent even though the act of inspecting such scenes exposes the retina to rapidly shifting and wildly juxtaposed cascades of images?

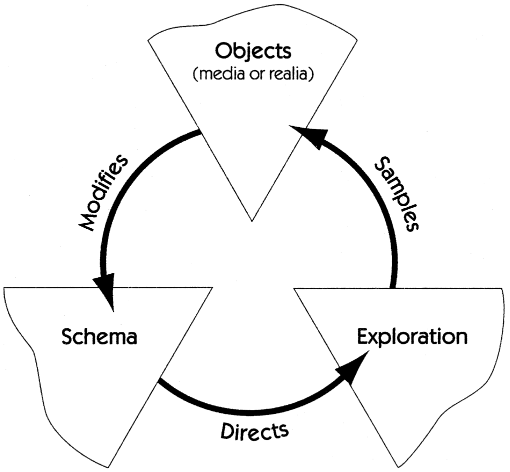

FIGURE 10.2. **Neisser's Perceptual Cycle.** In the language of ecological psychologists, an organism selectively samples available information in accord with the requirements of its niche. An organism's perceptions are tuned to the means that the environment offers for fulfilling the organism's intentions (after Neisser, 1976, p. 21).

The Neisser–Gibson alternative to the information processing models added the crucial function of exploration. This addition, illustrated in Neisser's Perceptual Cycle (Fig. 10.2), reflects the fact that organisms *selectively sample* available information in accord with the demands of their niches. An organism's perceptual capabilities are tuned to the means that its accustomed environment offers for realizing that organism's intentions.

Neisser's emphasis on exploratory perception reminds us that schemata can never be entirely complete as representations of realia. In his opinion, schemata are not templates for conceptualizing experiences. They are more like plans for interacting with situations. "The schema [is] not only the plan but also the executor of the plan. It is a pattern of action as well as a pattern for action" (Neisser, 1991, pp. 20–21).

The idea of the action–perception cycle, which is similar in some respects to early cybernetic models, can be reframed as a dialectic in which action and perception are codeterminant. In visual tracking, for example, retinal perception is codeterminant with eye movement. (See Clancey, 1993, and Churchland, 1986, on tensors as neural models of action–perception dialectics.)

Cyclic models such as Neisser's represent perception and action as separate phases or steps: "See the button, position the cursor, click the mouse." Dialectic models represent perception and action as covariates, in which action and perception are constantly adjusting to each other: "Use the mouse to drag the object to a new location, carefully positioning it at just the right spot." This kind of operation requires continuous integration and reciprocal calibration of perception and action that cannot be easily modeled as discrete steps; the eyes track the cursor *while* the hand moves the mouse.

Detection and analysis of covariation is a critical neural function which, according to psychologists such as MacKay (1991) often obviates the need for more complex models of cognition involving representations of the environment. "... the system has all it needs by way of an internal representation of the tactile world-as-perceived for the organization of relevant action.... readiness for action using other dimensions of the effector system, such as walking, can be derived directly from this representation, without any need for an explicit 'map' " (MacKay, 1991, p. 84).

Neisser's use of *schemata* and *plans* echoes a multiplicity of meanings from Kant (1781/1966) to Bartlett (1932) to Piaget (1971) to Suchman (1987). His meaning is close to what we will define as *actionable mental models*. An actionable mental model integrates perception of the environment with evolving plans for action including provisions for additional sampling of the environment. Actionable mental models draw not so much on memories of how the *environment* was structured in the past as they do on memories of how past actions were related to past perceptions. Rather than mirroring the workings of external reality, actionable models help organisms to attend to their perceptions of the environment and to formulate intentions, plans, and/or action sequences.

Our use of actionable mental models assumes first that mental models are rarely self-sufficient (see D. Gentner & Stevens, 1983). That is, mental models cannot function effectively (are not "runnable") without access to data. Actionable mental models must be "situated" (Collins, Brown, & Newman, 1989; Greeno, 1994) in order to operate.

Ecological psychology assumes that much if not most of the information required to guide effective action in everyday situations is directly perceivable by individuals adapted to those situations. It seems reasonable to assume that natural selection in favor of cognitive efficiency (Gatlin, 1972; Minsky, 1985; von Foerster, 1986) will work against the development and maintenance of complex MIROS if simple MIROS contribute to survival equally well. That is, the evolution of cognitive capacities will not favor unnecessary repleteness in mental models, or the neurological structures that support them, even when such models might be more truthful or veridical according to some "objective" standard of representation.

In many cases, MIROS cannot serve (or do not serve efficiently) as equivalents for direct perception of situations in which the environment does the "work" of "manipulating itself" in response to the actions of the perceiver. It is usually much easier, for instance, to observe how surroundings change in response to one's movement than it is to construct or use MIROS to predict such changes.

Even when humans *might* employ more complete MIROS, it appears they are often willing to expend energy manipulating things physically to avoid the effort of manipulating such things internally. Lave (1988) is on point in her discussion of a homemaker responsible for implementing a systematic dieting regime. After considering the effort involved in fairly complex calculations for using fractional measures to compute serving sizes, the homemaker, who had some background in higher mathematics, simply formed patties of cottage cheese and manipulated them physically to yield correct and edible solutions.

There are tradeoffs between elaborate and simple MIROS. Impoverished environments are likely to select *against* improvement of elaborate sensory and perceptual faculties and may even favor degradation of some of these faculties: We can assume that the blindness of today's cave fish evolved because eyes contributed little to the survival of their sighted ancestors. It seems reasonable to assume that, in the long run, the calculus of natural selection balances resources "invested" in perception against resources "invested" in other means of representing the environment.

In any case, for reasons of parsimony in scientific explanation (in the tradition of Occam's razor), descriptions of MIROS—which are of necessity often hypothetical—should not be any more complex than is necessary to explain observed facts. Accounting for observed behavior, then, with the simplest possible MIROS will assume that natural selection frequently favors organisms that attend to the environment directly because this is often more economical and more reliable than maintaining internal models of the environment or reasoning about it.

10.3.6 Perception

Gibson's seminal works (1966 and 1979, for example) established many of the theories, principles, concepts, and methods employed by contemporary ecological psychologists. Developed over a 35-year span of research on the problems of visuospatial perception, his "ecological optics" now serves as a framework for extending the ecological approach to other areas of psychology. The implications of Gibson's research go beyond the purely theoretical. He was instrumental in producing the first cinematic simulations of flying to use small cameras and miniature airfields to represent landings from a pilot's point of view. Gibson's novel conception of the retinal image[3] substituted dynamic, flowing imagery of the mobile observer for the static, picture-like image of classical optics. This inspired techniques of ground plane simulation and texture gradients that are the basis for many contemporary video games.

10.3.7 Invariants

In developing his radical ecological optics, Gibson (1979) focused on the practical successes of an organism's everyday behavior as it lives in and adapts to its environment. He was particularly concerned with characteristics and properties of the environment that supported such success.

Generalizing this interest, ecological psychologists investigate "information transactions between living systems and their environments, especially as they pertain to perceiving situations of significance to planning and execution of purposes activated in an environment" (Shaw, Mace, & Turvey, 1986, p. iii).

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[3] "... the natural retinal image consists of a binocular pair of ordinal structures of adjacencies and of successive transpositions and transformations of regions of texture delimited by steps or margins, which are characterized by gradients and changes in gradients" (Reed on Gibson, 1988, p. 136).

Ecological psychologists focus on ordinary everyday perceiving as a product of active and immediate engagement with the environment. An organism selectively "picks up" information in its habitat when such information is related to its ecological niche. In this context, it is useful to think of *habitat* as roughly equivalent to address, and *niche* as roughly equivalent to occupation.

While ecologists describe habitats in generally spatial terms, *niche* is essentially a thermodynamic concept. Selection pressure tends to drive "niche differentiation," in which two species competing for identical resources gradually come to exploit different resources. Since the perceptual capabilities of organisms are tuned to opportunities for action required to obtain enough energy and nutrients to reproduce, such perceptual capabilities also are shaped differentially by niche demands.

"Attunement to constraints" (attributed to Lashley, 1951, by Gibson, 1966) reflects the most fundamental type of information that an organism can obtain about its environment. With this in mind, ecologists such as von Foerster (1986) contend that "one of the most important strategies for efficient adjustment to an environment is the detection of invariance or unchanging aspects of that environment" (p. 82).

The detection of invariants—constrained and predictable relations in the environment—simplifies perception and action for any organism. Detection of invariants is also critical to successful adaptation by humans to any mediated environment. Perhaps the most ubiquitous invariants in media environments are the rectangular frames that contain moving and still images, bodies of text, and computer displays—pages, borders, windows, and the like.

The concept of invariance should not be taken so literally as to imply a complete lack of change in the environment. It is more useful to think of invariance as reliable *patterns of change* that organisms use as a background for detection of less predictable variation. Tide pool animals, for instance, are superb at detecting underlying patterns in the apparent chaos of the surf and adjusting their activity patterns to these fluctuations.

A beginning computer user who at first struggles to understand how movement of a mouse is linked to movement of a cursor will eventually come to understand "directly" and "intuitively" the higher order patterns that link movement of a handheld object across a horizontal surface with the changing position of a cursor on the vertical computer screen.

10.3.7.1 A Simple Experiment in Detecting Invariants. As an example of the importance of detecting invariants, consider the human visual system as it is often presented in simple diagrammatic models. Millions of rods and cones in the retina serve as a receptor array that transmits nerve impulses along bundled axons to an extensive array of neurons in the primary visual cortex. Neurons in this part of the brain are *spatiotopically mapped*—laid out in fields that preserve the spatial organization of the information captured by the retina. These fields of neurons then transmit information to specialized centers that process color, form, and motion.

There is much more to seeing than the processing of such retinal imagery. Seeing also integrates complex systems that focus lenses, dilate irises, control vergence and saccades, and enable rotation of the head and craning of the neck. Perception by the visual system of invariants in the environment can be thrown into complete confusion by interfering with the brain's detection of head and eye movement.

Try this simple experiment. Close your left eye and cock your head repeatedly to the side by two or three inches. Proprioceptors in your neck muscles allow the brain to assign this jerkiness to movements of your head rather than to changes in the environment. Without this natural ability to assign movement of retinal images to self-induced changes in head position, simply turning to watch an attractive person would "set one's world spinning."

Now close your left eye again and, keeping the right eye open, gently press on the right eyeball several times from the side. Your visual system now assigns roughly the same amount of eyeball jerkiness to radical movement of the environment itself. Your brain is temporarily unable to recognize the invariant structure of the environment and the walls of the room, furniture, or other spatial markers appear to be in motion.

Under normal circumstances, the brain does not attribute variation in retinal images resulting from head or eye movement to change in the environment. Rather, an elaborate system of proprioceptive and locomotor sensors operates automatically in concert with retinal data to generate a framework of perceptual invariants against which true environmental change can be detected.

10.3.8 Perception of Invariants: Some Implications for Media Design

Invariants remind us that the perceived quality or realism of mediated environments is not necessarily determined by the degree to which they approach arbitrary standards of "photographic" realism. Perceptual invariants play a key role in determining the degree of realism experienced by viewers.

Omissions of minor detail from a simulated road race—lug nuts on wheels, for example—are likely to remain unnoticed if they aren't connected to important tasks or goals. However, omitting key invariants that affect user actions are very likely to adversely affect perceived fidelity.

Gibson, for example, discovered that most people are very sensitive to texture gradients as cues to depth and distance. When a driver looks down a real asphalt road, the rough surface immediately in front of the car gradually transitions into an apparently smooth surface a few hundred feet away. The driver's perceptual system assumes that the "grain size" of the road texture is invariant, so the gradient suggests distance.

Texture gradients are also critical to realistic representations of depth in smaller spaces such as rooms. Thus, even when painters and computer artists follow rules of linear perspective and carefully render light reflection, pictures will look "flat" without such gradients.

While Gibson's work in the 1970s met with skepticism from his contemporary psychologists, he did generate a considerable following among human-factors engineers and ergonomicists and his work is now appreciated by virtual-world and interface designers. The central concern for these designers is how to engineer the relationship between perceptual variants and perceptual invariants so as to optimize the user's ability to perceive and act in complex, information-rich environments. The strongest invariants in such environments are ratios, gradients, calibration references, and optical flows tied to motion parallax, the ground plane, and ego perception (Gardner, 1987). By simulating the perceptual invariants that people use to navigate the real world, creators of virtual worlds invite exploration and action.

10.3.9 Perceptual Learning

Gibson did not believe that sensory inputs are "filtered" or processed by propositional or symbolic schemes. He favored a bottom-up paradigm in which exploratory action, rather than propositions, drives processes of selective perception. Yet none of Gibson's ideas preclude *learning* to perceive directly—as when children learn that they must automatically respond to icy sidewalks with flat-footed caution. Nor did Gibson deny the importance of "top-down" reasoning about perceptions—as when a mountaineer carefully analyzes the complex textures of an ice-covered cliff in planning an ascent.

Gibson believed that perceptual learning entails the tuning of attention and perception, not merely the conforming of percepts to concepts, as argued by many cognitive psychologists, or the linking of stimulus to response as posited by behaviorists. Perceptual learning is, in the words of Gibson's spouse, Eleanor, "an increase in the ability of an organism to get information from its environment as a result of practice with the array of stimulation provided by the environment" (E. J. Gibson, 1969, p. 77). In perceptual learning, the organism responds to variables of stimulation not attended to previously rather than merely emitting new responses to previously encountered stimulus. "The criterion of perceptual learning is thus an increase in specificity. What is learned can be described as detection of properties, patterns, and distinctive features" (Ibid).

10.3.10 Propositional Versus Nonpropositional Learning

Gibson's (1979) research on visual perception in everyday rather than laboratory situations led him to think of perceiving as a process in which organisms acquire information directly, without the mediation of propositional reasoning. Gibson thought our perception of objects and events is an immediate response to higher order variables of stimulation, not merely the end-product of associative processes that enrich otherwise meaningless sensations (Hochberg, 1974).

Gibson sometimes used the term "associative thought" in ways that implied that he meant propositional reasoning. Therefore, we have substituted the term "propositional reasoning" in this chapter when we discuss his ideas in order to avoid confusion with current usage of the term "associative," which is broadly inclusive of a variety of neurological processes. In any case, a brief review of the controversy regarding propositional and nonpropositional reasoning seems in order here (for more, see Vera & Simon, 1993, and Clancy's 1993 reply).

Cognitive psychologists and computer scientists have long used symbols and propositions to model human thought processes. Anderson's influential ACT* model (1983) was typical of rigorous efforts in the 1980s to use propositional logic to model learning. The ACT* model converted declarative knowledge—that is, knowledge that can be stated or described—into production rules through a process of *proceduralization*. The resulting *procedural knowledge* (roughly, skills) is highly automatic and not easily verbalized by learners.

Gordon (1994) offers this simplified example of how Anderson's (1983) notion of proceduralization might be used to model the way an agent learns to classify an object:

```
IF the figure has four sides
    and sides are equal
    and sides are touching on both ends
    and four inner angles are 90°
    and figure is black
THEN classify as [black] square.
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(p. 139; content in brackets added)

Such instructions might have some value as a script for teaching students about logic, or perhaps even as a strategy for teaching them to recognize squares. Yet even the most sophisticated computer models fail almost entirely to recognize more complex patterns and contexts when programmed to use this kind of reasoning even when such patterns are easily recognized by animals and humans.

There are other reasons to doubt assertions that the brain represents perceptual skills as propositions or production rules. While declarative knowledge expressed through language and propositions is obviously useful for teaching perceptual skills, the ultimate mechanisms of internal representation need not be propositional. The observation that propositions help people to learn to recognize patterns could be explained, for example, by a model in which propositional frameworks are maintained by the brain merely as temporary scaffolding ("private speech"; see Berk, 1994) that supports repeated rehearsal required for perceptual development. Once the perceptual skills have been automated, the brain gradually abandons the propositional representations and their encumbrance on processing speed. It then becomes difficult for learners to verbalize "how" they perceive.

Having decided that perceptual learning is not directly dependent on internalized propositions or production rules, many cognitive scientists have turned to models of non-symbolic representation. We suspect that Gibson would have found considerable support for many of his ideas in these models.

Kosslyn and Konig (1992), for instance, offers an excellent treatment of the ways in which connectionist models can explain the details of perceptual processing. Connectionist models (see also A. Clark, 1989) employ networks of processing units that learn at a *subsymbolic* level. These networks (also called *neural networks*) can be trained, without using formal rules or propositions, to produce required outputs from given inputs. The processing units mathematically adjust the weighting of connections through repeated trials. Neural nets are typically superior to proposition-based programs in learning tasks such as picture recognition.

A trained subsymbolic network cannot be analyzed or dissected to yield classical rules or propositions because the learned information is represented as weighted connections. The network represents learned information not stored as symbols or bits of code located at specific sites but in the fabric of connections. However, subsymbolic processing networks can serve as *substrates* for conventional symbolic processing and have shown some promise for modeling forms of human thought that *do* rely on symbols and language.

10.3.11 Affordances

In Gibson's (1974/1982) view, sensory information alone is insufficient for guiding and controlling the activities of living organisms. He believed that sensory discrimination was distinct from perceptual discrimination. Sensory discrimination accounts for properties that belong to objects—qualities that are measurable in concrete terms such as intensity, volume, duration, temperature, or timbre. Perceptual discrimination on the other hand, accounts for properties that belong to the environment—qualities that indicate opportunities for action. Therefore, perception involves meaning while sensation does not.

Selective perception generates much more information about an experienced event than can be obtained by sensation alone because during the selection process, the organism is informed by traces of its activities relating to location, orientation, and other conditions. In all but extreme laboratory settings, organisms employ the natural means available to them for locomotion in and manipulation of their environment—both to obtain additional information and to act on that information. For Gibson (1979), perception and action were inextricably and seamlessly coupled. To describe this coupling, he introduced the concepts of *affordances* (roughly, opportunities for action) and *effectivities* (roughly, capabilities for action).

Affordances are functional, meaningful, and persistent properties of the environment (J. J. Gibson, 1979)—"nested sets of possibilities" (Turvey & Shaw, 1979, p. 261) for activity. In active perceiving, "the affordances of things is what gets attended to, not the modalities, qualities, or intensities of the accompanying sensations . . . " (J. J. Gibson, 1977/1982, p. 289). In other words, organisms attend to functional properties and the opportunities implied by these properties rather than sensations and physical properties per se.

Thus, an affordance is a pathway for action that enhances the survivability of an organism in its niche: having a firm surface for support, a tree limb to grasp, or a mate. Gibson claimed that affordances such as these are specified by the structure of light reflected from objects, and are directly detectable. "There is, therefore, no need to invoke representations of the environment intervening between detection of affordances and action; one automatically leads to the other" (Bruce & Green, 1990, p. 382).

In the Gibsonian (1979) paradigm, affordances are opportunities for action rather than physical artifacts or objects. Nevertheless, it is useful to think of sets of affordances as bundled in association with tools or devices. The affordance of "browse-ability" is itself composed of clusters of affordances; one exploits the turnability of a book's pages in order to exploit the readability of their text. We can characterize a telephone by its "handle-ability," "dial-ability," "listen-to-ability," or "talking-into-ability"—affordances that in some cases serve multiple ends. The complete action pathway for realizing the opportunity afforded by a phone for talking to someone at a distance must be perceived, though not necessarily all at once, and "unpacked" through the effectivities of a human agent. Interface designers refer to this unpacking as *entrainment*.

It may seem peculiar or contrived to use *climb-ability* as an alternative to the familiar forms of the verb *to climb*. The grammar of most human languages is, after all, centered on action in the form "agent-action-object" or "agent-object-action." Organizing propositions in terms of action, however, is a serious limitation if one wants to describe mediated environments as complex fields of potentialities. The language of affordances and effectivities refocuses attention on *how* the environment structures activity rather than on descriptions of activities per se.

Affordances simultaneously enable some possibilities and constrain others. Hence, they make some actions more predictable and replicable, more closely coupled to, and defined by, the structure and order of the environment. This in no sense reduces the statistical variety of environmental features; rather, it is the affordance properties associated with these features that reduce the statistical variety in a population's perceptions and actions (Hawkins, 1964).

As a general rule, we can assume that organisms will not squander sensory or cognitive resources on aspects of the environment that have no value as affordances. Natural selection (or learning) will have effectively blinded organisms to objects and phenomena which they cannot exploit. "We see the world not as *it is* but as *we are,*" in the words of the Jewish epigram. To paraphrase this from the perspective of ecological psychology, organisms perceive the world not as it is, but as they can exploit it.

10.3.12 Automaticity

One of the reasons Gibson argued that direct perception is independent of deliberate reasoning is because, by definition, the properties of an affordance are persistent, even invariant. They are the knowns of the problem—the "climb-ability" of a branch for the squirrel, the "alight-ability" of a rock for the seagull, or the "grab-ability" of a deer for the wolf. Such affordances are perceived automatically as the result of repeated engagement with consistent circumstances—"hard wired" in the form of dendrites and synaptic connections.

Although Gibson almost certainly would have disagreed with the lexicon of Shiffrin and Schneider (1977), their seminal theories of automaticity, broadly conceptualized, overlap Gibson's concept of direct perception. Shiffrin and Schneider contrasted *automatic* and *controlled* cognitive processing. Automatic processing relies on long-term memory (LTM), requiring relatively little in the way of attentional effort or cognitive resources. Controlled processing, which is typically invoked when an individual is challenged by less familiar circumstances or some degree of novelty, relies much less on processing routines previously stored in LTM and therefore demands deliberate, effortful attention. Controlled and automatic processes can be viewed as ends of a continuum.

Mature human beings have typically developed tens of thousands of "automaticities." While the number of these automaticities may be less in other mammals, they are critical to success in complex environments. All mammals, humans included, are fundamentally limited in their ability to accommodate novelty. Moreover, the evidence is overwhelming that the development of human expertise proceeds primarily through a reinvestment of mental resources that become available as a result of automating interactions with environmental regularities.

Unfortunately, many laypersons associate the term "automaticity" with development of "automatons," people who resemble machines "by obeying instructions automatically, performing repetitive actions, or showing no emotion" (MSN Encarta, 2002). In any case, we use automaticity in this chapter to refer to capabilities that are so well developed as to minimize demands on working memory and other cognitive functions associated with conscious, controlled, deliberate processing.

Much of an organism's capacity to detect and respond to affordances results from encounters, that, over time—in the life of the individual or the species—are consistent enough to induce automaticity in perception and action. Affordances influence the interaction of the organism with its environment by enabling and constraining action and by entraining the organism's perceiving and acting in predictable, repeatable sequences.

In the natural calculus of planning and action, detection of the invariant properties of affordances allows some aspects of a situation to be stipulated or assumed, freeing cognitive resources to attend to unknowns—those aspects of the environment that vary in less predictable ways: Is this branch too thin? Are the waves too frequent? Is the bison too big?

10.3.13 Effectivities

Effectivities (roughly, capabilities), are intentional, meaningful properties of a perceiving organism that trigger, guide, and control ongoing activities directed toward exploiting inherent possibilities of affordances (Turvey, Shaw, Reed, & Mace, 1981). An effectivity encompasses the structures, functions, and actions that might enable the organism to realize an intention. Using its "climber-things," the squirrel exploits the climb-ability of branches to escape predators. Using its "alighter-things," the seagull exploits the alight-ability of rocks for rest. Using its "grabber-things," the wolf exploits the grab-ability of deer to obtain nutrients.

Effectivities are geometrical, kinetic, and task constrained. The geometric and kinetic constraints are measurable by external reference frames such as one's height or weight. Task constraints are more functional and "psychological," encompassing such factors as intentions, goals, or disposition (Mark, Dainoff, Moritz, & Vogele, 1991).

Affordances and effectivities are mutually grounded in and supported by both regularities of the physical structure of the environment and by psychosomatic structures of the perceiver. Affordances and effectivities are neither specific organs of perception nor specific tools of execution but rather emergent properties produced by interactions between the perceiver and his/her environment. It is meaningless to consider whether an object provides an affordance without also considering the nature of corresponding effectivities that some organism might employ to exploit that affordance to achieve the organism's intentions: A flat, two-foot-tall rock affords convenient sitting for a human, but not for a bull elephant.

A well-tuned relationship between affordances (opportunities) and effectivities (abilities) generates a dialectic, which Csikszentmihalyi (1990) argues, is experienced by humans as a highly satisfying "flow experience" (p. 67). Fundamental meaning is extant in the relationship of organisms to their environments. Here is our working definition of *ecological meaning: Those clusters of perceptions associated with the potential means—that is, affordances and effectivities—by which an organism pursues opportunities related to its ecological niche.* Our definition does not assume that organisms are conscious or that they use semantics or syntax. It does not necessarily assume that organisms are purposeful. However, our definition does assume that many organisms engage in activities that can be characterized as intentional or goal oriented.

Many biologists and psychologists would criticize these notions of intentionality or goal orientation, especially when applied to simpler forms of life. Intentionality implies teleological thinking and such critics typically hold teleology in disrepute because it has been associated with doctrines that seek evidence of deliberate design or purpose in natural systems—vitalism and creationism, for example.

A narrower conception of intentionality is convenient in studying self-organizing and cybernetic systems that involve feedback mechanisms. When input is controlled by output, resulting system stability tends to resist disturbing external influences. Thus, stability of output may be considered the "goal" of such a system (Gregory, 1987, p. 176). When ecological psychologists attribute intentions and goals to nonhumans, they typically do so in this more limited sense associated with functional maintenance of homeostasis (or in Maturana's (1980) terms *autopoesis*) rather than as an result of deliberate design or purpose.

10.3.14 Unification of Effectivities and Affordances

A curious phenomenon emerges in humans when effectivities engage with affordances. The affordances often seem to disappear from awareness. Winograd and Flores (1986) cite Heidegger's example of hammering a nail. The hammer user is unaware of the hammer because it is part of the background ("readiness-to-hand" in translations of Heidegger) that is taken for granted. The hammer is part of the user's world, but is not present to awareness any more than the muscles and tendons of the user's arm.

Likewise, a computer user is no more aware of a mouse than she or he is aware of his or her fingers. As observers, we may talk about the mouse and reflect on its properties, but for the user, the mouse does not exist as an entity although the user may be very aware of certain objects he or she is manipulating with the mouse.

Such skilled but unaware tool use is the hallmark of automaticity. It can also be seen in people who, having lost both arms, adapt their feet to function as secondary "hands." With time, such individuals often learn to write, type, even sew or play the guitar. Presumably the same neural plasticity that engenders such prehensile adaptation also allows amputees to become skilled users of prosthetic devices. Norman (1993) asks the next question in this progression: Is the neural "rewiring" that underlies prehensile and prosthetic adaptation essentially the same as the rewiring that supports highly skilled use of *discrete* tools such as hammers, pencils, keyboards, and computer mice? Are the underlying mechanisms of neural adaptation essentially the same whether we are using a body part or a tool?

While a foot is clearly an effectivity in Gibson's terms, should we think of a prosthetic foot as an effectivity or an affordance? And why should a computer mouse be considered an affordance when it's clearly a means for effecting action? These apparent inconsistencies can be resolved by thinking of the linked effectivities and affordances as a kind of pathway of opportunity. As the user becomes increasingly familiar with the interaction between his/her effectivities and the affordance properties of the tool, the effectivities merge psychologically with the tool.[4]

One can think of this union as an extension of the effectivity by the affordance or as establishment of a *way,* or *route* for action–perception. In everyday activity, the *routinization* of such effectivity–affordance pathways renders them "transparent" to the individual's conscious awareness.

Factors that influence the transparency and learnability of these pathways include:

(a) Availability of opportunities that users will perceive as relevant to his or her needs, wants, or interests;
(b) Tightness of coupling in real time ("feedback")—basically the immediacy and resolution with which users can perceive the results of his or her own actions;
(c) Invariants or regularities in the relationship between the users' actions and perceptions; and
(d) Opportunities for sustained and repeated engagement.

As a child uses a mouse to manipulate objects on a computer screen, the effectivity–affordance pathway for such manipulation becomes increasingly transparent and "intuitive." In less metaphorical terms, we can say that the child's consistent engagement with invariant structures associated with mouse movement (e.g., moving the mouse forward on a horizontal surface moves the cursor toward the top of the computer screen) automates patterns of action and perception associated with these invariants.[5] This in turn frees up cognitive resources for engaging more complex patterns which at first appear novel and then also reveal underlying invariant patterns. For example, most mouse control systems incorporate an "acceleration" feature which moves the mouse proportionately greater distances with a quick stroke than with a slow stroke.

As effectivity–affordance links become transparent, new affordances become apparent: an icon leads to a web page which leads to a password field which leads to a simple control system for a camera at the bottom of a kelp bed off the Southern California coast. With repetitive engagement, this entrainment of affordances progressively extends the user's effectivities, creating a reliable and robust pathway to new opportunities. And if the transparency is sufficient, the affordances seem to fall away as the user perceives directly and intuitively new possibilities in a distant world.

10.3.15 Extension of Effectivities and Breakdown

Eventually, the action–perception pathways formed through coupling of effectivities and affordances rupture and corresponding opportunities for immediate action diminish or terminate. Heidegger's hammer reemerges in awareness when it breaks or slips from the user's hand or if the user wants to drive a nail and the hammer cannot be found (Winograd & Flores, 1986). Dirt accumulates on the mouse ball and the mouse no longer provides an accurate reading of x-y coordinates. Thus, as most readers know, the mouse loses its transparency and becomes annoyingly obvious.

In terms of ecological psychology, we can think of the reemergence of the mouse to awareness as a kind of decoupling of an effectivity from its corresponding affordances. Such decoupling ("breakdown" in most translations of Heidegger) advances awareness and understanding by "revealing to us the nature of our practices and equipment, making them 'present-to-hand' to us, perhaps for the first time. In this sense they function in a positive rather than a negative way" (Winograd & Flores, 1986, p. 78).

This reminds us that while automaticities play a critical role in constructing human competencies, broader aims of education almost always involve challenging and reshaping automaticity of perception and action. Efforts to help students to surface and confront highly automatic stereotypes, prejudices, and misconceptions often involve arranging circumstances that force

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[4] The psychological and cultural reality of this unification has become an enduring literary theme, from Thoreau, who warned that "Men have become the tools of their tools" to Antoine de Saint Exupéry (1939) who waxed rhapsodically about unification with his airplane. Exploration of the relationship of effectivities and affordances also underlies postmodern literary exploration of the prospects and pitfalls of cyborgian culture.

[5] Readers wishing to simulate early childhood mouse learning may want to try turning their mouse around so the cord or "tail" points opposite the normal direction (towards the computer screen). This effectively inverts the mouse's x-y coordinate system, removing some of the interface transparency available to skilled mouse users. In Heidegger's framework, this "breakdown" of normal "readiness-to-hand" reveals properties of the mouse that are rarely "visible" to skilled users.

students to experience "breakdowns" in automatic cognitive processes.

Thus, metaphorically, educators search for ways to "add dirt to the mouse ball," so as to help students see the nature of their dispositions and practices—making automated, transparent processes visible, making nonproblems problematic. Reasoning and propositional logic can play a role in structuring such challenges. "Only critical vision," in the words of Marshall McLuhan (1965), can "mitigate the unimpeded operation of the automatic."

The Constructing Physics Understanding (CPU) curriculum discussed later in this chapter develops this critical vision by asking students to develop theories and models that explain familiar phenomena. The students then examine the adequacy of these theories and models by interacting with real and simulated laboratory apparatus. CPU pedagogy assumes that challenging students to make explanatory ideas explicit and testable forces the students to confront the inadequacy of their ideas and fosters a search for ideas with greater predictive validity and explanatory power.

10.3.16 Everyday Learning and Media Environments

For Gibson, the world of everyday learning and perception was not necessarily the world as described by conventional physics textbooks, not the world of atoms and galaxies, but the "geological environment:" earth, water, sky, animate and inanimate objects, flora and fauna. Gibson insisted that these sources of information must be analyzed in ecological, rather than physical, terms. "Psychology must begin with ecology, not with physics and physiology, for the entities of which we are aware and the means by which we apprehend them are ecological" (cited in Reed, 1988, p. 230).

The popularity of Donald Norman's (1990) book, *The Design of Everyday Things,* which shares key ideas with Gibson's work, testifies to an increased awareness by the general public that media engineers and scientists must look beyond the merely physical properties and attributes of systems. In an age of post-industrial knowledge workers, human habitats and artifacts must accommodate mentality as well as physicality, and support creativity as well as consumption. Cognitive ergonomics (Zucchermaglia, 1991) is becoming just as important as corporal ergonomics. Both depend on understanding fundamental human capabilities that were tuned by ecological circumstances long ago.

If new media are to support the development and use of our uniquely human capabilities, we must acknowledge that the most widely distributed human asset is the ability to learn in everyday situations through a tight coupling of action and perception.

10.3.17 Direct Perception, Context Sensitivity, and Mechanicalism

> The modern theory of automata based on computers . . . has the virtue of rejecting mentalism but it is still preoccupied with the brain instead of the whole observer in his environment. Its approach is not ecological. The metaphor of inputs, storage, and consulting of memory still lingers on. No computer has yet been designed which could learn about the affordances of its surroundings. (J. J. Gibson, 1974/1982, p. 373)

In the process of reinventing the concept of retinal imagery that underlay his radical theoretical postulates concerning perception, Gibson (1966) implicitly relied on the context and situatedness of ambulatory vision. In his empirical research, he paid particular attention to the boundary conditions that affect and constrain visual perception in everyday living. This investigatory focus led Gibson to findings that he could not explain within the paradigms of the positivist tradition. Thus, Gibson was forced to rethink much of what psychologists had previously supposed about perception and to propose a new approach as well as new theoretical concepts and definitions.

Positivism, in addressing questions of perception and knowledge, relies almost exclusively on the conventional physicist's characterization of reality as matter in motion in a space–time continuum. This "mechanicalism" of Newtonian physics and engineering is allied with sensationalism—a set of assumptions permeating philosophy, psychology, and physiology since the beginning of the modern era.

Roughly speaking, sensationalism maintains that only that which comes through the senses can serve as the basis for objective scientific knowledge. Sensations, however, as Gibson consistently argued, are not specific to the environment: "They are specific to sensory receptors. Thus, sensations are *internal states* that cannot be used to ensure the objectivity of mechanistic descriptions. Gibson argued that what has been left out of the picture in most twentieth-century psychology is the active self observing its surroundings" (Reed, 1988, p. 201).

Conventional psychology, with its roots in positivism, relies on sensationalism and mechanicalism to treat perception as a mental process applied to sensory inputs from the real world. This treatment of perception, however, fails to bridge the gap between (a) incomplete data about limited physical properties such as location, color, texture, and form, and (b) the wider, more meaningful "ecological awareness" characterized by perception of opportunities for action.

Such actions are not always easy to describe within the confines of traditional Cartesian metrics. Ecological psychologists employ "geodesics" (Kugler, Shaw, Vincente, & Kinsella-Shaw, 1991, p. 414) to complement mechanistic systems of description. Examples of geodesics are least work, least time, least distance, least action, and least resistance. Ecological psychology conceives of these pathways as "streamlines" through the organism's niche structure.

Ecological psychologists often think of habitats as environmental layouts rather than as simple traversals of Cartesian space. Geodesics are constrained by factors such as gravity, vectors associated with the arc of an organism's appendages or sensory organs, and energy available for exertion. For a simple example of geodesics, consider how cow paths are created by animals avoiding unnecessary ascents and descents on an undulating landscape. In addition to serving as records of travel through Cartesian space, the paths reflect cow energy expenditure and the ability of the cows to detect constraints imposed by gravity.

Geodesics are essentially a thermodynamic construct and as such can be applied to human activity in media environments. Optimal perceiving and acting in mediated environments does not necessarily follow boxes, frames, or other contrivances based on arbitrary grids imposed in the Cartesian tradition such as pages, tables, rules, keyboards, or screens. True optimums for action and perception must be measured in terms of cognitive and corporal ergonomics rather than the metrical efficacy assumed by a one-grid-fits-all-organisms approach. Designing keyboards to conform to a grid may simplify circuitry and manufacture, but such keyboards may strain the human wrist.

Media designers and researchers can use geodesic analysis to study how users interact with print and computer-based media by, for example, tracking the extent to which users recognize opportunities for action afforded by features such as headers, indexes, icons, "hot buttons," and modal dialog boxes. In terms of thermodynamic efficiency, skilled use of short cuts and navigational aids to wend one's way through a media environment is similar to the challenge faced by the cows: What pathway of action yields the desired result with the least expenditure of energy?

10.4 ECOLOGICAL VERSUS EMPIRICAL APPROACHES

> The act of perceiving is one of becoming aware of the environment, or picking up of information about the environment, but . . . nothing like a ***representation*** of the environment exists in the brain or the mind which could be in greater or lesser correspondence with it—no "phenomenal" world which reflects or parallels the "physical" world. (J. J. Gibson, 1974/1982, pp. 371–372)

Gibson (1979) found himself at odds with both the fading metaphors of behaviorists who often likened the brain to a mechanical device and the emergent metaphors of the cognitivists who frequently spoke of the brain as an information processing computer. One of his important insights was that *actions* involved in detecting and selecting information are just as important to subsequent understanding of what is perceived as the processing of sensory stimuli. As in the sport of orienteering—the use of a map and compass to navigate between checkpoints along an unfamiliar course—locomotion informs perception by providing critical data regarding origin, path, and orientation.

Gibson's ideas about the importance of orientation led him to question the mind–body dualism of behaviorists and cognitivists who treated the brain metaphorically as a mechanical device or computer and therefore made it seem reasonable to separate mind from body. Essentially, Gibson converted this ontological dualism into a useful tool to distinguish differences in observational conditions regarding stimulus variables (J. J. Gibson, 1979).

According to Reed (1988), this methodological innovation led Gibson to a novel distinction between *literal* and *schematic* perceptions. Gibson realized that laboratory psychophysical experiments are often arranged so that subjects will make the best observations of which they are capable, resulting in perception that is veridical and accurate—the "literal visual world." Experiments that employ impoverished or ambiguous stimulation or that constrain observation time typically result in schematic perception. While such "quick and dirty" perception usually grasps the gist of situations, it is notoriously prone to inaccuracies and errors.

Perhaps Gibson's (1979) greatest doubt about information processing models was the emphasis they placed on analytical processing of stimulus information at the expense of processes involved in *detection* and *selection*. Thus, information processing models of the last three decades have tended to minimize the *context* of stimuli—their locality, temporality, and relatedness to other factors in the environment and in the organism.

10.4.1 Situation and Selectivity

In place of a sensation-based theory of perception, Gibson (1974/1982) proposed a theory based on situations and selectivity: Perception entails detecting information, not the experiencing of sensations. Rather than building his theories around an idealized perceiver, or an objective "God's Eye View" (Putnam, 1981), Gibson opted for a real, everyday perceiver, with all the possibilities and limitations implied by ordinary contexts. He situated this perceiver in an environment populated by ordinary, everyday people, living organisms, and natural as well as artificial affordances, rather than imagining the perceiver in an objectively accessible world defined and measured by conventional, mechanistic physics.

Gibson also appropriated familiar terms to create a new ecological vocabulary designed to complement the lexicon of physics (Reed, 1988):

1. Substances, surfaces, and media as complements for matter;
2. Persistence and change as complements for space and time;
3. Locomotion as a complement for motion; and
4. Situatedness in a niche as a complement for location in space and time.

Gibson's (1979) development of ecological theory began with studies of the properties of surfaces. He identified several issues that have become important to designers of virtual realities and simulations. He noted that surfaces are not discrete, detached objects but are nested within superordinate surfaces. According to Gibson, a surface does not have a location—a locus—as does an object, but is better thought of as situated relative to other surfaces in an "environmental layout" (1979, p. 351).

The concept of environmental layouts reflects a persistent concern expressed in the writings of ecological psychologists that successful systems of formal description and analysis employed by classical physics have been misapplied in describing fields of action and perception available to organisms.

There is little doubt that descriptions derived from classical physics are well suited to disciplines such as mechanical engineering and even biomechanics. Nevertheless, if we infer from thermodynamic principles that opportunities for action are ultimately determined by complexity of organization rather than space and time per se, then the usefulness of space–time grid maps for analyzing and explaining organic behavior is only partial. Such Cartesian representations can be complemented by environmental layout maps that indicate opportunities and pathways for action and perception.

Critics such as Fodor and Pylyshyn (1981) have questioned the empirical foundations of ecological psychology, demanding that its new lexicon be verified within the conventions of laboratory-bound experimentalism. On the other hand many ecological psychologists (e.g., Johansson, 1950; Koffka 1935; Lashly, 1951; McCabe, 1986; and Turvey, Shaw, Reed, & Mace,1981) share concerns with field biologists and anthropologists that excessive reliance on laboratory experiments often results in factual but misleading findings based on unrealistic contexts. Indeed, some of the most serious conceptual errors in the history of psychology—errors that misled researchers for decades—began with naive attempts to remove phenomena from their natural contexts. We would argue that context effects are impossible to eliminate, and that we should not try to eliminate them totally, but study them. There is no zero point in the flow of contexts. They are not merely incidental phenomena that confound experiments: They are quintessential in psychology. “There is no experience without context” (Baars, 1988, p. 176).

Like many other life scientists, Gibson (1979) had to defend his ideas against some fairly vociferous opponents. Many of his defenses were polemical. In our reading of his work, we have learned to tolerate an imprecision in terminology and syntax that unfortunately left his ideas and arguments open to misunderstanding and marginal criticism. Nevertheless, we believe Gibson’s views on empiricism reflect the philosophical dispositions of many ecological psychologists and offer a basis for reconciling current conflicts between constructivist thinking and traditional scientific paradigms.

First, empiricism can be distinguished from objectivism. Eschewing objectivist theories of description need not imply abandonment of the scientific method, only rejection of unwarranted extensions that impute to human descriptions of reality a God-like objective status. Second, the risks of misunderstanding inherent in cultural relativism, objectivism, and scientism can be ameliorated if reports of empirical observations are taken as instructions to others about how to share, replicate, and verify findings and experiences rather than as veridical descriptions of reality.

10.4.2 Indirect Perception, Mediated Perception, and Distributed Cognition

> Our species has invented various aids to perception, ways of improving, enhancing, or extending the pickup of information. The natural techniques of observation are supplemented by artificial techniques, ***using tools for perceiving by analogy with tools for performing***. (J. J. Gibson, 1977/1982, p. 290; emphasis added)

Although he never developed a clear definition or theory of indirect perception, Gibson clearly considered it an important topic and recognized degrees of directness and indirectness. His writing on this issue, which consists mostly of unpublished notes, is inconsistent—as if he were still vacillating or cogitating about the idea. While we have found the concept of *direct perception* useful as an approximate synonym for perception that is mostly automatic, we will only briefly summarize Gibson’s views on indirect perception here.

According to Gibson, indirect perception is assisted perception: “the pick-up of the invariant in stimulation after continued observation” (1979, p. 250). Reed suggests that Gibson’s preliminary efforts to distinguish direct and indirect forms of perception assumed that (a) ambient energy arrays within the environment (e.g., air pressure, light, gravity) provide the information that specifies affordance properties and (b) the availability of these arrays has shaped the evolution of perceptual systems. Gibson thought the exploratory actions of an organism engaged in perceiving energy arrays evidenced the organism’s “awareness” that stimulus information specifies affordance properties relevant to the requirements of its niche. On the other hand, Gibson recognized that “simpler pictures” can also support direct perception.

Gibson referred to knowledge gained through language and numbers as *explicit* rather than direct and noted that “not all information about the world can be captured by them” (J. J. Gibson, 1977/1982, p. 293). Gibson also argued that symbols (i.e., *notational symbols* in Goodman’s 1976 sense) are quite different from pictures and other visual arrays. He believed that symbols constitute perhaps the most extreme form of indirect perception because symbolic meanings are derived via association:

> The meaning of an alphanumeric character or a combination of them fades away with prolonged visual fixation, unlike the meaning of a substance, surface, place, etc. . . . They make items that are unconnected with the rest of the world. Letters can stand for nonsense syllables (but there is no such thing as a nonsense place or a nonsense event). (1977/1982, p. 293)

Like other ecological psychologists, Gibson recognized the constructive nature of indirect perception, especially the important role that it plays in the creation and use of language. He argued that language helped fix perceptual understandings. However, since the range of possible discriminations in most situations is unlimited, selection is inevitable, “the observer can always observe more properties than he can describe” (J. J. Gibson, 1966, p. 282).

10.5 DISTRIBUTED COGNITION

We argued earlier that humans and other organisms may benefit from a thermodynamic “leverage” when they can off-load information storage and processing to nonbiological systems such as mediated representations and cognitive artifacts.

Such off-loading may require improved perception—more reliable access to external information. It is not always easy to compare the “costs” associated with internal and external representation because the information is often allocated dynamically between internal and external storage-processing systems. For example, after repeatedly forgetting some information item, one might decide to write it down (external, mediated representation), or alternatively, to make a deliberate effort to memorize it (internal representation). Computer designers and users similarly attempt to optimize dynamics of storage and processing between *internal* mechanisms (fast, but energy-consuming and volatile CPUs and RAMs) and *external* media (slow but energy-efficient and stable DVDs and CDs).

Where humans are concerned, such dynamic allocation of storage and processing can be modeled as *distributed cognitive tasks*—defined by Zhang and Norman (1994) as "tasks that require the processing of information across the internal mind and the external environment" (p. 88). Zhang and Norman conceive of a *distributed representation* as a set of representations with (a) *internal* members, such as schemas, mental images, or propositions, and (b) *external* members such as physical symbols and external rules or constraints embedded in physical configurations. *Representations* are abstract structures with referents to the represented world.

Zhang and Norman (1994) propose a theoretical framework in which internal and external representations form a "distributed representational space." Task structures and properties are represented in "abstract task space" (p. 90). Zhang and Norman developed this framework to support rigorous and formal analysis of distributed cognitive tasks and to assist their investigations of "representational effects [in which] different isomorphic representations of a common formal structure can cause dramatically different cognitive behaviors" (p. 88). Figure 10.3 freely adapts elements of the Zhang–Norman framework (1994, p. 90) by substituting MIROS for "internal representational space" and by further dividing external representational space into media (media space) and realia (real space).

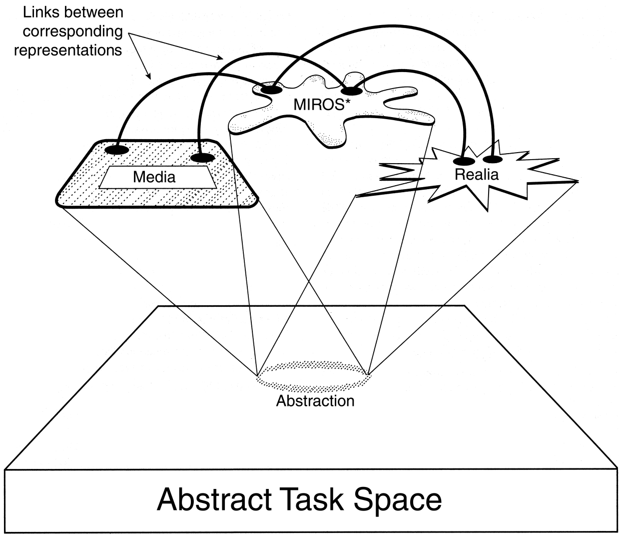

FIGURE 10.3. **A tripartite framework for distributing cognition among media, realia, and mental–internal representations of situations (MIROS).** Freely elaborated from Zhang and Norman (1994, p. 90), this framework subdivides external representational space into media space (media) and real space (realia). The framework does not assume that corresponding elements in three spaces will necessarily be isomorphic in function or structure. On the contrary, there are usually profound differences.

We do not propose in this chapter to rigorously define mutually exclusive categories for media and realia. There are many types of hybrids. Museums, for example, often integrate realia with explanatory diagrams and audio. Recursion is also a problem: A portrait of George Washington is of interest as a physical artifact and also as a mediated representation of a real person; a spreadsheet program may include representations of itself in online multimedia tutorials. Our modification of the Zhang–Norman framework distinguishes real space from media space nevertheless because there are often considerable differences between the affordance properties of realia and the affordance properties of media.

Our adaptation of the Zhang–Norman model does not assume that corresponding elements in the media space, real space, and internal representational space will necessarily be isomorphic in function or structure. On the contrary, there are often profound differences between the way information is structured in each space. Furthermore, as we noted earlier, MIROS vary in completeness and complexity. As Zhang and Norman (1994) demonstrated in their study of subjects attempting to solve the Tower of Hanoi problem, incongruent internal and external representations can interfere with task performance if critical aspects of the task structure are dependent on such congruence.

Whatever the degree of correspondences between the structures of media, MIROS, and realia, external representations allow individuals to distribute some of the burden of storing and processing information to nonbiological systems, presumably improving their individual thermodynamic efficiency. A key to intelligent interaction with a medium is to know how to optimize this distribution—to know when to manipulate a device, when to look something up (or write something down), and when to keep something in mind.

Of course media and realia can also support construction of MIROS that function more or less independently of interactions with external representational space. Salomon (1979, p. 234) used the term *supplantation* to refer to internalization of mediated representations as when viewers perform a task after watching a videotaped demonstration. Salomon thought of such learning by observation, not as a simple act of imitation, but as a process of elaboration that involves recoding of previously mastered constituent acts.

Distributed cognition informs the design of more efficient systems for supporting learning and performance. Yet new representational systems afforded by emergent computer and telecommunications technologies will challenge media researchers and designers to develop better models for determining which aspects of a given situation are best allocated to media or realia, and which are best allocated to MIROS.

10.6 MEDIA AND MIROS

> To describe the evolutions or the dances of these gods, their juxtapositions and their advances, to tell which came into line and which in opposition, to describe all this without visual models would be labor spent in vain. (Plato, *The Timaeus*)

Gibson's (1977/1982) insights about visual displays remind us that, like other primates, humans have well-developed faculties for managing information about objects and spaces when that information is derived through locomotor and stereoscopic functions.

As mediated perception extends and substitutes for direct perception, so do the affordance properties of mediated environments extend and substitute for the affordance properties of real environments. Effective use of media requires that users understand implicit conventions and explicit instructions that guide them in constructing the MIROS required to compensate for missing affordance properties of mediated representations—the properties that are lost when such things are represented by text descriptions, pictures, functional simulations, and the like.

Media technologies impose profound constraints on representation of real or imaginary worlds and require tradeoffs as to which aspects of a world will be represented. A topographical map, for instance, represents 3-D landforms on a 2-D surface. For much of the 20th century such maps were constructed through electromechanical processes in which numerous aerial photos taken from different angles were reconciled to yield a single image. Aided by human interpreters, this process encoded some of the visual indications of affordance properties available to actual aerial observers—shadings, textures, angles, occlusions, for instance—as well as ways the values for these properties change in response to the observer's movement. The original affordance information—the climb-ability and walk-ability of the terrain, for example—was represented on the map as a flat image that indicated elevation through contour intervals and ground cover or other features through color coding. Much of the information detected by the aerial observer was thus available vicariously to map viewers, *provided* that the viewers could use the affordances of the map—contours, color coding, legends, grids—in concert with their mental models of map viewing to imagine the affordances of the actual terrain. Thus,

$$\textit{Media} + \textit{MIROS} \approx \textit{Realia}.$$

Mediated habitats encompass a range of affordances and effectivities related to cognitive artifacts such as a book, a calculator, or a television. These artifacts do some of the work of storing and transforming information and thus lessen the user's need to construct or maintain more complex MIROS. But such artifacts also afford opportunities to engage in reasoning. "Reasoning is an activity that transforms a representation, and the representation affords that transformational activity" (Greeno, Moore, & Smith, 1993, p. 109).

10.6.1 Depiction

Pictorial representations of complex environments often pose problems for writers of captions and narratives. Picture captions also impose task-irrelevant cognitive processing burdens when readers must hunt through large bodies of text to find and correlate descriptions with depictions. A typical illustration (see Fig. 10.4) and its caption from *Gray's Anatomy* (Gray, 1930, p. 334) makes it clear that, lacking information about the viewpoint of the artist, and lacking information about more subtle relationships between the components depicted in the drawing, viewers will be unable to construct a suitable MIROS to complement mediated representations.

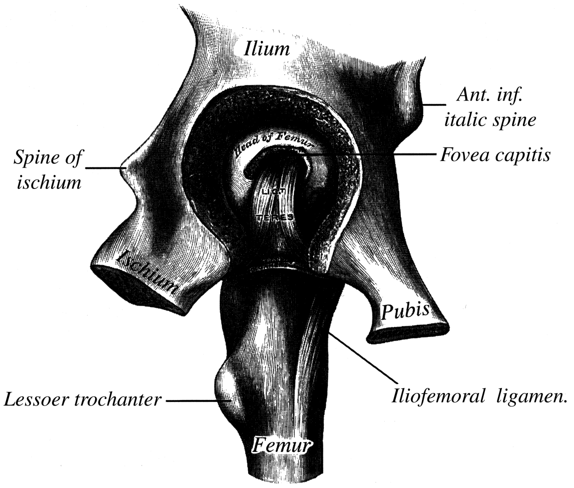

FIGURE 10.4. A drawing from *Gray's Anatomy* (1930, p. 334).

Fortunately, anatomists have developed a rich lexicon for describing relationships between viewers and depictions. For example, the text description matched to the preceding figure from *Gray's* reads:

> The ligament teres femorais is a triangular, somewhat flattened band implanted by its apex into [a small pit on the head of the femur]; its base is attached by two bands, one into either side of the ace tabular notch . . . (p. 334).

Using only propositions to tell people about how to construct a MIROS for a 3-D structure may be a misappropriation of cognitive resources if better means are feasible—a physical or pictorial model, for instance. The issue is partly a matter of instructional intent. Designers of an anatomy course might decide to use animated 3-D renderings of a situation—with orienting zooms and pans—to teach gross structure. If the goal is to teach spatial nomenclature as preparation for dissection through a particular structure, however, the designers might select a strategy with less emphasis on explicit visual representation of operations and more emphasis on narration. The two approaches are not mutually exclusive.

10.6.1.1 Photography. Consider the camera as a tool for capturing photographic images. A photograph excludes large quantities of information that would have been available to bystanders at the scene who could have exercised their powers of exploratory action, ranging from gross motor movements to tiny adjustments in eye lenses. To create a photographic image, the photographer selects a single viewpoint in space and time, one of many possible viewpoints.

A subsequent user of the photograph might be able to manipulate the position and orientation of the photo itself, take measurements of objects as they are depicted, and engage in selective visual exploration. However, such exploration will be an imperfect substitute for ambulatory perception at the original scene. Both the user's perception of the depictions in photographs and the user's interpretation of these depictions require prior knowledge of conventions of photographic culture as well as knowledge of ways in which photography distorts situational factors such as orientation, distance, texture, hue, contrast, and shadows. The user's ability to perceive and interpret the photo may be enhanced if he or she can integrate information in the photo with adjunct–verbal information such as captions, scales, and dates that, however inadequately, support development of MIROS complementary to depiction of the actual situation.

Scanning a photo is not the same as scanning a scene, although ecological psychologists will argue that much is similar about the two acts. Viewing a scene vicariously through a photo frees one of the need to monitor or respond immediately to events depicted in it—permitting, even promoting, reflection not possible at the scene.

10.6.1.2 Cinematography. Cinematographs record the transformation of imagery as a camera moves through multiple viewpoints. Like photographs, cinematographs evoke mediated perceptions in the end user which are fundamentally decoupled from the exploratory ambulation that would have been possible in the actual situation. In other words, attention is partially decoupled from action and from intention: Viewers can attend to changes in imagery, but are unable to affect these changes or engage in exploratory actions.

Conventional cinematography substitutes camera dynamics for dimensionality by recording the way the appearance of objects transforms in response to motion parallax associated with camera movement. Reed (1988) suggests that more importantly cinematographs establish invariant structure by presenting the environment from many viewpoints. Filming multiple views of a scene helps viewers to construct MIROS representing the unchanging physical layout of objects and events.

However, film directors and editors must work carefully to orchestrate camera movement and shot sequences so they help viewers build a consistent understanding. Beginning film students fail to do this when they "cross the director's line" by splicing two shots of a scene taken from opposite positions on a set. By omitting a "traveling shot" showing the camera's movement from one side of the scene to the other, the spliced sequence will depict a strange violation of assumptions about the invariant structure: the whole environment will suddenly appear to flip horizontally so that actors and props on the left suddenly appear on the right and visa versa.

Reduced possibilities for ambulation when viewing conventional film and video remind us of the importance of exploration in mammalian perceptual development. Numerous studies demonstrate that interfering with proprioception and ambulation retards adaptation by mammalian visual systems. For example, when experimenters require human subjects to view their surroundings through an inverting prism apparatus, the subjects adapt to the upside-down imagery after several weeks, achieving a high degree of functionality and reporting that their vision seems "normal" again (Rock, 1984). This adaptation does not occur, however, if the experimenters restrict the subjects' kinesthetic and proprioceptive experience or subjects' ability to engage in self-controlled locomotion.

In a study more directly related to use of media in education and training, Baggett (1983) found that subjects who were denied an opportunity to explore the parts of a model helicopter were less effective at a parts-assembly task than subjects who explored the parts in advance—even though both types of subjects saw a videotape depicting the assembly process before performing the task.

POWERS OF TEN:
LANGUAGE AND INDIRECT PERCEPTION

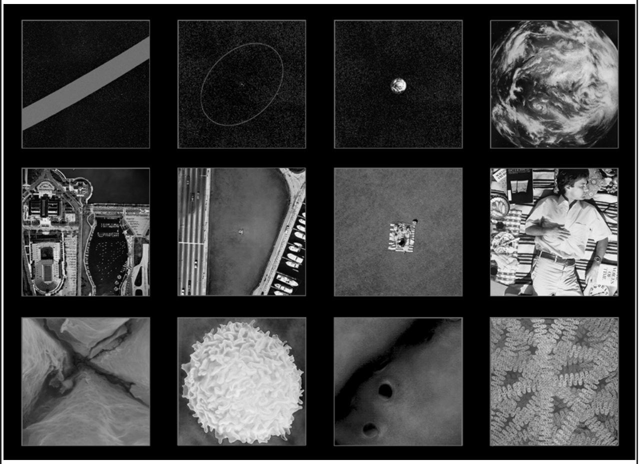

FIGURE 10.5. **Images from *Powers of Ten*** (courtesy of The Office of Charles and Ray Eames, http://www.powersof10.com)

The short film *Powers of Ten* (C. Eames & R. Eames, 1977/1986) offers a neatly constrained example of language as an aid to interpreting mediated representations. Created by the Office of Charles and Ray Eames to help viewers grasp "the relative size of things in the universe," *Powers of Ten* opens on a picnic blanket in Chicago, initiating a trip that takes the viewer to the farthest reaches of universe and back. The trip ends nine and one-half minutes later, in the nucleus of a carbon atom embedded in the hand of a man lying on the blanket. The film version of *Powers of Ten* is now available in CD-ROM and DVD versions with extensive collateral material.

Such a visual experience would be meaningless for many viewers without a verbal narrative guiding interpretations of the film's rapidly changing imagery which includes diverse depictions ranging from galaxies, to the solar system, to Lake Superior, to a cell nucleus, to the DNA double helix. The book version of *Powers of Ten* (Philip Morrison & Phylis Morrison, 1982) displays 42 frames from the film, supplemented by elaborative text and supplementary photos. The authors use a set of "rules" (pp. 108–110) to describe the film's representation of situations including propositions such as . . .

Rule 1. The traveler moves along a straight line, never leaving it.

Rule 2. One end of that line lies in the darkness of outermost space while the other is on the earth in Chicago, within a carbon atom beneath the skin of a man asleep in the sun.

Rule 3. Each square picture along the journey shows the view one would see looking toward the carbon atom's core, views that would encompass wider and wider scenes as the traveler moves further away. Because the journey is along a straight line, every picture contains all the pictures that are between it and the nucleus of the carbon atom . . .

Rule 4. Although the scenes are all viewed from one direction, the traveler may move in either direction, going inward toward the carbon atom or outward toward the galaxies . . .

Rule 5. The rule for the distance between viewpoints [is that]. . . each step is multiplied by a fixed number to produce the size of the next step: The traveler can take small, atom-sized steps near the atom, giant steps across Chicago, and planet-, star-, and galaxy-sized steps within their own realms.

The Morrison rules can be taken as an invitation to propositional reasoning. Yet the rules can also be construed as instructions for constructing a MIROS that complements and partially overlaps the work of representation carried out by the film. Rule 2, for example, provides a framework for the reader to imagine moving back and forth on the straight line connecting the starting point (outermost space) and ending point (carbon nucleus), thus substituting for the action of the imaginary camera "dollying" (moving forward) across outer and finally inner space. Rule 3 describes the way in which each square picture encompasses a wider or narrower scene.

Rules 2 and 3 can also be directly perceived in the film itself by attending to the symmetricalness of image flow as various objects and structures stream from a fixed center point and move at equal rates toward the edge of the visual field. The film also depicts movement via changes in the texture gradients of star fields and other structures. Such cues to both movement and direction epitomize the appropriation by filmmakers and other media producers of visual processing capabilities that are widespread among vertebrates, and as common among humans as a jog on a forest trail or a drive down a two-lane highway.

What viewers cannot obtain by direct perception of either the film or the photos, however, is information indicating deceleration of the hypothetical camera as it dollies toward earth. Rule 5, which concerns the logarithm governing the speed of camera motion, cannot be perceived directly because (a) the camera motion simulates a second-order derivative (deceleration rather than speed) that humans cannot distinguish from gravity and (b) because the objects flowing past the camera are largely unfamiliar in everyday life and therefore have little value as scalars.

10.6.2 Collapsing Multivariate Data

The limitations of photography and cinematography reflect the central challenge for authors and designers of other media products: how to collapse multivariate data into flat, 2-D displays while optimizing the ability of the end user to exploit the affordances of the displays.

As Tufte explains in *Envisioning Information* (1992), techniques for collapsing multivariate data to paper-based representations involve opportunities as well as constraints. Yet Tufte believes most of our methods for representing multidimensional data on 2-D surfaces are a hodgepodge of conventions and "particularistic" solutions. "Even our language, like our paper, often lacks immediate capacity to communicate a sense of dimensional complexity" (p. 15). Tufte quotes Paul Klee on this issue: "It is not easy to arrive at a conception of a whole which is constructed from parts belonging to different dimensions . . . For with such a medium of expression, we lack the means of discussing in its constituent parts, an image which possesses simultaneously a number of dimensions" (cited in Tufte, 1992, p. 15). On the other hand, as Tufte so richly illustrates, tradeoffs so necessary to successful compression of a data set with four or five variables into a 2-D representation may serve the end user very well if the sacrificed data would have been confusing or superfluous.

Regardless of medium, designers and producers must always sacrifice options for exploratory action that would have been available to unimpeded observers or actors in the represented situation. Media cannot represent realia in all their repleteness. What is critical is that enough information be provided so that users can construct useful, actionable mental models appropriate to their needs and goals.

10.6.3 Distributed Cognition and the Construction of Physics Understanding

How might educational product designers apply the tripartite framework of distributed cognition reflected in Fig. 10.3? Constructing Physics Understanding (CPU) represents a rethinking of the relationship between media, mental models, and realia as well as a rethinking of the roles of students and teachers (CPU, 2002). Led by San Diego State University professor Fred Goldberg, the CPU development team designed a physics curriculum based on student investigations of the interplay between experiments involving real and simulated laboratory apparatus.

These apparatus simulators include special part and layout editors that allow students considerable flexibility in varying the organizations and components of any particular apparatus. Students can use the simulator to view a particular layout in different modalities, each with its own representational conventions.

A current electricity simulator, for example, allows students to connect various types of virtual batteries, bulbs, and switches in different combinations and thereby test theories of current flow. One view of the simulator represents the components and interconnections fairly concretely as "pictorial" representations seen from a high angle and rendered with simplified color, shading, and depth cues. The students can also switch to a formal circuit diagram representing the same setup. When students make changes in one view, these changes are immediately updated in the other view. However, only the pictorial view represents events such as the illumination of a light bulb.

This approach provides opportunities to correlate different representations of similar setups and to reconcile differences in representational conventions. The students come to learn, for example, that while illuminating a "real" or "pictorial" bulb requires that it be connected to a battery with two wires, the corresponding circuit diagram represents these wires with a single line.

CPU designers also struggle to reconcile differences in representational capabilities. Illumination of bulbs in the real apparatus for studying electrical currents ranges from a dull red glow to white hot. But computer monitors used to display the pictorial representations typically have fairly limited contrast ratios and are thus unable to fully simulate this range of luminosity.

The primary purpose of the CPU curriculum is to support science learning through experimentation and discourse. Students are responsible for the development and critical evaluation of ideas, models, and explanations through interactions with each other in small groups.

Teachers act as guides and mentors. During the "elicitation phase" of a particular unit, CPU challenges students to predict the results of other hands-on experiments with other phenomena such as waves and sound, force and motion, and light and color.

Students articulate their models (MIROS)—including prior knowledge, ideas, assumptions, and preconceptions—related to the featured phenomena. They then use real apparatus (realia) to conduct traditional experiments, often revealing their misconceptions when their predictions fail. Then they pursue new ideas using simulated apparatus (media) that emulate, with an appropriate degree of functional fidelity, properties and behaviors associated with the featured phenomena.

The students abandon ideas that don't work and construct new theories and models to explain what they observe in the simulated experiments. During the "application" phase of the curriculum, students further explore the featured phenomena by conducting experiments of their own design using the lab apparatus, computer simulations, and other resources to further refine their mental models and clarify their understanding.

10.6.4 Media as Arenas for Unified Perception and Action

Emerging media systems and technologies appear headed toward a technical renaissance that could free media products from constraints that now limit end users: the static symbols and limited dimensionality of paper and ink; the shadows captured and cast from a single point of view in photographs and films; and the fixed sequences and pacing of analog broadcast technology.

Paradoxically, trends toward ever more rapid and extensive externalization of cognitive functions in nonbiological media leaves us as creatures with an ancient, largely fixed core of perception–action modalities surrounded by rapidly fluctuating and increasingly powerful technological augmentation frameworks. Thus, whether emergent media technologies serve human beings well depends on the extent to which they honor ancient human capabilities for perceiving and acting—capabilities that are grounded in the fundamental ecological necessities of long ago.

10.6.4.1 Alienation and Transformation. While glib marketers of computer-based media tantalize us with vast fields of electronic action and apparently unlimited degrees of freedom, skeptics (W. Gibson, 1984; Mander, 1978; McKibbin, 1989) have served up warnings of isolation, manipulation, and diminished authenticity that can be traced back through McLuhan (1965) to Rousseau's (1764/1911) classic treatise on alienation from nature.

Much public discussion of the limitations and negative effects of so-called "passive" media such as television implicitly acknowledges both the epistemological and moral dimensions of mediated experience. During the 1990s some advocates of multimedia technology argued that interactivity might help address the putative problems of an obese couch potato nation that mindlessly surfs television channels in search of sex and violence. Such advocacy was partly based on the assumption that somehow interactivity would empower viewers with more choices and promote a greater awareness and understanding of nature and culture.

The hope of human history has often been that technological augmentation would make us gods or angels or at least make us superior to enemies and aliens. Media technologies and the cognitive artifacts associated with them have played a special role in this regard by offering seductive possibilities of transformation: more than mere augmentation, a permanent acquisition of special knowledge and experience through recorded sounds and images. Yet receiving the word or beholding a revelation, whether real or artifactual, without active and appropriate participation risks distorted understanding and resultant alienation. Recognition of such risks underlay the prohibition of graven images that has figured strongly in Judaic, Islamic, and Buddhist religious traditions. And in Christianity, doubts about religious imagery peaked in the eighth century with the radical proscriptions of the iconoclasts, who wanted to eliminate all religious depictions as demonic; such doubts dampened Western artistic exploration until the Renaissance.

For humans and all organisms, integration of action with perception is a necessary but not sufficient condition for living well. "Perception is the mechanism that functions to inform the actor of the means the environment affords for realizing the actor's goals" (Turvey, Shaw, Reed, & Mace, 1982, p. 378). Perceptual faculties languish and degrade when they are decoupled from opportunities for action. Separated from action, perception cannot serve as a basis for formulating hypotheses and principles,

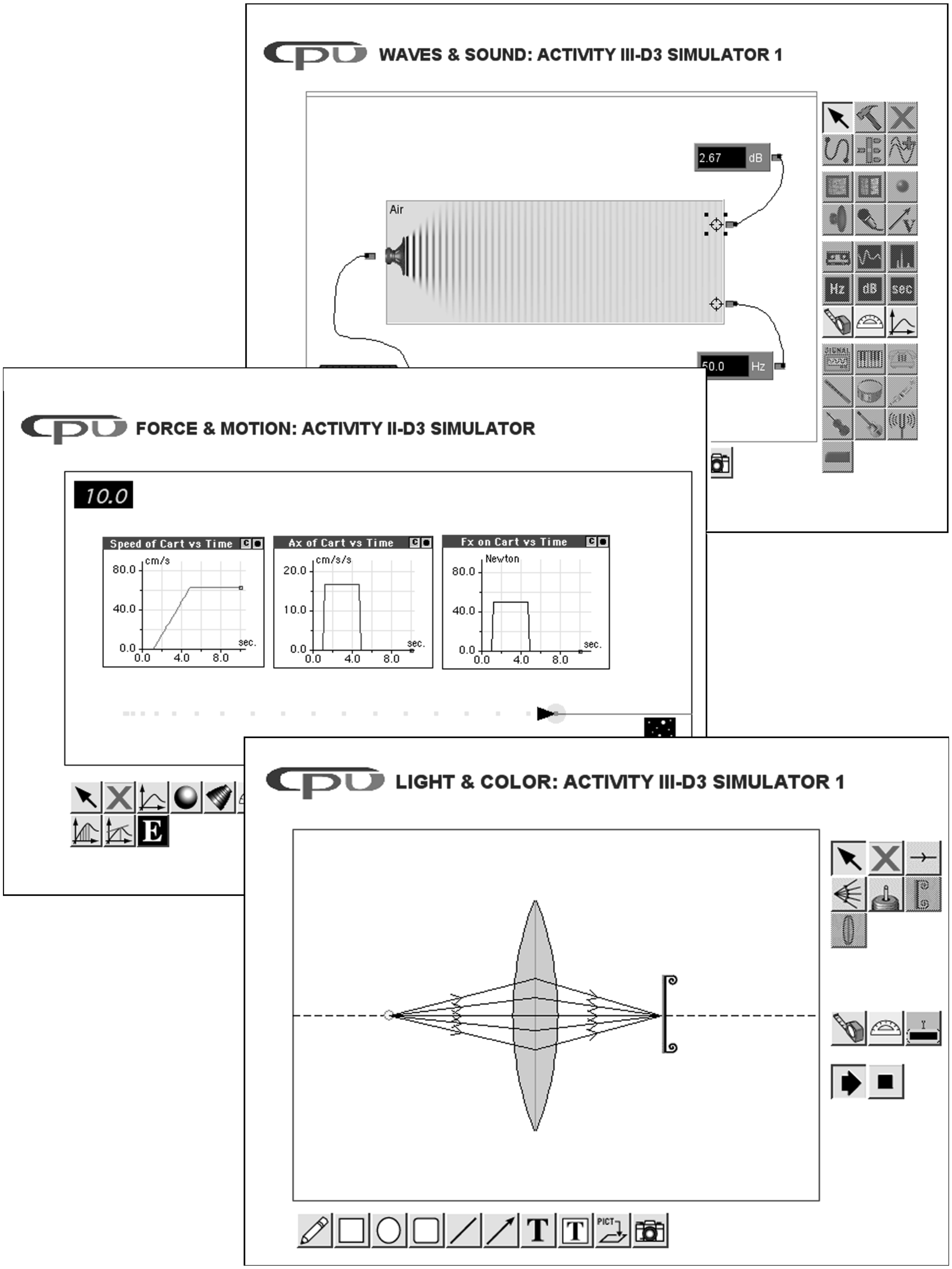

FIGURE 10.6. **Sample simulator screens from *Constructing Physics Understanding.*** These Java applets complement hands-on laboratory activities in a wide variety of contexts, providing students with both phenomenological and conceptual (model-based) evidence that helps them develop mental models with greater robustness and predictive validity. *For more information, see http://cpuproject.sdsu.edu/CPU*

for testing models and theories, for choosing alternatives, or for exploring consequences.

Indeed, Eleanor Gibson (1994) has reviewed a growing body of evidence which strongly suggests that without opportunities for action, or appropriate substitutes for action, perception does not develop at all or takes on wildly distorted forms. Behavioral capabilities likewise languish and degrade when they are decoupled from perception. "Action is the mechanism that functions to select the means by which goals of the actor may be effected" (Turvey, Shaw, Reed, & Mace, 1982, p. 378). Deprived of information concerning opportunities for action, perception alone results in ritualistic performance unrelated to any real task and hence any realizable goal.

It is worth noting in this context that *sin* in the original Christian sense of the word meant *to miss the mark,* implying a failure that cannot be assigned to either action or perception alone. A similar understanding of the incompleteness of perception isolated from action can be found in other traditions—notably Zen (see, for example, Herrigel's 1953 classic *Zen and the Art of Archery*). Many meditative disciplines teach integration of perception and action by training students to unify attention (perception) and intention (action), using exercises such as "following one's breathing."

Caves and Consciousness

> We need to move from our exclusive concern with the logic of processing, or reason, to the logic of perception. Perception is the basis of wisdom. For twenty-four centuries we have put all our intellectual effort into the logic of reason rather than the logic of perception. Yet in the conduct of human affairs perception is far more important. Why have we made this mistake? We might have believed that perception did not really matter and could in the end be controlled by logic and reason. We did not like the vagueness, subjectivity and variability of perception and sought refuge in the solid absolutes of truth and logic. To some extent the Greeks created logic to make sense of perception. We were content to leave perception to the world of art (drama, poetry, painting, music, dance) while reason got on with its own business in science, mathematics, economics and government. We have never understood perception. Perceptual truth is different from constructed truth. (Edward de Bono, *I Am Right—You are Wrong: From Rock Logic to Water Logic,* 1991, p. 42)

Among the ancient perplexities associated with the human condition, the relationship between perception, action, and environment has endured even as technical context and consciousness have continued to evolve. In the annals of Western Civilization, Plato's Allegory of The Cave (Plato, *The Republic*) remains one of the most elegant and compelling treatments of the central issues. Chained and therefore unable to move, his cave-dwelling prisoners came to perceive shadows cast on the walls by firelight as real beings rather than phantasms. Why? Plato argues that this profound misperception resulted from external as well as internal conditions.

First consider the external conditions: We will take some license in imagining that if the prisoners were rigidly bound and deprived of ambulatory vision, then they were probably (a) denied the cues of motion parallax that might have indicated the two-dimensionality of the shadows; (b) suffering from degraded stereopsis and texture recognition due to lighting conditions; and (c) incapacitated in their ability to investigate the source of illumination or its relationship to the props that were casting the shadows that captured their imagination.

Many readers of Plato's allegory have been tempted to assume that they would not personally be fooled in such a situation, leading us to consider the internal conditions: With a rudimentary knowledge of optics and commonsense understanding of caves, it might have been possible for the prisoners to entertain plausible alternatives to their belief that the shadows were real beings. For the prisoners to entertain such an alternative would have required that they be able to construct a model of the situation that would be "runnable," that is, serve as an internal analog for the physical actions of inspecting the layout of the cave, the pathways of light, and so on. In our (re)interpretation of Plato's Cave, what doomed the prisoners to misperception was not only that they were constrained from exploratory action by external conditions, but also that they were unable to integrate working mental models with what they saw.

Plato's allegory involves both epistemological and moral dimensions. Epistemology considers problems involved in representing knowledge and reality (knowing–perceiving), whereas moral philosophy considers problems involved in determining possible and appropriate action (knowing–acting). Plato reminds us that perceiving and acting are complementary and inseparable: The prisoners cannot perceive appropriately without acting appropriately, and they cannot act appropriately without perceiving appropriately.

Alan Kay (1991) summarized our thoughts about this dilemma as it applies to contemporary education over a decade ago:

> Up to now, the contexts that give meaning and limitation to our various knowledges have been all but invisible. To make contexts visible, make them objects of discourse and make them explicitly reshapable and inventable are strong aspirations very much in harmony with the pressing needs and on-rushing changes of our own time. It is therefore the duty of a well-conceived environment for learning to be contentious and even disturbing, seek contrasts rather than absolutes, aim for quality over quantity and acknowledge the need for will and effort. (p. 140)

Who knows what Plato would say about the darkened cave-like structures we call movie theaters and home entertainment centers, where viewers watch projections cast upon a wall or screen, only dimly aware of the original or true mechanics of the events they perceive? Our ability to interpret the shadowy phantasms of modern cinema and television is constrained not only by collapsed affordances of cinematography—two-dimensional, fixed-pace sequencing of images—but also by the lack of affordances for exercising action and observing consequences. We also often lack the mental models that might allow us to work through in our minds alternatives that are not explored on the screen. Yet even when we possess such mental models, it is often impossible to "run" or test them due to interference from the relentless parade of new stimuli. And as McLuhan (1965) noted in the middle of the last century, we frequently succumb to the unconscious inhibition that attends most television and movie watching: Reflect too much on what you observe and you will be left behind as the medium unfolds its plans at a predetermined pace.

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