8. MEDIA AS LIVED ENVIRONMENTS: THE ECOLOGICAL PSYCHOLOGY OF EDUCATIONAL TECHNOLOGY

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We are rapidly moving towards an era in which most everyday activity will be shaped by environments that are not only *artificial—most* humans now live in cities—but also *mediated.* In developed countries, emotional and cognitive activity in all levels and segments of society is increasingly vested in information-rich venues supported by television, radio, phone, and computer networks. Even in remote areas of the world, peasants watch satellite broadcasts and play battery-operated video games. And in the depths of the Amazon River basin, primitive tribes use small videocams to document territorial encroachments and the destruction of rain forest habitat.

The narrow bandwidth of midcentury media technologies, however, has engendered a paradigm in which people think of *media* primarily as *channels* for sending and receiving symbols and messages (see 4.3, 4.4). Derivatives of this notion liken knowledge to content or even to a commodity that can be stored, transmitted, and received. The utility of this channel communications metaphor is being challenged by emerging computer-based media technologies that function less like books, journals, films, and broadcasts and more like workshops, laboratories, offices, and studios. These new venues for working, playing, teaching, and learning allow and often require exploratory action and ambulatory perception and thus are not entirely consistent with models of cognition that treat perception primarily as *reception.*

Indeed, the ergonomic utility of many contemporary human-computer interfaces 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 processing of symbols, messages, and discourse are limited because the channel communications metaphor fails to specify many of the modalities by which humans as organisms understand their surroundings. These modalities include locating, tracking, identifying, grasping, moving, and modifying objects (see 31.2.2.2). There is a profound but not always obvious difference between receiving communication and acquiring information through such modalities.

8.1 OVERVIEW

Our 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 ecological perspective 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 chapter explores paradigms for linking the work 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 in which ecological psychology might inform the design of products and systems that are efficient in the sense that they promote wise use of human cognitive resources and humane in the sense that they enable authentic modes of being.

The metaphor of media as environments helps us to reconsider trade-offs between the cost of (a) *external* storage and processing of information in the form of realia[1] or media and the cost of (b) *internal* storage and processing of information as *Mental-Internal Representations of Situations.*[2] As a matter of convenience, we will use MIROS throughout this chapter as a general alternative to the superabundance of terms for internal representations, including stimulus-response mechanisms, memories, images, associations, schemata, models, propositions, productions, and neural networks.

As will be argued later in greater detail, many MIROS are quite incomplete, functioning as *complements to* rather than *substitutes for* the external representation of situations provided by media and realia. Investment of organic resources in improved perception, whether such perception is acquired through learning or by natural selection, is an important alternative to construction of more complete MIROS, because improved perception allows organisms to 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. In the long run, environments lacking such information favor development of enhanced MIROS. This trade-off between internal and external storage and processing provides a basis for coordinating media with MIROS so that they can "share the work" of representing situations (see 2.3.3).

The actions afforded by media environments are not always the same as those afforded by imaginary or real environments represented by media. Media technologies can partially overcome dislocations in time through storage of information and dislocations in space through transmission of information. Opportunities for perceiving and acting on media, however, are rarely identical to the opportunities for perceiving and acting on corresponding realia or MIROS.

Controversies that treat media as mere conveyances of symbols and messages often neglect differences in actions enabled, respectively, by media, realia, and MIROS. The pages of a book on human anatomy, for example, afford examination of the structures of the human body, as does a film of an autopsy. Each of these two types of media environments, however, offers radically 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 have to be weighed against some loss in *verity* (Thurman & Mattoon, 1994) and functional fidelity. Older technologies such as print and film have well established conventions for helping end users reconstitute missing circumstances and points of view. Prominent among these conventions are the cues and explicit directions that accompany two-dimensional pictures and that serve to guide viewers in constructing the MIROS required for interpretation and understanding. These conventions, which we will examine in a later section of the chapter, help us understand how perception in mediated environments can substitute for hypothetical actions.

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.

8.2 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 framework for examining the implications of ecological psychology for media design and research.

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

1 Perceiving environmental layout (inseparable from the problem of the ego and its locomotion)
2 Perceiving the objects of the environment (including their texture, color, shape—and including 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 the expressive responses of other persons
6 Perceiving by communication or speech
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 action intuitively and automatically. Direct perception, 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 tightly linked in real time with ongoing action.

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."

[1] Realia (Latin, *realis,* relating to 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, England: Oxford University Press.

[2] A situation can be defined as a structured relation between two 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.[4] ''The natural retinal image consists of a binocular pair of ordinal structures of adjacencies and of successive transpositions and transformations of region of texture delimited by

Thus are teeth and jaws the effectivities that permit killer whales to exploit the "grab-ability" of seals; and so are wings the effectivities that allow birds to exploit the air.

In contrast to direct perception, indirect perception operates on intermediaries such as diagrams, symbols, words, and propositions that inform an organism or agent about a world or environment via indexical bonds (Nichols, 1991) with that environment. 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 to human thought of such intermediaries as symbols and language-based propositions. He was skeptical, however, about claims that general cognitive processes can be modeled in terms of such intermediaries, and he argued that models that relied excessively on symbols and propositions would inevitably neglect critical relationships between perceiving and acting.

Although Gibson (1977/1982) did not develop a complete theory of *mediated* perceiving (see 7.3.4)—that is, perception 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 world view, 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.

Every media technology from book to video to computer simulation, however, imposes profound constraints on representation or description of real or imaginary worlds (see 12.3.1) and requires trade-offs as to which aspects of a world will be represented. Even museums, as repositories of "unmediated," authentic artifacts and specimens, must live within the technical limitations of display technologies that favor some modalities of perception over others— looking in lieu of touching, for instance.

8.3 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. Many of the processes of natural selection that shaped *Homo sapiens* have been superseded by much faster mechanisms of adaptation. The human evolutionary clock may have slowed for the moment in some respects, because selection pressure can be accommodated by technical and social means rather than natural selection.

As Donald (1992) argues, the information age extends previous trends in the evolution of human cognition. His reconstruction of the origins of the modem mind makes the credible claim that the unfolding drama of our distinctly human neurological capacity has been characterized primarily by 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) has succinctly captured 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 on information in order to serve representational functions.

As Greeno (1991) notes, "a significant part of what we call 'memory' involves information that is in situations . . . rather than just in the mind of the behaving individual" (p. 265). Indeed, a sizable body of literature describes some profound limitations of internal representations, or in our terms, MIROS, that is, Mental-Internal Representations of Situations (see, for example, Carroll & Olson, 1988; Craik, 1943; di Sessa, 1983, 1988; D. Gentner & D. R. Gentner, 1983; D. Gentner & Stevens, 1983; Greeno, 1989; Johnson-Laird, 1983; Larkin & Simon, 1987; Lave, 1988; Payne, 1992; Rouse & Morris, 1986; Wood, Bruner & Ross, 1976; Young, 1983; see also 12.3.1.2). These works suggest that without the support of external devices or representations, MIROS are typically simplistic, incomplete, fragmentary, unstable, difficult to run or manipulate, lacking in firm boundaries, easily confused with one another, and generally unscientific.

8.3.1 Thermodynamic Efficiency of Externalization

There is reason to believe that the scope and complexity of MIROS are constrained by the thermodynamics of information storage and processing in biological systems (see 3.1.35). Seemingly lost in 3 decades of discussion on the problems of internal representation is Hawkins's (1964) insight that *external* representations can confer gains in *thermodynamic* efficiency.

> The capacity to learn is an externalization of function, the creation outside the cell nucleus of a new way of acquiring and storing vital information. The nucleus has its limitations, of information capacity and rate of evolution. . . . The point of innovation is that the code description of a machine [cell] that learns, that acquires information from and about the environment, can be small compared with what the machine [cell] learns. . . . When such a step occurred in the evolution of animal species, an essential limitation upon all previous evolution was removed: The self-reproducing molecule was

no longer burdened with the organism's entire stock of information. The importance of such a step is comparable to that of the beginning of life itself . . . (pp. 272—73).

This line of argument is based partly on the work of Shannon and Weaver (1949), the mathematicians who applied thermodynamic analysis to technical problems such as the coding of messages, transmission of messages over channels, the maximum rate of signal transmission over given channels, and the effects of noise. Hawkins (1964) reasoned from Shannon and Weaver's theoretical treatment of information that learning, whether the system that learns be machine or human, ultimately confers its benefits through increased thermodynamic efficiency.

In the conditioned reflex and in the switching mechanism that is the basis of the large digital computer, the essential thermodynamic condition is again the availability of free energy for the performance of entropy-reducing, order-increasing work. The switching mechanisms transmit flows of energy larger than the incoming signals that direct their behavior. Through reinforcement and inhibition, relatively simple stimuli come to release complex responses adapted to the character and behavior of the environment. The patterning of such responses represents, vis-à-vis the environment, a lowered entropy of arrangement (p. 273).

The externalization of information beyond the limits of the cell nucleus referred to by Hawkins is only one of the first of many strategies that 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 environment itself and thus reduce the biological costs associated with maintaining and processing in neural networks. Unfortunately, explanatory models in the cognitive sciences still emphasize relatively complete mental representations rather than models that account for representation as distributed between the environment and the brain. As Zhang and Norman (1994) argue, this traditional approach to cognition

. . . often assumes that representations are exclusively in the mind (e.g., as propositions, schemas, productions, mental images, connectionist networks, etc.). External objects, if they have anything to do with cognition at all, are at most peripheral aids. For instance, written digits are usually considered as mere memory aids for calculation. Thus, because the traditional approach lacks a means of accommodating external representation in its own right, it sometimes has to postulate complex internal representations to account for the complexity of behavior, much of which, however, is merely a reflection of the complexity of the environment (p. 88).

All things being equal, we might expect investment of organic resources in improved perceptive capabilities to be a more effective strategy for organisms than construction of elaborate MIROS. Regardless of whether improved perception is acquired through learning or natural selection, it allows organisms to more effectively exploit information reflected in the structure of the environment—information that is maintained at 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 . In addition, when information acquisition involves exploration or investigation by the organism, 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 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 ask. "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, balconies, and furniture.

Returning to the high-security building, suppose a second group, more nefarious and temporary, are commandos 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 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 familiarizing themselves with the layout of a building they may raid only 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."

8.3.2 Coupling and Information Transfer

Perception, in the view of ecological psychologists, cannot be separated from action: Perceiving involves selecting and attending to some sources of information at the expense of others. Human eyes, for instance, are constantly flicking across the visual field in rapid eye movements called *saccades.* Natural 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 use inadequately the communications metaphor, 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 sensor networks in a way that would be consistent with Shannon and Weaver's rigorous technical meaning for *channel* in which they model information flow as a single stream of serial bits (see 4.4.2).

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

Hawkins extended another Shannon and Weaver insight by noting that some kind of coupling is a necessary condition for duplication or transmission of patterns. He argued 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, a concept of coupling that not only accounts for the possible gains in efficiency but also preserves the ancient Greek sense of information as transference of form:

> Man's physical coupling with his environment is not that of an intrinsic source of energy, but is weaker, more purely thermodynamic. He controls his environment by subtle changes in its order, so that the streams of natural process flow in new channels. But the control runs both ways. Competence is derived from acceptance of the de facto order of things. The potter who shapes the clay has long been the image of a godlike power, but this is not the perception the potter has of himself. He must be sensitive to the properties of the mix and to its responses to firing in shape and color and texture. The potter is as much transformed by his art as the clay is (Hawkins, 1964, p. 310).

As Maturana (1978) notes, information conceived as transfer of pattern or form implies that

> . . . learning is not a process of accumulation of representations of the environment; it is a continuous process of transformation of behavior through continuous change in the capacity of the nervous system to synthesize it. Recall does not depend on the indefinite retention of a structural invariant that represents an entity (an idea, image, or symbol) but on the functional ability of the system to create, when certain recurrent conditions are given, a behavior that satisfies the recurrent demands or that the observer would class as a reenacting of a previous one (p. 45).

Behavior so informed by the environment represents a lowered entropy-that is, a greater orderliness of arrangement. Chaotic, disorganized, and arbitrary aspects of an organism's activity are ameliorated by attention and intention directed towards aspects of the environment that are related to the organism's ecological niche. The orderliness and organization of behavior that results from niche-related attention and intention can be characterized as intelligence. Such intelligence 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 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.

To summarize the preceding discussion of coupling and information transfer, one should understand that the extension of human cognitive capacity through media technologies reflects broader evolutionary trends characterized by increasing externalization of information storage and processing. Such externalization increases thermodynamic efficiency, reducing the organic costs of cognition by distributing the "work" of representing situations between humans and their external environment. Indeed, one arguable 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."

8.3.3 Simplicity and Complexity

Ecology in general is concerned with predicting and explaining how matter and energy are transferred and organized by members of biological communities. Since transfer and organization of matter and energy are ultimately governed by thermodynamics rather than purely mechanical exchanges, 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.[3] Information is thought of roughly as a measure of *level of organization* or relatedness. Entropy is a measure of degrees of freedom (von Bertalanffy, 1967; Gatlin, 1972) or *opportunities for action.* So viewed, complex systems can be said to offer more freedom of action than simple systems because complex systems (see 3.1.1.1.1) are more highly organized, with more and higher-level relations. Complex biosystems, for example, encompass more species and support longer food chains than simple biosystems; tropical rain forests afford more freedom of action, more opportunities to hunt and gather than does arctic tundra. To change the context, a city offers many more opportunities for human action-different types of work, recreation, and socializing-than does even the largest cattle ranch.

Extremely simple systems can be said to offer no opportunities for action because (a) there is no organization-all is chance and chaos or (b) organization is rigid—all relations are absolutely determined. A square mile of ocean surface is simple and chaotic, whereas a square mile of sheer granite cliff is simple and rigid. Rigid systems compel, yet they do not enable.

8.4 A MULTIPLICITY OF MEDIA

Amidst dramatic changes enabled by convergent computing and telecommunications technologies, there are fundamental shifts in concepts associated with the word *media.* Many conventional connotations of this term originated during the early 1 900s in the concerns of advertisers who wanted to use newspapers and radio to reach mass markets. The term *medium* has been applied variously to:

1 Storage surfaces such as tapes, discs, and papers
2 Technologies for receiving, recording, copying, or playing messages
3 Human communication modalities such as text, diagrams, photos, or music
4 Physical and electronic infrastructures such as broadcast networks or cyberspace
5 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 "something intermediate in nature or degree [or] an intervening substance, as air, through which a force acts or an effect is produced" (Random House/ Reference Software, 1993). This notion of intermediacy underlies technical usage and popular imagination of media as channels for sending and receiving messages. Intermediacy 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. A logical extension of this kind of thinking is that the way for humans to work with computers is to communicate with them through symbols and language-based discourse, including verbal commands.

This chapter is grounded in an emerging paradigm in which a *medium* is conceptualized as "the element that is the natural habitat of an organism [or] surrounding objects, conditions, or influences; environment" (Random House/ Reference Software, 1993). This media-as-environments metaphor is certainly relevant in an era where electronic information pervades virtually every aspect of everyday life. Our perceptions of the planet are influenced by worldwide "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 (see Chapter 15) has grown steadily since the early 1 990s as these technologies have been popularized in films and amusement parks, and as they have been more widely used in architecture, medicine, aviation, and other disciplines.

Developers of computer-based environments of all types, and especially interactive multimedia, rely increasingly on object-oriented design and object-oriented 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 endow the objects with varying degrees of behavioral autonomy.

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[3] Here thermodynamics (or bioenergetics) sets the boundary conditions. Yet real events are controlled by rate processes (barriers, compartments, enzymes, etc.) that are both biotic and abiotic. As Hawkins notes, ". . . the reality of chance is not contravened by the hypothesis of exact, deterministic laws of motion, for these do not give a complete account of physical systems, which also have a certain number of degrees of freedom represented by spatio-temporal variables . . . the nondynamical premises of thermodynamics are of the kind—namely, premises of probability—that complement the laws of motion. . . . The most remarkable consequence of this development (Maxwell & Boltzmann's kinetic theory of heat) was that entropyreappeared in the new theory, not as a phenomenological variable measurable in the heat laboratory but as a parameter of the probability law describing the statistical behavior of large systems of particles, and was definable far outside the experimental range of ordinary calorimetry. As a result, thermodynamics received an extension of the range of phenomena to which it could be applied, becoming a truly universal science. The dimensionless variable (entropy) reappeared in the formulation of statistical mechanics as a nonmechanical variable—namely, as a parameter of the probability law characterizing the phase-space distribution of the system being described. In the meaning of this parameter was hidden the final explanation of the apparent contradiction between the symmetry of time direction in dynamics and its asymmetry in thermodynamics (1964, p. 194).

Similarly, it is difficult to model as communication the kind of user interactions that typify graphical user interfaces (GUI) as employed by the Macintosh or Windows operating systems. When a user drags a folder into a trash-can icon, does the user intend to "communicate" with the computer? Possibly. When the trashcan icon puffs up after receiving the file, does the user interpret this as evidence of the trashcan's intention to communicate? Possibly. Yet the act of tossing an actual file into a *real* trashcan would not normally be interpreted as the result of some intent to communicate with the trashcan but rather as an intent to dispose of the file. And the presence of the file in the trash-can would not normally be interpreted by the tosser as the result of some intention of the trashcan to communicate its status as "containing something." What is the difference between virtual file tossing and real file tossing? To well-adapted computer users, both virtual and real trashcans have similar dispositional properties: From the user's point of view, trashcans are not receivers of messages but receivers of unwanted files.

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. Letters in this sense refer to sounds, numerals refer to quantities, and isobars on a weather map refer to readings of air pressure. 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; and in estimating the distance between isobars, one is not sensing the wind.

The dispositional properties of computer icons and tools set them apart from conventional symbols (see 5.4.4.2) because icons and tools afford opportunities for direct action. Double-clicking on a selected file icon does not *symbolize* the action of opening the selected file. Rather, it *is* the action of opening the file; the double-click causes the operating system to execute the code associated with the selected object. Clicking on a selected file does not symbolize file opening anymore than toggling a light switch symbolizes activation of the light bulb.

However useful engineers may find the communications metaphor in rationalizing the logic of information flows within hardware and software subsystems, questions about the research and design of contemporary user interfaces cluster at the level of object perception and manipulation precisely because perception and manipulation of objects invokes 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 the user 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 that are shared 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 snowfield and buries them until spring.

Contemporary, object-oriented regimes for interface design result in complex communities of semiautonomous 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 but are, rather, participants in arenas that have been likened to theaters (Laurel, 1986) and living communities ("vivaria"; Kay, cited in Rheingold, 1991, p. 316).

8.5 AN ECOLOGY OF 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 19th 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).

8.5.1 Integrated Perception and Action

Dominated by information-processing theories, the recent history of perceptual psychology has emphasized research paradigms that attempt to constrain action and to isolate sensation from attention and intention. This predilection for ignoring codeterminant relations between perception and action has resulted in a relatively weak foundation for the design of new media products and a limited basis for understanding many traditional media forms.

Ulric Neisser's (1976) perceptual cycle—which frankly acknowledges the influence of both J. J. Gibson and his spouse, Eleanor Gibson-serves as a simplified framework for examining the relationship between action and perception in mediated environments. Neisser (1976) was concerned

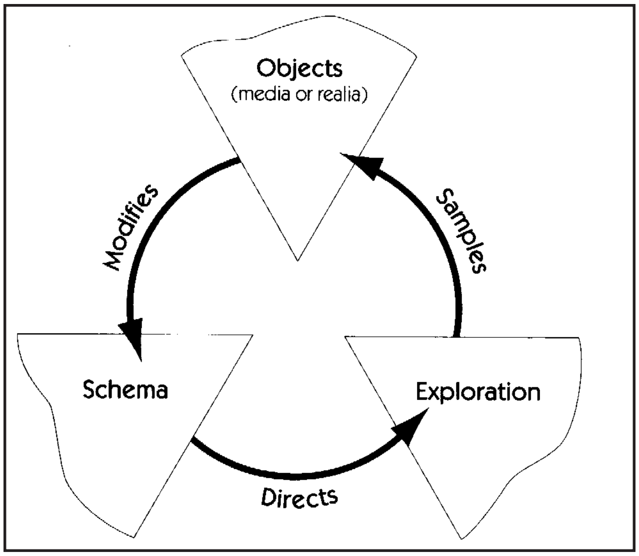

Figure 8-1. Neisser's Perpetual Cycle (modified from Neisser, 1976, p. 21). In the language of ecological psychologists, an organism selectively samples available information in accord with the demands of its niche. An organism's perceptions are tuned to the means that the environment offers for fulfilling the organism's intentions.

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. How, then, Neisser asked, would such models explain why different people attend to different aspects of the same situation? How would information-processing models help to 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?

The Neisser-Gibson alternative to the information-processing models adds the crucial function of exploration. This addition, reflected in Neisser's Perceptual Cycle (Fig. 8-I) reflects the fact that organisms *selectively sample* available information in accord with the demands of their niches and, further, that organisms' perceptual capabilities are tuned to the means that their accustomed environment offers for fulfilling the organisms' intentions.

Neisser's emphasis on exploratory perception reminds us that schemata can never be entirely complete as representations of realia. Schemata are not, in Neisser's opinion, to be thought of as templates for conceptualizing experience but rather as 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 (see 3.1.2.5), can also be fruitfully thought of 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).

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 draw on memories of how past actions were related to past perceptions. Rather than mirroring the workings of external reality, actionable models help organisms attend to their perceptions of the environment and to formulate intentions.

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 about a situation. Actionable mental models, in other words, 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 will 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 size, 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 trade-offs 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 usually 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 organisms attend to the environment directly because this is often more economical and more reliable than maintaining models of the environment or "reasoning" about it.

8.5.1.1. 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 extend beyond the purely theoretical: He was instrumental in producing the first cinematic simulation of flying using model airplanes and model landing fields, Gibson's novel conception of the retinal image [4] substituted dynamic, flowing imagery of the mobile observer for the static, picturelike image of classical optics and inspired techniques of ground plane simulation and texture gradients that are the basis for many electronic games.

8.5.1.2. 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 "the 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). 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. The perceptual capabilities of organisms are tuned to opportunities for action required to obtain enough energy and nutrients to reproduce.

"Attunement to constraints" (attributed to Lashley, 1951, by Gibson, 1966) thus 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 invariances— constrained and predictable relations in the environment-simplifies perception and action for any organism. As we shall argue, detection of invariances is also critical to successful adaptation by humans to any mediated environment.

8.5.1.3. A Simple Experiment. As an example of the importance of detecting invariants, consider the human visual system as it is often presented in simple 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 called Vi. Neurons in V1 are *spatiotopically mapped,* i.e., laid out in fields that preserve the integrity of the information captured by the retina. Neurons in VI transmit to specialized centers that process color, form, and motion. Yet there is much more to seeing than the processing of 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. You may want to try this simple experiment: Close your left eye and cock your head repeatedly to the left 2 or 3 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 left eyeball several times from the side. Under these abnormal conditions, your visual system now assigns roughly the same amount of eyeball jerkiness to radical movement of the environment itself.

Under normal circumstances, the brain does not attribute variation in retinal images resulting from head or eye movement to changes 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.

It is important to note that the concept of perceptual invariance does not necessarily imply a lack of change in the environment, but rather that the organism is able to detect reliable patterns in the change and therefore able to use the patterns as a background for 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.

8.5.1.4. Perception of Invariants: Some Implications for Media Design. The idea of a framework of invariants is very useful in the design, management, and utilization of media environments because it reminds us that

> ...it is not necessarily better to throw more graphics techniques, more rendering power, or more artificial intelligence into the scene. These are not necessarily going to give us a better artificial world. The quantity of what goes into your artificial world is not what makes it better or more interesting; it is the quality of what goes into it. What defines quality for this activity are these environmental invariants, which drive the human perceptual system. We can think of it as though the levels of detail had a weighting system attached, telling us how important that *type* of detail is or that *level* of detail. If these details are not associated with perceptual invariants, then the weighting factor is small. Often you can remove certain kinds of detail from an image and people cannot perceive the difference. On the other hand, if the detail has a tight link to some kind of perceptual invariant, then the weighting factor is high. . . . (Gardner, 1987, pp. 106—07).

While Gibson's work in the 1970s met with skepticism from his contemporary psychologists, he generated even in his day a considerable following among human-factors engineers and ergonomicists. He is now read widely 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 .

> Gibsonian psychology points to perceptual invariants that enrich our depth and distance perception. Many of the invariants relate to the ever-existent, textured, ground surface of our environment. . . . The strongest invariants are the ratios, gradients, calibration references, and optical flows tied to motion parallax, surface texture, the ground plane, and ego perception. By enabling the same perceptual invariants that people use to navigate the real world, the creator can construct a world that encourages exploration (Gardner, 1987, pp. 107—09).

8.5.2 Perceptual Learning

Gibson did not believe that sensory inputs are "filtered" or processed by propositional or symbolic schemes. Rather, he strongly favored a bottom-up paradigm in which exploratory actions rather than propositions drive processes of selective perception. Yet none of Gibson's ideas preclude *learning* to perceive directly, as when children come to understand that they must automatically respond to icy-slick sidewalks with flat-footed caution. Nor did Gibson deny the importance of reasoning about perceptions, as when a mountaineer carefully analyzes the complex textures of an ice-covered cliff in order to plan an ascent. Nevertheless, consistent with his view that action, not conception, drives perception, Gibson believed that learning entails the tuning of attention and perception, not the conforming of percepts to concepts. Such perceptual learning is, in the words of Gibson's spouse, Eleanor, essentially

> . . . 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. This definition implies that there are potential variables of stimuli which are not differentiated within the mass of impinging stimulation, but which may be, given the proper conditions of exposure and practice. As they are differentiated, the resulting perceptions become more specific with respect to stimulation, that is, in greater correspondence with it. There is a change in what the organism can respond to. The change is not acquisition or substitution of a new response to stimulation previously responded to in some other way, but is rather responding in any discriminating way to a variable of stimulation not responded to previously. 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 (E. J. Gibson, 1969, p. 77).

8.5.2.1. Propositional vs. Nonpropositional Learning. Gibson's (1979) research on visual perception in everyday situations 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. Hochberg (1974) thinks that one of Gibson's most important ideas is that

> . . . there exist higher-order variables of stimulation to which the properties of the objects and events that we perceive are the direct and immediate response . . . [thus] the properties of the perceived world . . . are not the end products of associative processes in which kinesthetic and other imagery come to enrich two-dimensional and meaningless visual sensations with tri-dimensional depth and object meaning (Hochberg, p. 17).

Gibson sometimes used the term *associative thought* in ways that implied propositional reasoning. We have therefore substituted the latter 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 widely influential ACT* model (1983) is typical of rigorous efforts in the 1980s to use propositional logic to model learning. The ACT* model converts declarative knowledge—that is, knowledge that can be stated on 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

(p. 139; content in brackets added):

IF the figure has four sides and sides are equal

and sides are touching on both ends

and four inner angles are 90 degrees and figure is black

THEN classify as [black] square.

Such instructions might have some value as a script for teaching students about logic, or perhaps even as a crude strategy for teaching them to recognize squares. Yet even the most sophisticated computer models fail almost entirely when they attempt to use this kind of reasoning to recognize pattern and contexts that are very easy for animals and humans.

There are other reasons to doubt assertions that the brain represents perceptual skills as propositions or production rules. While declarative knowledge (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 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 arguable encumbrance of 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 in these emerging models considerable support for many of his ideas about indirect perception.

Kosslyn and Koeing (1992), for instance, offers an excellent treatment of the ways in which connectionist models can explain the details of perceptual processing. Connectionist models (see 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, because the processing units mathematically adjust the weighting of connections through repeated trials. Neural nets are superior to proposition-based programs at learning tasks such as face recognition.

A trained subsymbolic network cannot be analyzed or dissected to yield classical rules or symbols, because the learned information is represented as weighted connections rather than as propositions. The learned information is not stored as symbols on bits of code located at specific sites. Rather, it is represented by the overall fabric of connections. Subsymbolic processing networks can, however, serve as *substrates* for conventional symbolic processing and therefore have some potential for modeling forms of human thought that do rely on symbols and language.

8.5.2.2. Affordances. In Gibson's view, sensory information alone is insufficient for guiding and controlling the activities of living organisms:

> The variables of sensory discrimination are radically different from the variables of perceptual discrimination. The former are said to be dimensions like quality, intensity, extensity, and duration, dimensions of hue, brightness, and saturation, of pitch, loudness, and timbre, of pressure, warm, cold, and pain. The latter are dimensions of the environment, the variable of events and those of surfaces, places, objects, of other animals, and even of symbols. Perception involves meaning; sensation does not . . . (J. J. Gibson, 1974/1982, p. 351).

Selective perception generates much more information about an experienced event than can be obtained by sensation alone because the organism is informed during selection 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 coupled in a seamless cycle. To describe this coupling, he introduced the concepts of *affordances* (opportunities for action) and *effectivities* (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 towards which the organism is oriented by its perceptual history and heritage. 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).

> If ecological information specifies the affordances of things . . . then it does not specify abstract physical properties

of the classical sort (for example, the three Cartesian dimensions), but rather ecologically relevant properties such as texture, resistance to deformation, and manipulability. Both kinds of properties may be real, but it is the functional properties, the affordances, that we animals are aware of directly . . . (Reed, 1988, p. 232).

Thus, an affordance is, roughly speaking, a pathway for action that enhances the survivability of an organism in its niche—an *opportunity* for action

> . . . such as support by a firm surface, grasping by a limb of a tree, or mating by an animal of the opposite sex. 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).

Affordances simultaneously enable some possibilities and constrain others, and they make actions more predictable and replicable.

> Speaking more humanely, we do not in any sense reduce the statistical variety of nature when we are engaged in learning the fixed patterns, the constancies of nature. Rather, it is nature that reduces the statistical variety in us.
>
> Our subsequent behavior becomes more predictable to an outside observer who knows the order of nature because it comes to be more closely coupled to, and defined by, that order. We have acquired, in Spinoza's phrase, more "aptness of the body" because our ideas are less "mutilated and confused" (Hawkins, 1964, p. 239).
>
> Mediated habitats encompass a range of affordances and effectivities related to cognitive artifacts such as the book, the calculator, and the television. Such artifacts can do some of the work of storing and transforming information, and this work may therefore lessen the user's need to construct or maintain more complex MIROS. In addition, such artifacts can provide . . . affordances for reasoning. . . . [which] are properties of representation in relation to a person's or group's abilities to use the representations to make inferences. Reasoning is an activity that transforms a representation, and the representation affords that transformational activity. Abilities for reasoning activities include knowing the operations to perform on the notational objects in the representation and understanding the semantic significance of the objects and operations (Greeno, Moore & Smith, 1993, p. 109).

In the Gibsonian (1979) paradigm, affordances are opportunities for action rather than physical artifacts or objects. Nevertheless, it is useful to think of sets or suites of affordances as bundled in association with tools or devices (see 24.2). 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 the phone by its "handle-ability," "dial-ability," "answer-ability," "listening-to-ability," and "talking-into-ability," affordances that in some cases serve multiple goals or ends. The complete action pathway for realizing the opportunity afforded by the telephone 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.*

One of the reasons Gibson argued that direct perception is independent of 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, 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 durable connections between dendrites (see Crutcher, 1986; Kupfermann, 1991).

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 activity per se.

In the calculus of planning and action, detection of the invariant properties of affordances allows some aspects of a problem to be stipulated or assumed, freeing cognitive resources to attend to the unknowns, those aspects of the environment subject to change: Is this branch thick enough? Are the waves too frequent? Is the buck too big?

The capacity to detect and respond to affordances results from repeated engagement with sets of circumstances that over time—in the life of the individual or the species—are consistent enough to induce automaticity (Sternberg, 1977) in perception and action. Affordances influence the interaction of the organism with its environment, not only by enabling and constraining action but also by entraining the organism's perceiving and acting in predictable and repeatable sequences .

As a general rule, it can be assumed that organisms will not squander sensory or cognitive resources on aspects of the environment that have no value as affordances, because natural selection (or learning) will have effectively blinded them to objects and phenomena 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 a Gibsonian perspective, we see the world not as it is, but as we can use it.

8.5.2.3. Effectivities. Effectivities (or capabilities; Greeno, Smith & Moore, 1993) are intentional, meaningful properties of a perceiving organism that trigger, guide, and control ongoing activities directed towards exploitation of the inherent possibilities of affordances (Turvey, Shaw, Reed & Mace, 1982). An effectivity encompasses the structure, functionality, and actions that might enable the organism to pursue what is, roughly speaking, in human terms, a goal (see 3.1.4.5). Using its "climber things," the squirrel exploits the climb-ability of the branch to escape a predator. Using its "alighter things," the seagull exploits the alight-ability of the rock for rest. Using its "grabber things," the wolf exploits the grab-ability of the deer to obtain nutrients.

> Taken together, geometrical, kinetic, and task constraints constitute a description of a person's effectivities. . . . Geometrical and kinetic constraints are intrinsic to physical properties of the actor and can be directly measured! calculated with respect to an external frame of reference (i.e., height, weight). Task constraints are more functional and "psychological." They include all of the intentional, goal-directed considerations that encourage the person to perform one action rather than another (Mark, Dainoff, Moritz & Vogele, 1991, pp. 484—85).

Affordances and effectivities are neither specific organs of perception nor specific tools of execution, Rather, they are emergent properties produced by interactions between the perceiver and its environment.

A well-tuned relationship between affordances (opportunities) and effectivities (abilities) generates a dialectic that, Csikszentmihalyi (1990) argues, is experienced by humans as highly satisfying. He calls this dialectic the "flow experience" (p. 67).

Affordances and effectivities are mutually grounded in and supported by both the regularities of the physical structure of the environment and by the psychosomatic structure of the perceiver. It is meaningless to consider whether an object affords action 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, 3-feet-tall rock affords convenient sitting for a human but not for a bull elephant.

Indeed, meaning, of perhaps a quite fundamental sort, 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 might realize its intentions.

Our definition does not assume that organisms are conscious or that they use semantics or syntax, nor does it necessarily assume that organisms are purposeful. Our definition does assume, however, that all 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 orientedness, especially when they are 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 in natural systems evidence of deliberate design or purpose-vitalism and creationism, for example. A narrower conception of intentionality and goal orientedness, however, is very convenient in the study of self-organizing and cybernetic systems (see 3.1.2.5) in which

> ...feedback mechanisms are characterized by the fact that the input is controlled by the output, and thus stabilizes the output, or makes the performance relatively independent from disturbing influences. One can consider the stability of the output as the "goal" of the system. To turn the argument around, whenever a behavior in biology is described as goal directed, i.e., teleological, it is very likely that a feedback mechanism is involved (Gregory, 1989, p. 176).

When ecological psychologists attribute intentions and goals to nonhumans, they typically do so in the more limited sense associated with functional maintenance of homeostasis—or in Maturana's (1980) terms, *autopoesis—rather* than as an attribution of deliberate design or purpose (see 3.1.3.5).

8.5.2.4. 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:

> To the person doing the hammering, the hammer as such does not exist. It is part of the background of *readiness-to-hand* that is taken for granted without explicit recognition or identification as an object. It is part of the hammerer's world, but is not present [to awareness] any more than are the tendons of the hammerer's arm (p. 36).

The disappearance of an affordance from awareness signals the psychological unification of the effectivity with the corresponding affordances. One can think of this unification as an extension of the effectivity by the affordance or as a "path" for action-perception. In everyday activity, the very "routine-ness" and familiarity of such paths makes them invisible to the organism. Thus, another metaphor for directness of action-perception is transparency. The organism perceives and acts *through* the unified effectivity-affordance (arm and hammer) and is therefore only aware of the object of perception and action (the nail).

> The hammer presents itself as a hammer only when there is some kind of breaking down or *readiness-to-hand.* Its "hammerness" emerges if it breaks or slips from grasp or mars the wood, or if there is a nail to be driven and the hammer cannot be found. . . . As observers, we may talk about the hammer and reflect on its properties, but for the person engaged in . . . unhampered hammering, it does not exist as an entity (Winograd & Flores, 1986, p. 36).

In terms of ecological psychology, we can think of Heidegger's concepts of *breakdown* and resulting *unreadiness-to-hand* as a partial decoupling of an effectivity from its corresponding affordance. Breakdowns "serve an extremely important cognitive function, 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, p. 78).

8.5.2.5. Everyday Learning and Media Environments. For J. J. Gibson, the ordinary world of everyday learning and perception is

> . . . not the world of physicists. It is far larger than atoms and far smaller than galaxies. It is the geological environment of ground, water, earth, and sky, and it is the evolved world of flora and fauna. The substances and surfaces of the ground and the animate and inanimate things above it need to be described at their own level, if we are to understand what animals are aware of. Equally important, the energy fields in the medium of the air (or water) exist at an ecological level and contain information about the furnishings of our habitat. These sources of information in stimulation must therefore be studied ecologically, not physically. 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 (Reed, 1988, p. 230).

The popularity of Donald Norman's (1988) book, *The Psychology 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 knowledge workers and postindustrialism, human habitats and artifacts must accommodate mentality as well as physicality, and support creativity as well as consumption. Cognitive ergonomics (Zucchermaglia, 1991) is just as important as corporal ergonomics (Mark, Dainoff, Moritz & Vogele, 1991): Both depend to a considerable extent on understanding fundamental human capabilities that were tuned long ago by ecological circumstances.

Yet if new media are to support the development and utilization of our uniquely human capabilities, then 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.

> Covariations of tactile, auditory, visual, and other sensory inputs are normal concomitants of most action, and must be presumed to provide most of our normal clues for the integrated perception of our environments. The detection and analysis of covariation is thus the main function required of the relevant cortical network. Given this, the system has all it needs by way of an internal representation of the tactile world-as-perceived for the organization of relevant action. The state of conditional 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).

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

Saba (1988), for example, argues that the virtual contiguity afforded by integrated telecommunications systems (incorporating venues such as two-way video conferences and distributed or networked multimedia) transforms possibilities for participation in communities of production and learning. In his view, the convergence of media technologies, techniques for multitasking, and sharing of tools for communication reduces the transactional distance between participants and reduces dependence on communication through explicit discourse.

8.6 ECOLOGICAL VS. EMPIRICAL APPROACHES

> Instead of . . . [assuming that] perception is some kind of *internal operation* of the brain (the seat of the mind) on the signals from the world, e.g., interpretation, addition, supplementation, or organization, but in any case a "processing" of the input . . . I suggest *that* the act of perceiving is one of becoming aware of the environment, or picking up of information about the environment, but that nothing like a *representation* of the environment exists in the brain on 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—72).

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 a computer. One of his important insights was that *actions* involved in detecting and selecting information are, like *orienteering* (the use of a map and compass to navigate between checkpoints along an unfamiliar course) just as important to subsequent understanding of what is perceived as the processing of sensory stimuli.

Gibson's ideas about the importance of orientation led him to question the mind-body dualism of behaviorists and cognitivists , which dualism assumes the mind is a mechanical device or a computer and is therefore separable from mental phenomena (see 2.1, 7.2). Essentially, Gibson converted this ontological dualism into a useful methodological distinction:

> The aim of a perceptual experiment was no longer to ascertain what hypothetical processes converted inadequate inputs into percepts, but rather what stimulus variables specified what perceptions (J. J. Gibson, 1979, p. 25).

This methodological innovation regarding stimulus variables led Gibson to the

> . . . novel distinction between *literal* and *schematic perception.* When psychophysical experiments are arranged so that a subject "will make the best observations of which he

is capable," perception is usually accurate and veridical, yielding what Gibson called the literal visual world. When one's experimental method involves "impoverished, ambiguous, or equivocal stimulation" with constraints on observation, such as brief exposure time, one obtains schematic perception of the visual world. Schematic perception is often inaccurate and erroneous, but, Gibson insisted, "the alterations and distortions might have been eliminated if the conditions of observation had been different" (Gibson, 1950, p. 217). The effects of perceptual habits and social custom on perceiving were assimilated by Gibson to the concept of schematic perception: The origin of perceptual error lies, not in mistaken processes of imagination, but in a mixture of inadequate stimulus conditions and the human tendency to adopt the customs of the group, even when they are less than fully adaptive (Reed, 1988, pp. 184-185).

Perhaps Gibson's (1979) most serious doubt about information-processing models was that such models focus on the organism's *analysis* of stimulus information at the expense of the organism's activities in *detecting and selecting* stimulus information. Thus, information-processing models tend to minimize the *context* of stimuli-their locality, temporality, and relatedness to other factors in the environment and in the organism.

8.6.1 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).

Despite significant improvements in sensor and computing technologies, artificial-intelligence (AI) systems have been unable to emulate everyday tasks performed by animals and people, because AI technologies lack sufficient means for selecting and encoding contextual and situational variables (Winograd & Flores, 1986) and because artificial intelligence is not embodied (Johnson, 1987). As McCabe (1986) notes," 'Context sensitivity' is the bane of all associationistic models" (p. 26).

In the process of reinventing the concept of retinal imagery that underlies 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 that convention had imposed on his discipline. 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.

The problem is that positivism relies almost exclusively on the traditional 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 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 (1966) 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.

Conventional psychology 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.

The grand irony of the Cartesian tradition in psychology is that it forces on proponents of the mechanistic schools of thought concepts from the mentalist tradition, and vice versa. Recently this Cartesianism has cloaked itself in the computer metaphor of information processing; nonetheless, many of the most prominent neuroscientists of this century have been forced by their mechanistic account of perception into an outright mind-body dualism. What has been left out of the picture altogether in 20th-century psychology, as Gibson makes clear, is the active self observing its surroundings (Reed, 1988, p. 201).

Ecological psychologists employ "geodesics" (Kugler, Shaw, Vincente & Kinsella-Shaw, 1991, p. 414) to complement mechanistic systems of description based on Cartesian metrics. Examples of geodesics are least work, least time, least distance, least action, and least resistance. Ecological psychology conceives of these action pathways as "streamlines" through the organism's niche structure and environmental layout rather than 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 cowpaths 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 they can be applied to human activity in media environments. Optimal perceiving and acting in mediated envi-

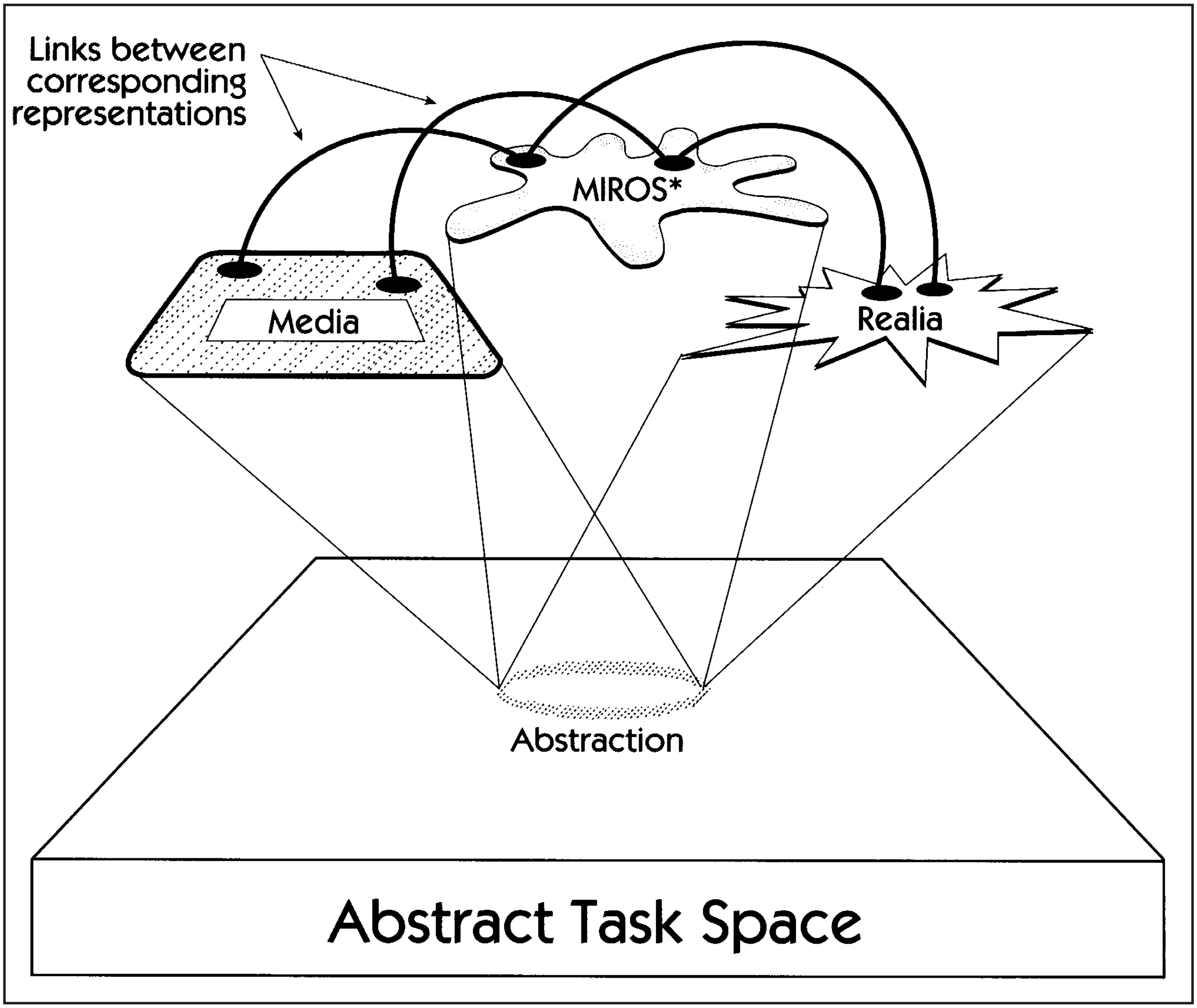

Figure 8-2. A framework for distributing cognition among media, realia, and mental-internal representations of situations (MIROS). Freely adapted from Zhang and Norman (1994, p. 90), this framework subdivides external representational space into *media space* (media) and *real space* (realia). The framework does not assume that corresponding elements in the *three* spaces will necessarily be isomorphic in function on structure. On the contrary, there are usually profound differences.

ronments does not necessarily follow boxes, frames, or other contrivances based on arbitrary grids imposed in the Cartesian tradition—pages, tables, rules, keyboards, screens, and the like. 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 shortcuts 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?

8.6.2 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 the detecting of information, not the having of sensations. Rather than assuming a hypothetical perceiver, Gibson opted for a real, everyday perceiver, with all the possibilities and limitations implied by the ordinary. 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):

l. Substances, surfaces, and media as complements for mat ter
2. Persistence and change as complements for space and time
3. Locomotion as a complement for motion
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 since proved important to designers of virtual realities and simulations.

> First, a surface is not *discrete* like a detached object, and thus surfaces are not denumerable. Instead, a surface is nested within superordinate surfaces. Second, a surface does not have a *location* as an object does, a locus in space. Instead, it is part of what I call the environmental *layout;* it is situated relative to the other surfaces of the habitat underlaid by the ground, the surface of support (J. J. Gibson, 1979, p. 351).

8.6.3 Alternatives to Traditional Empiricism

The idea of environmental layouts serves as a useful example of the tension between the mechanistic approach and the ecological approach. "Environmental layout" reflects a persistent concern expressed in the writings of ecological psychologists: The very successful systems of formal description and analysis employed by classical physics have been misapplied in describing the 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 *(see* earlier discussion), then the usefulness of space-time grid maps for analyzing and explaining organic behavior is only partial. More useful are 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. Yet, ecological psychologists such as Koffka (1935), Johansson (1950), Lashly (1951), McCabe (1986), and Turvey, Shaw, Reed, and Mace (1981) share with field biologists and anthropologists doubts about excessive reliance on laboratory experiments for gathering data relevant to the study of complex interactions between organisms and their environments.

Experimental psychologists often seem to feel that context effects are to be controlled and eliminated from an experiment if at all possible. This, we would argue, is a mistake. One can indeed suggest that 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 rather that context effects are impossible to eliminate and that we should not wish to eliminate them totally, but only to study them. There is no zero point in the flow of contexts. They are not incidental phenomena that confound our careful experiments: They are *quintessential* in psychology. There is no experience without context (Bars, 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, and 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. Without, then, either defending or exonerating his rhetoric, we offer our summary of Gibson's views on empiricism:

l. Empiricism can be distinguished from objectivism.

2. Eschewing objectivist theories of description need not imply abandonment of the scientific method, only rejection of unwarranted extensions in which the observations of a hypothetical observer are elevated to the status of a "God's-eye view" (Putnam, 1981).

3. 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 replicate or verify findings and experiences rather than as veridical descriptions of reality (Winograd & Flores, 1986). We would add that when the authenticity of mediated representations is doubtful, the most ethical policy is to ensure that users can obtain instructions about how to replicate or verify represented objects and events. Lacking such instructions, users should be able to access information about the provenance of the representations.

8.7 INDIRECT PERCEPTION, MEDIATED PERCEPTION, AND DISTRIBUTED COGNITION

> Our species has invented various aids to perception, ways of improving, enhancing, on 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).

If the great advantage that direct perception confers on organisms lies in an improved ability to detect affordances, a secondary benefit is that direct perception underlies "all less direct kinds of apprehension on cognition" (J. J. Gibson, 1977/1982, p. 289). Although he never developed a theory of indirect perception, Gibson clearly considered it an important topic, and he 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.

Indirect perception is assisted perception: "the pickup of the invariant in stimulation after continued observation" (J. J. Gibson, 1979, p. 250). "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.25 1).

Reed (1988, p. 315) points out 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 that the exploratory actions of an organism engaged in perceiving energy arrays evidences the organism's "awareness" that stimulus information specifies affordance properties relevant to the requirements of the organism's niche.

On the other hand, Gibson recognized that instruments, pictures *(see* 26.2.3), and language can also be used to select, modify, and represent energy arrays.

> Knowledge that has been put into words on, similarly, into numbers can be said to be *explicit.* It is rather different from the knowledge got by direct perception, by the simpler instruments, and by pictures. Not all information about the world can be put into words and numbers. Sometimes there are no words for what can be seen and captured in a picture. Is this because no verbal description is possible, or only because it has not yet been formulated? (J. J. Gibson, 1977/1982, p. 291).

Gibson (1977/1982) argued that symbols (i.e., *notational symbols* in Goodman's 1976 sense) are quite different from pictures and other visual arrays. Gibson believed that symbols constitute perhaps the most extreme form of indirect perception because:

> . . . their meanings are attached by 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) (p. 293).

Gibson, like other ecological psychologists, recognized the intellectual and constructive nature of indirect perception and, particularly, the important role that indirect perception plays in the creation and use of language.

> Perceiving helps talking, and talking fixes the gains of perceiving. It is true that the adult who talks to a child can educate his attention to certain differences instead of others. It is true that when a child talks to himself he may enhance the tuning of his perception to certain differences rather than others. The range of possible discriminations is unlimited. Selection is inevitable. But this does not imply that the verbal fixing of information distorts the perception of the world. The . . . observer can always observe more properties than he can describe (J. J. Gibson, 1966, p. 282).

We argued earlier that human beings and other organisms benefit from thermodynamic leverage when they can off-load information storage and processing to nonbiological systems. Such off-loading requires improved perception—more reliable access to external information. It is not always easy, however, to estimate the costs associated with, respectively, internal representation and external representation, because the information is allocated dynamically. For example, after repeatedly forgetting some information item, one might decide to write it down (external, mediated representation) on, alternatively, to make a deliberate effort to memorize it (internal representation). Wise computer designers and users similarly attempt to optimize storage and processing of information between *internal* mechanisms (fast, but energy-consuming and volatile CPUs and RAMs) and *external* media (slow but energy efficient and stable CD-ROMs and backup tapes).

Where human beings 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 representations and external representations form a "distributed representational space" that represents the abstract structures and properties of the task in "abstract task space" (p. 90). They 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 8-2 freely adapts elements of the Zhang-Norman framework (1994, Fig. 1, p. 90) by substituting MIROS for "internal representational space" and by further dividing external representational space into media (media space) and realia (real space).

We do not propose in this chapter to define rigorously 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 on-line 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 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 corresponding information is structured in each space. Furthermore, as we argued 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-thus presumably improving 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 external representations as when the arithmetic operations of an abacus are internalized by expert abacus users. Salomon saw such learning by observation, not as a simple act of imitation or copying but as a process of elaboration involving recoding and mastery of constituent acts.

Distributed cognition points the way to *the* design of more efficient systems for supporting learning and performance. Yet the new representational systems offered 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.

8.8 AN ECOLOGICAL APPROACH TO UNDERSTANDING MEDIA

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. End users therefore must be guided by implicit conventions or explicit instructions that help them to select or construct MIROS that can substitute for the missing affordances.

8.8.1 Analogs for Acting

Every media technology from book to video to computer simulation imposes profound constraints on representation of real or imaginary worlds and requires trade-offs as to which aspects of a world will be represented.

A topographical map, for instance, represents three-dimensional land forms on a two-dimensional surface. Such maps are constructed through electromechanical processes, aided by human interpreters, in which numerous aerial photos taken from different angles are reconciled to yield a single image. This process captures some of the normal affordance properties available to the aerial observer-shadings, textures, angles, and occlusions, for instance-as well as the ways the values for these properties change in response to observer movement. The original affordance information—the climbability and walkability of the terrain, for example—is re-presented as a flat image that indicates elevation through contour intervals and ground cover or other features through color coding. Much of the information detected by the aerial observer is thus available vicariously to map viewers, *provided* that *the* viewers can 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,

Media + MIROS = Realia

Many activities of everyday living are generally intuitive and relatively automatic because perceived affordances can be immediately exploited with minimal mental effort and because consequences can be immediately perceived. This tight linkage of action and perception in real time characterizes the praxis that enables much unschooled learning.

The collapsed affordance structures of many mediated environments, however, transform the means by which users can exercise their powers of perception, mobility, and agency: Scanning a photo is not the same as scanning a scene, although ecological psychologists will argue that much is similar about the two acts. The lack of certain affordances in mediated representations may even promote reflection by reducing cognitive load: Viewing a scene vicariously through a photo frees one of the need to monitor or respond to immediate events: A topographical map can be read at leisure; there is no need to attend to the immediate passage of land forms under the reconnaissance airplane.

8.8.2 The Importance of Being There (or Not)

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

8.8.2.1. Depiction. Pictorial representations of complex environments often pose extreme problems for writers of captions or other information about spatial relations. Picture

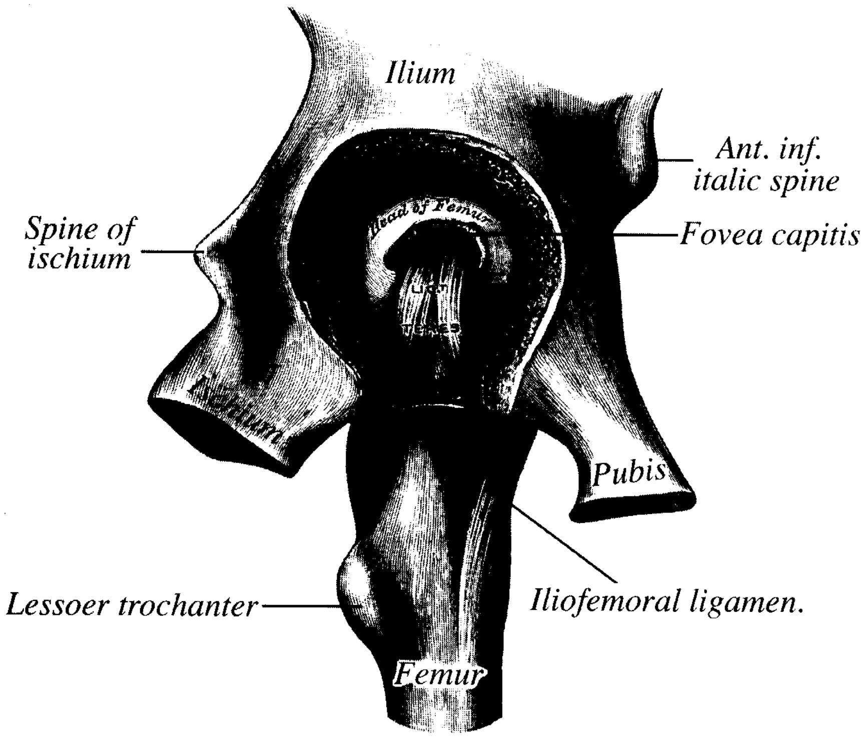

Figure 8-3. A drawing from ***Gray's Anatomy*** (Gray, 1930, p. 334).

captions also impose on readers task-irrelevant cognitive-processing burdens such as referencing figures in the text by cited numbers or hunting through the text of the caption to find relevant descriptions. Inspection of a typical illustration and its caption from *Gray's Anatomy* (Gray, 1930, p. 334) makes it clear that, lacking information about the hypothetical viewpoint of the artist, and lacking information about the more subtle relationships *between the* components depicted in *the* drawing, viewers will be unable to construct a suitable MIROS (Mental-Internal Representation of Situations) to complement the mediated representations *(see* Fig. 8.3).

Fortunately, anatomists have developed a rich lexicon for describing spatial relationships between viewers of an illustration and the objects portrayed by the illustration. For example, the text description matched to the preceding figure from *Gray's* reads:

> *The Ligamentum Teres Femoris—The* ligamentum teres femoris is a triangular, somewhat flattened band implanted by its apex into the antero-superior part of the fovea capitis femoris; its base is attached by two bands, one into either side of the acetabular notch, and between *these* bony attachments it blends with the transverse ligament. It is ensheathed by the synovial membrane, and varies greatly in strength in different subjects; occasionally only the synovial fold exists, and in rare cases even this is absent (p. 334).

Using only propositions to tell people about how to construct a MIROS for a three-dimensional 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, say, 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 spatial structure, however, the designers might select a strategy in which there is less emphasis on explicit visual representation of operations and more emphasis on narration. The two approaches are not mutually exclusive.

8.8.2.2. 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. In capturing the image, the photographer chooses to take the picture from a single viewpoint in space and time-a viewpoint that is but one of a number of possible viewpoints that are in principle infinite.

Even though a subsequent user of the photograph might be able to manipulate the position and orientation of the photo itself, take measurements of the objects as they are depicted, and engage in selective visual exploration, such exploration is an imperfect surrogate 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 about the conventions of photographic culture as well as knowledge of the 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 *the* actual situation.

8.8.2.3. Cinematography. Although cinematography can record the transformation of imagery that results from camera movement through multiple viewpoints, cinematographs, like photographs, evoke mediated perceptions in the end user that are fundamentally decoupled from the kind of action that would have been possible in the actual situation. In other words, attention is partially decoupled from intention: The viewer can attend to changes in imagery but is unable to effect changes through exploratory action. Several studies have shown, in fact, 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' tactile and proprioceptive experience or their 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.

Conventional cinematography substitutes dynamism for dimensionality by recording the way perspective views of objects transform in response to camera movements, collocating information on a single plane. Cinematic dynamism provides information about perspective, which always implies a single point of view or movement along a path. More importantly, cinema portrays invariant structure, the environment of many observers,

> through such devices as multiple points of view, glimpses of the surrounding of a scene (establishing shots). . . . *It* is important in editing a film to splice sequences in such a way that this invariant information is not destroyed by the sequence. For example, one must avoid splicing together two views of the same scene taken from opposite parts of the layout, for this would make the left side of the first sequence suddenly transform—without any information about *the* observer's path—into the right side. Ecological optics, with its emphasis on flow, might very well provide a scientific basis for the empirical, trial-and-error practices of film editing (Reed, 1988, p. 291).

8.8.3 Collapsing Multivariate Data

The problems of cinematography reflect the central challenge for authors and designers of most media products: How to collapse multivariate data into flat, two-dimensional 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 involve constraints as well as opportunities. On *the* one hand,

> . . . nearly every escape from flatland demands extensive compromise, trading off one virtue against another; the literature consists of partial, arbitrary, and particularistic solutions; and neither clever idiosyncratic nor conventionally adopted designs solve the inherent general difficulties of dimensional compression. Even our language, like our paper, often lacks immediate capacity to communicate a sense of dimensional complexity. Paul Klee wrote to this point: "It is not easy to arrive at a conception of a whole which is constructed from parts belonging to different dimensions. And not only nature, but also art, her transformed image is such a whole. . . . 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" (p. 15).

On the other hand, as Tufte richly illustrates, the tradeoffs necessary to successful compression of a data set with four or five variables, such as a map with an integrated train schedule, can work to *the* end user's advantage if the sacrificed data would have been confusing or superfluous.

8.8.4 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*

Regardless of the medium and whether its representational constraints affect spatial and temporal dimensions or other properties such as form, color, and texture, authors of mediated representations 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. Therefore, what is critical is this: that enough information be provided so that users can construct useful actionable mental models according to their needs and goals.

The short film *Powers of Ten* (C. Eames & R. Eames, 1977/1986) offers another 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 with a viewpoint somewhere in the dark void of intergalactic space, initiating a trip that ends in the nucleus of a carbon atom, 9 1/2 minutes later in Chicago.

Such a visual experience would be meaningless for most viewers without an audio narration about how to interpret the rapidly changing imagery—which includes diverse depictions ranging from galaxies, to the solar system, to Lake Superior, to a cell nucleus. 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" to describe the film's representation of situations, including propositions such as:

> Rule l. 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 (pp. 108—10).

The Morrison rules might be taken as an invitation to propositional reasoning. Yet the rules can also be usefully 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 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 indicates movement by depicting 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 human beings as a jog on a forest trail or a drive down a two-lane highway.

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

8.9 MEDIA AS ARENAS FOR UNIFIED PERCEPTION AND ACTION

The trend towards evermore rapid and extensive externalization of cognitive functions in nonbiological media leaves us paradoxically as creatures with an ancient and 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.

8.9.1 Transformation and Alienation

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. For example, the hope that multimedia technology will redress the problems of an obese couch-potato nation that mindlessly surfs television channels in search of sex and violence is partly based on the assumption that somehow interactivity will empower viewers with more choices and promote a greater awareness and understanding of nature and culture. Yet what is interactivity and how do the ways we interact with media model the ways we interact with nature or culture? To begin to answer such questions we need to examine the relationship between perception and action-both in real worlds and in the artificial worlds represented by media systems and products.

The hope of human history has often been that technological augmentation would make us into 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 the seductive possibility 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 Bhuddist religious traditions.

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 helped to dampen Western artistic exploration until the Renaissance.

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

Indeed, Eleanor Gibson (1994) has reviewed a growing body of evidence that 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."

8.9.2 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 24 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: If we take the liberty of imagining that 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 common-sense 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, however, 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 interpretation, what doomed *the* prisoners to misperception was not only that they were constrained from exploratory action 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) summarizes our thoughts about this dilemma as it applies to contemporary education:

> 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. These 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 cavelike structures we call *movie theaters* and *home entertainment centers,* where patrons 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. Even when we possess such models, it is often impossible to "run" them, due to interference from the relentless parade of new stimuli and the unconscious inhibition that attends most movie watching: Reflect too much on what you observe and you will be left behind as the medium unfolds its representations at a predetermined pace.

8.10 RESTATEMENT OF THEMES IN THIS CHAPTER

Widespread metaphors that liken media to channels for conveying messages do not lend themselves well to explanations of how human beings interact with mediated representations. Nor can they entirely explain how mind and media interact with each other to generate complex and dynamic cognitive phenomena that neither mind nor media can alone support.

Thinking of media as channels for sending and receiving symbols has often led by extension to the conclusion that perception is a process of *reception* and that cognition is the processing of symbols and language-based propositions. However, many interactions of mind and media are not easily explained in terms of channels and symbols, because humans, like most organisms, understand their environments through exploratory action and active perception. Successful design of products and services for emergent media technologies will depend in part on the extent to which such products and services honor modalities of integrated action-perception grounded in the necessities of survival and reproduction and tuned to opportunities for action in ecological niches.

Ecological psychology assumes that thermodynamic laws govern the structure and function of living communities and that successful strategies for living must be in accord with these laws. An organism's thermodynamic efficiency is partly a function of the means by which the organism obtains information about its environment and the strategies by which it uses this information to influence or control energy and matter. Living communities generate "organized complexity" by leveraging relatively small amounts of information to influence or exploit larger flows of energy and matter. Information storage and processing in turn require energy and matter, and this requirement can be thought of metaphorically as a cost to organisms, or as an investment.

The most widespread and common systems for storing and processing information on this planet are based on DNA. Yet DNA-based information systems are fundamentally limited in capacity and rate of evolution. While nervous systems offer the advantage of greatly increased flexibility for storing and processing information about the environment, such systems also impose biological costs. Off-loading information storage and processing to systems that are external to the organism can reduce this cost.

From the standpoint of cognitive theory, the environment can be considered a generator of information about itself, and perception the means of obtaining this information. In general, natural selection appears to favor investment of resources by a species in systems for detecting, selecting, and perceiving information in the environment when the cost of obtaining such information is less than the cost of generating or obtaining equivalent information from sources internal to the organism. Investing resources in improved perception is a means of obtaining information about the environment while minimizing investment in biological mechanisms for internal information processing.

The most important information an organism can derive from perception is information about invariant or unchanging aspects of the environment, for example, gravitational fields. Invariants anchor perception and action by functioning as "knowns" in decision-making or problem-solving processes. Action-perception related to invariants is often highly automatic, and in human beings is typically processed unconsciously.

Natural selection tunes perceptual processes to affordances or opportunities for action associated with an organism's ecological niche or occupation. Since selection similarly tunes effectivities or capabilities for action to opportunities, perception in most organisms is strongly associated with action. Indeed, a fundamental tenet of ecological psychology is that divorcing the study of perception from the study of action leads to a distorted understanding of attentional and intentional processes in organisms. Although cybernetic models often treat the relationship between action and perception as cyclic, a more appropriate alternative in many cases is to treat this relationship as covariant or codeterminant.

Human evolution has been accompanied by an increasing reliance on external information storage and processing. Social routines and gestures probably allowed early human beings to "off-load" much of their individual information processing to external venues associated with group activity-sharing the work of cognition with artifacts as well as with other human beings. However, it seems unlikely that human beings used language in the form of high-speed articulate speech to externalize information until the last few hundred thousand years. External storage became even more stable and reliable with the advent of markings, glyphs, and alphabets.

Modern minds can be arguably characterized as much by their dependence on tools and artifacts as by any purely internal mental process. Indeed, it appears that thinking and reasoning in today's artifact- and media-rich societies are best viewed as emergent functions of distributed cognitive systems in which the work of information storage and processing is shared between realia, media, and Mental-Internal Representations of Situations (MIROS).

It seems reasonable, therefore, to assume that much everyday cognition and many important modalities of thought are governed not by purely internal mental models of the way the world works but rather by open models that require a constant flux of data about how action is related to perception. Much conventional thinking about media technologies has been strongly influenced by traditions of empirical research that have divorced the study of perception from the study of action. These traditions treat perception as the processing of symbols and cognition as the analysis of propositions. Yet many emerging computer environments for learning, work, and play invoke modalities of action-perception in which dispositional and enactive properties of objects take precedence over *the* purely symbolic meaning of such objects. Typically, these environments offer opportunities for action in which users realize their intentions by manipulating objects rather than by constructing language-based commands. Some of the most powerful and effective strategies for using interactive media, however, employ mixed modalities in which language and symbol-based communication operate in concert with object-oriented manipulation.

Although older media formats such as print and cinematography do not support a high degree of object manipulation, these formats invoke human capacities for integrating perception and action by selectively substituting perception components *for* action components. Verbal descriptions, for example, can serve as surrogates for action by informing viewers of how and where photographic images were captured. By reducing the action component, photographs create opportunities for reflection and deliberation that may not have been available to observers at the original scene. In contrast, cinematographs substitute the dynamics of camera movement for the real or imaginary actions of observers. Such dynamism may suppress reflection and deliberation.

As we acknowledge media for their potential as arenas for action, as means for exploring the relation between acting and perceiving, researchers and designers will begin to address strategies for modulating and varying these opportunities in order to support specific educational purposes and functions. Yet only by respecting our fundamental evolutionary heritage as organisms whose cognitive capacities are grounded in ecological necessity can we hope to build media environments that allow us to live well as human beings.

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