BRINGING TECHNOLOGY TO THE RESOURCE MANAGER ... AND NOT THE REVERSE*

Daniel L. Schmoldt
USDA Forest Service
Southeastern Forest Experiment Station
Brooks Forest Products Center
Virginia Tech University
Blacksburg VA 24061-0503

ABSTRACT

Many natural resource managers envision their jobs as pressed between the resources that they have a mandate to manage and the technological aides that are essential tools to conduct those management activities. On the one hand, managers are straining to understand an extremely complex array of natural systems and the management pressures placed on those systems. Then, at the same time, managers are expected to perform their management tasks using tools that few individuals understand well enough to apply to their fullest advantage. We need to provide resource managers with technologies that operate intuitively and are well-adapted for natural resource problems. To do this, we must deliver technology to managers in a manner that integrates the technology almost seamlessly with managers' ways of thinking and performing their work. Unfortunately, it has been the historical pattern to ask, instead, that managers conform to the technology. This mechanocentric attitude is counter-productive. Innovations in human-machine interfaces are essential "translators" between managers and management tools. Recent work in the areas of visualization, virtual reality, spatial data management, and intelligent systems will enable us to lay existing technologies right into the hands of managers, rather than drop those technologies at their feet.

INTRODUCTION

To make an informed decision, a resource manager must collect, analyze, and integrate extensive information about natural resources. Scientific inquiry provides such information and helps us learn about our natural surroundings. However, we are gradually becoming overwhelmed with increasing amounts of information--information that managers are often unable to digest and to apply to natural resource problems (Rauscher 1987). Scientific inquiry reduces complex problems to smaller and smaller pieces and as the scope of any scientific problem becomes smaller, the problem is easier to understand. The scientific community has been extremely productive by providing new information and by introducing new technologies that allow us to analyze and model the real world (McRoberts et al. 1991). While this strategy has allowed science to accu-

*Paper presented at the 1992 American Society for Photogrammetry and Remote Sensing / American Congress on Surveying & Mapping / Resource Technology 92 Convention: Monitoring and Mapping Global Change, held August 3-7, 1992 in Washington DC.

mulate vast stores of knowledge about many things, it does not address the difficulty of organizing and synthesizing such a large body of knowledge.

Once individual pieces of knowledge are understood to some degree, they must be glued back together because that is how a system functions, as a whole and not a collection of disjoint pieces. It is the job of the manager to reconstruct these pieces into a model, either implicit or explicit, that reflects the workings of the real-world system. Many technological innovations are designed to aid the manager in this task. Information technologies enable the resource manager to collect, organize, store, and analyze information essential to the stewardship of large acreages composed of diverse resources.

Historically, work performed by people has been action centered and closely tied to physical cues provided by concrete objects in the real world (Zuboff 1988). Human thinking modalities are firmly based on the interaction of physical environment cues and physical action. Over the past few decades, however, information technologies have removed the physical nature of work and replaced those traditional cues with abstract symbols. The remainder of this paper examines a number of recent information technology innovations that attempt to reverse the trend that has replaced the physical with the symbolic. These innovations are surfacing in response to the realization that the computer can never be an effective medium for human problem solving so long as it operates in a manner that forces people to think and work in unnatural ways. A more natural work climate, on the other hand, incorporates physical cues (especially visual), sentient action, and problem-specific context.

ACTION-CENTERED WORK

Our most basic and natural modes of learning and thinking are grounded in the *oral* tradition. A reliance on concrete experience and multisensory context is part of this oral culture. In this culture, we learn and pass on what we know to a large extent by speaking, observing, touching, listening, and doing. Skills are honed over long years of physical experience, so work is associated with concrete objects and the cues they provide. These experiential activities provide a referential context for what we learn, and the knowledge we acquire is inextricably tied to these actions and experiences. Action-centered skill possesses the following qualities (Zuboff 1988):

(1) *Sentience.* Action-centered skill is based upon sensation derived from physical cues accompanied by little cognitive attention,

(2) *Action-dependence.* Action-centered skill is developed in physical performance and hence is implicit in action,

(3) *Context-dependence.* Action-centered skill only has meaning within the context in which its associated physical activities can occur, and

(4) *Personalism.* It is the individual body that takes in the situation and an individual's actions that display the required competence.

These qualities of action-centered knowledge create a strong linkage between the knower and the known. "I see, I touch, I smell, I hear, therefore I know" (Zuboff 1988) becomes our epistemological axiom. We can distinguish two variants of action-centered work, acting-on and acting-with.

Acting-On

Acting-on work involves close physical interaction with the objects to be created or manipulated. Knowledge acquired in this setting has a strong sentient quality that results more in reflex action than in cognitive action. Few of those who have such knowledge are able to explain, rationalize, or articulate it. Montgomery (1979) describes acting-on as the functional knowledge of craftspersons, derived through decades of sustained physical involvement during which the knowledge of each craft is systematized, not in explicit rules, but through practical action. The sense of "knowing" involves both perception of the objects around us and our physical relationship to those objects, including our ability to affect them. It is appropriate that such knowledge be referred to as "know-how" for it is knowledge that derives from action and displays itself in action, knowledge that means knowing how to do, to make, to *act-on* (Zuboff 1988). While this description of acting-on seems skewed toward physical laborers, it also applies to workers (e.g., resource managers) whose thinking cues are taken from the physical world and whose actions operate at a distance through other agents. Natural resource management has traditionally been more art than science and the resource manager has played the role of artisan and craftsperson.

Acting-With

The second type of action-centered work is *acting-with* work. Acting-with often describes more accurately the role of managers than does acting-on. Here, a worker coordinates people, things, and events to accomplish specific tasks. Mintzberg (1973) identifies 3 role domains that account for most management activities: (1) the interpersonal, (2) the informational, and (3) the decision making. Interpersonal work may involve elaborate combinations of verbal, visual, and physical interactions with other workers. In the informational and decision-making roles, managers rely on "tangible information", i.e., concrete stimuli, rather than gradual trends displayed in routine reports. In each of the three roles there is a strong preference for live action; the manager works in an environment of stimulus-response (Mintzberg 1973). Even though the manager's work is less sentient, it remains action centered. Intermediary agents now act as the manager's arms and tools. Acting-with work, more so than acting-on work, involves cognitive processes, but the presence of physical cues and the reaction to them are still critical components of the manager's skill.

The process of learning, remembering, and displaying action-centered skills does not necessarily require that the knowledge they contain be made explicit. Physical cues do not require inference; learning in an action-centered context is more likely to be analogical than analytical (Zuboff 1988). Formal training in the oral tradition consists of an apprenticeship during which time the trainee listens, watches, and acts under the tutelage of the master. In contrast, the use of written language (printing culture) is still a relatively recent medium for transferring knowledge, but it changes the formal transfer of knowledge toward symbol-based educational establishments. The printing culture has replaced physical cues and actions with symbols and abstractions. Information technologies continue this trend away from the oral tradition and remove additional physical cues by multiplying the volume of information presented to the manager and by presenting information in a bland, non-contextual way. In so doing, these prior information technologies displace resource managers from the physical cues that are part of their oral tradition and force managers into an abstract, data-centered world.

TECHNOLOGY

Information Technology

The goal of technological innovation is to increase productivity. Technology provides tools to leverage existing abilities--to do more things, to do things better, to do things faster. This capability is particularly critical for resource management where more and diverse products and services are demanded from dwindling resources. Nevertheless, not every innovation that looks like a productivity-enhancing tool eventually plays that role. Introduced technologies can create entirely new cultures that, if they are not carefully blended into the existing culture, may run counter to established or natural modes of working and thinking. When new technologies clash with existing cultures, they may lose their ability to enhance productivity. Many of the information technologies fall into this category.

New technologies (particularly the information technologies) have disrupted the traditional action-centered knowledge used by resource managers. Historically, natural resource knowledge was acquired by working and experiencing the resources within the physical domain of the landscape. Managers' understanding and information were first-hand. On the contrary, first-hand knowledge is frequently not experienced today. Aerial surveys, satellite imagery, user surveys, and ground sampling provide resource information that used to be gathered by touching, smelling, seeing, and hearing. Mathematical models for timber growth and yield, animal/insect population dynamics, fire behavior, hydrologic processes, etc., replace the managers' internal, personal models that were developed by direct observation. When technology *informates,* it increases the quantity and extent of information available. It informates resource management by extending managers' abilities through time and space. Managers are no longer limited by what they can immediately experience at particular points in time and in particular locations. In the words of Zuboff (1988):

> "Technology represents intelligence systematically applied to the problem of the body. It functions to amplify and surpass the organic [and temporal] limits of the body...The new technology signals the transposition of work activities to the abstract domain of information. Toil no longer implies physical depletion."

Along with extending the availability of information, technology creates a new order. It gives birth to new ways of doing things and new ways of thinking about that which we do. Managers are removed and insulated from the physical world that is their "workshop." Instead, managers must operate in a "virtual" workshop that consists of tables of numbers, graphs of relationships, spreadsheets of calculations, and mathematical models that are designed to convey the workings of a now detached physical world. Work becomes the manipulation of symbols, and when this occurs, the nature of skill is redefined (Zuboff 1988). Work becomes more abstract as it depends upon understanding and manipulating information. Unless the manager makes a special trip out into the landscape, the technological tools in the office provide the only available vision of the content and condition of the resource.

Mechanocentric Technology

When technology is introduced in such a way that people must conform to the style, methods, and models of that technology, then the technology becomes the center of focus; this is mechanocentric. Because people working in this newly created environment must adapt and adjust to the technology, in effect the technology creates a new culture. Workers must revise their thinking modes to accommodate new stimuli and new responses. For example, instead of examining forest stand structure *in situ,* a manager may be looking at graphs and tables of figures and then using a forest growth model to project future yield and a spreadsheet to estimate allowable cut. But what does the combination of site index, diameter class distribution, and basal area convey about the appearance of a stand? Decision support tools force the manager into a 2-d, computer-screen world of abstractions, where digital symbols replace concrete reality. Abstract cues available through the data interface require explicit inferential reasoning, particularly in the early phases of the learning process. It is necessary to reason out the meaning of those cues--what is their relation to each other and to the world "out there"?

The "sterilizing" effect of information technology creates a sense of disassociation and detachment from reality for the manager. Often the technologist's response is to provide more information, i.e., more abstract cues. Additional information, however, only serves to intensify the need to ascertain their referential function without providing any new mechanisms that might aid in that process (Zuboff 1988). Human abilities to learn and adapt mitigate some of these problems, but when the natural context is unavailable, it is difficult for the manager to actuate the knowledge that is closely tied to that context. That is, in the absence of traditional physical cues, experiential knowledge--knowledge developed within the context of the physical environment--can no longer be summoned and applied to the problems at hand.

It then becomes necessary for the manager to construct a new set of cues within the context of the new technology and link those cues to knowledge acquired in the physical setting. Because the data interface provides no immediate referential interpretation, managers invent ways to narrow the perceived distance between electronic symbols and natural reality. The manager must paint an internal picture of what the data mean in order to connect the symbol medium to the action context. This inner vision that helps to solve the problem of reference is part imagination and part memory (Zuboff 1988). The act of *visualization* brings internal resources to bear to soften the sense of distance, disconnection, and uncertainty that is created by the withdrawal from a natural action context. Ironically, it means creating a doubly abstract world, where the reference function of the electronic symbols becomes less problematic because another layer of abstractions (mental images) are called up to serve as referents (Zuboff 1988).

The process of creating this internal vision of the world from electronic cues takes time and effort. Whereas managers can use their time and efforts to better advantage in actual problem solving activities, it seems to make more sense to let the technology perform these visualization and imaging steps for the manager. This not only allows managers to focus on the work that they are really supposed to be doing, but also provides them with the physical cues so important to their understanding of natural resource management. The next four sections examine several new developments in human-machine interfaces that can provide the images necessary for the manager to think and work in a visual, physical world and to do so in an intuitive way. The goal of these new technologies is not to informate the manager, as in the past use of technology, but to amplify the manager's intellect, to help the manager *see*, both literally and intellectually.

VISUALIZATION

The previous discussion about human skills and their action-centered nature strongly suggests that it is important to reintroduce physical cues into the workplace. It is unnecessary, however, to do so in the traditional way, i.e., by placing the resource manager in direct spatial and temporal contact with the environment. What has been obvious to every child playing a video game has finally arrived in science, the power of interactive computer graphics--*scientific visualization* (Rheingold 1991). As simple as this idea is, it also is very powerful. As McKim (1980) notes:

> "Visual thinking pervades all human activity, from the abstract and theoretical to the down-to-earth and everyday....Surgeons think visually to perform an operation; chemists to construct molecular models; mathematicians to consider space-time relationships; engineers to design circuits, structures, and mechanisms; administrators to coordinate and administer work; architects to coordinate function and beau†y; carpenters and mechanics to translate plans into things."

Visual stimuli and responses are natural and important aspects of intelligent human behavior. Given the present level of computer graphic capabilities, it is no longer necessary to represent information to the computer user in unintuitive ways.

Geographic information systems (GIS) have been a tremendous aid in dealing with geo-referenced data. They permit one to store, analyze, manipulate, and display landscape information. They automate the creation of maps in ways that were unavailable before. Visualization, on the other hand, presents information that was previously displayed in abstract form only, for which there were no established imaging mechanisms.

While the topic of visualization is relatively new, there are some impressive examples of its effectiveness. Welty et al. (1985) created a timber-marking simulator as an educational tool using computer graphics. Kline et al. (1992a) produced an edger/trimmer training program that presents users with realistic pictures of rough sawn lumber and then allows them to place edge and trim lines interactively on the lumber to increase its value. The user can compare his or her results with optimal values stored in the program and can also test speed and accuracy for a set of boards. Occeña and Tanachoco (1988) demonstrated the use of a graphic sawing simulator (GSS) as a research tool to investigate different sawlog cutting strategies. It requires extensive data about log geometry and internal defects. Work by Zhu et al. (1991) aims to provide such data by producing visual images of logs from computed axial tomography scan data. Each of these efforts takes traditionally nonvisual information and creates images that the user can intuitively understand.

While the above reports deal with timber resources, in fact all environmental and resource management issues can be understood better by integrating visualization with existing GIS and simulation methods. Simulation is learning by doing, action centered, but only if the interface strongly supports the sense of "doing." Host et al. (1992) provide an overview of SILVATICA that uses a game-playing format to link visualization, simulation, GIS, hypertext, knowledge-based systems, and tutorial systems. Burk and Nguyen (1992) combined timber growth and yield models and visualization in a forest growth simulator. The user can view 2-d and 3-d renditions of a forest stand and is able interactively to modify the stand (thin, harvest, grow, etc.) and view the visual effects. Kline et al. (1992b) combined simulation and animation to model processing in a furniture roughmill. They noted that the dynamic nature of the visual representation highlighted mill processing problems and illuminated likely causes, observations that might not be apparent from tabular or graphic data.

Many other opportunities exist to merge visualization with remotely sensed data, simulation, and GIS. The combination of real-time satellite imagery, topographic and fuels GIS data, and fire behavior models could produce computer-generated flyby's of ongoing wildland fires. A fire boss could then take an imaginary airplane flight over a 3-d landscape and select where to place suppression forces for best effect. In another instance, air pollution monitoring stations could provide data that, combined with weather and atmospheric models and topographic data, would generate a time-lapse movie of air pollution cycles and patterns. As visualization becomes more realistic, i.e., more like what we would image the real world to be, and as it becomes more interactive, i.e., we can literally move about in this new world and affect changes in it, we are entering into a virtual world with its own virtual reality.

VIRTUAL REALITY

At what point visualization stops becoming only computer graphics and images and starts becoming *virtual reality* depends on the imagination of the user and the sophistication of the technology. Rheingold (1991) distinguishes between virtual reality (VR) and visualization by noting that VR puts the user inside a computer-generated world, instead of the user peering at it through a narrow window. He also states, however, that the "desktop metaphor" presented on the Macintosh* computer is, in some sense, a virtual world. On the contrary, I prefer to think of the Macintosh desktop as visualization, i.e., a graphical interface to the computer's operating system.

Virtual reality has its roots in several different technologies: computer graphics, cinematography, and artificial intelligence. Krueger (1974) is generally credited with coining the term *artificial reality*, which has since changed to VR. The foundations of VR technology are (Rheingold 1991):

> (1) immersion--the illusion of being inside a computer-generated scene (requires visual communication and gestural input devices) and
>
> (2) navigation--moving about inside a computer model of some space (e.g., a city or a molecule or National Forest terrain).

By this definition, VR is more than simulation. In VR the underlying model includes a visual representation of the environment and a sentient model of the user's place within that environment.

Immersion requires that the user and the scene be tightly coupled sensorially. For many applications, vision is the most important sensory dimension; however, sound, smell, and touch also contribute substantially to the projection of reality. In VR's current state of development visual interaction usually implies the use of some type of head-mounted display technology, which has been around for 25 years (Rheingold 1991). This provides the wearer with a 3-d view that moves as one moves one's head from side to side. When a gesturing device is added, the user has tactile interaction with the visual environment. A number of such devices may be used, among them the "data glove" and the "wand" (Jacobson 1991, Johnson 1992, Newquist 1991). A gesturing device not only points at objects in the environment, it may also receive feedback in terms of resistance or weight. For example, one virtual reality application allows chemists to visually "dock" different molecules to create new anticancer chemicals (Newquist 1991, Rheingold 1991). Molecular attraction and resistance are reflected back to the user's controls so that the chemist can actually feel the bonding.

Navigational capabilities allow the virtual "explorer" to move about in the virtual environment. Combined with immersion, navigation allows the user to move about and view objects from all sides. There is no longer the sense of just viewing a depiction of reality, but rather the sense that one is part of the virtual world. A resource manager would then not have to imagine what a particular stand looked like, but could immerse himself or herself in the stand (as described by the stand data) and "walk about." Of course, a realistic portrayal of the stand requires reasonably accurate stand data. To continue with this example, suppose some type of selective cutting is required in this stand. The manager could "walk" through the virtual stand and selectively mark virtual trees.

---

*Tradenames are used for informational purposes only and do not imply any endorsement by the U.S. Department of Agriculture.

These could then be removed from the virtual stand and a simulated growth of the virtual stand would provide feedback on whether the objectives of the cut might be realized in practice.

To create images rapidly enough to give the user a sense of motion (24-30 frames per second) requires special-purpose hardware. However, often only certain aspects of scenes need to be changed from one frame to the next. Greenberg (1991) describes an evolution in architectural designing that shifts from computer-aided design to moving 3-d images that allow the architect to "walk" through a building before construction. These images are photorealistic, complete with lighting, shading, and proper perspective, and provide the architect with a relatively accurate view of the final design.

The only virtual reality application in natural resources appears to be the parachute training simulator developed at the Missoula Technology Development Center, Region 1, USDA Forest Service (Hogue et al. 1991). The simulator is designed to train novice parachutists in the skills required to maneuver parachutes for safe landings. The trainee stands in front of a large color monitor and grips two overhead controls similar to those that guide a parachute. The display begins with an aerial view from an airplane and changes in response to the jumper's control of the parachute. This virtual environment has been used to train smokejumpers in this country and in Mongolia (Pierce 1990).

SPATIAL DATA MANAGEMENT

Spatial data management refers not to managing geo-referenced data, as in GIS, but instead to the management of data using spatial techniques. The difficulties of managing large amounts of data do not reside in the mechanisms of storing and retrieving the data. Rather the greatest problems lie in finding the data that are needed and interpreting them. The traditional, relational data base model is an extension of the paper form consisting of rows of records, each with some value in each column (attribute) field. It becomes very difficult for data base users to compose useful queries to extract the information that they need. Once retrieved, the data are often not in a form that allows users to understand and interpret their important qualities.

Data should be represented in a form that more closely matches the subject matter and the user's ways of reasoning about the data. Natural resource management is a land-based activity. Therefore, it makes sense that data bases should represent such data in some visual way. Maps are one possibility. Three-dimensional maps can use elevation to depict graphically the magnitude of some feature of interest, e.g., timber volume or wildlife population density. Maps might be used not only for display purposes, but also as actual representations of data bases. The user would point (using one of the gesturing devices mentioned above) to particular land areas and their attributes to formulate data base queries. Johnson (1992) describes a spatial data management application under development by American Express in which their cardholders are represented as trees and located on a globe in relation to their actual addresses. In their model, individual transactions are leaves on the tree and the size and vigor of the tree represents some measure of credit integrity.

It seems clear that no one spatial model of a data base must necessarily be superior to all others. In fact, it's likely that different departments or users would want to impose their own spatial models on the data for their specific applications. These specialized models would reflect each user's personal way of thinking about the subject matter. Current data base management systems have a similar feature that can accommodate different "views" of the same data for different users. So, in this sense, any data base could be fine-tuned to the perceptions of each user.

INTELLIGENT SYSTEMS

The application of *intelligent systems* in the human-machine interface moves away from the visual context of the three previous topics. Interface improvements resulting from this technology arise, instead, from the conceptual assistance that intelligent systems can provide. By intelligent systems, I am referring to any developments that make working with a computer more like working with another human. This might mean an operating system that has some understanding of what a computer user desires to do, so that explicit and unambiguous commands are not necessary, or perhaps simulation-model parameterization software that helps a scientist select a mathematical function that closely models his or her data (Olson and Hanson 1987). By removing many of the technological hurdles to the effective use of computers, intelligent systems aim to make computers behave more like consultants or assistants and less like complex calculators.

Intelligent GIS and intelligent data bases are two separate efforts to make data sources more understandable, more useful, and easier to use. These systems combine their information technologies with developments in artificial intelligence. Parsaye et al. (1989) distinguish three levels of intelligent data bases: (1) high-level tools, which may include intelligent search and automated discovery (see below), (2) high-level user interfaces, which may include multimedia, semantic data base editing, and navigational tools, and (3) intelligent data base engines, which represents information so that it can be expressed and operated on in many ways. GIS's can be enhanced in similar ways to improve the usefulness of geo-referenced data (Friedl et al. 1988). In either case, the result is an information system that helps with data search and interpretation tasks.

Vast amounts of data are collected regularly without any specific scientific investigation intended (inventory and monitoring efforts on public lands are examples of this). Occasionally scientists dig out this "happenstance" data and subject it to various analyses. Their results often uncover new relationships or previously unknown concepts. To perform this analysis requires human attention and a specific hypothesis or purpose to direct the analyses. When we consider that tremendous amounts of computing resources are at our disposal for 24 hours each day and that no more than 1/3 of those resources are actually utilized fully, we must wonder whether there is some way to automate and systematize the analyses of data bases. One might image that we could develop "explorer-bots", intelligent software robots that would wander through data bases looking for "interesting" relationships. When an explorer-bot finds some qualifying relationship, it would be presented to human subject matter experts to evaluate its scientific significance. We could allow these explorer-bots to run nights and weekends when most computers lie unused. Langley et al. (1987) developed a number of computer programs to demonstrate the feasibility of automating scientific discovery. Many of them use induction to infer either quantitative or qualitative regularities in data. Others use postulates such as symmetry and conservation to guide the discovery of physical laws. Michalski and Stepp (1982) created a computer program to perform conceptual clustering, another type of learning task. As its name implies, it is closely related to statistical clustering methods, whereby a taxonomy is created that groups similar objects together. Once developed, explorer-bots would require little active attention by humans and would like savants carry out their work with methodical regularity.

DISCUSSION

From our very first experiences as newborn infants we constantly distill the essence of our reality to formulate models of how the world operates. We would be totally dysfunctional if we were unable to relate new experiences to prior familiar scenes (models) and to act based on prior learned behavior. However, we do not remember entire experiences and later recall them in subsequent situations; rather we retain only the important aspects of any experience. The essential contents of our experiences provide the foundation to build these models. This model building is our only way to deal with the ceaseless variety of experience we encounter. In so doing, we create layers of mental models that serve as our reality. These models are no longer the realities of experience but they are virtual realities that affect what we perceive and how we function. Pagels (1988) states:

> "Our ability to represent and simulate reality implies that we can approximate the order of existence and bring it to serve human purposes. A good simulation, be it religious myth or scientific theory, gives us a sense of mastery over our experience. To represent something symbolically, as we do when we speak or write, is somehow to capture it, thus making it one's own. But with this approximation come the realization that we have denied the immediacy of reality and that in creating a substitute we have but spun another thread in the web of our grand illusion."

So, creating virtual realities with hardware and software is just another way of doing what we, as humans, have been doing all our lives. The computer is our new medium of expression akin to symbolic utterances, art, science, or natural language.

The prominent goal of these efforts at creating a more human-centered information technology is "intellect augmentation" or "amplification" (Rhein-gold 1991). This perspective regards computers as an extension of human abilities to perceive, think, and create. A properly designed information environment can enhance human capabilities to perceive objects that are removed in time and space, to think about and deal with difficult problems, and to build better objects and better ideas. Many people think of powerful computers in terms of megahertz and megabytes and millions of instructions per second. This sort of attitude misses the point entirely. True, fast and powerful hardware is important, but it provides very little "mega"-consolation when the productivity bottleneck lies in the interface.

Creativity in problem solving results from playing more than from analysis (Cleese 1991). Many of the greatest discoveries in science have been later recounted as occurring during periods of mental wandering or playfulness, as opposed to diligent analysis (Boden 1991). Certainly, careful study of a problem precedes discovery, but the sudden insight associated with discovery occurs during relatively relaxed and unfocused moments. Playing constitutes the primary activity of children throughout the most productive learning period of their lives. Playing is not capricious and undirected, however. Rather, it consists of experimentation, theory formation, and more experimentation; that is, it is research on how the world works (Piaget 1954). The capability to "mess around" in virtual realities much like a child exploring a new toy opens up opportunities to unleash the "child within" that intuitively knows how to probe new territory. In that virtual reality the scientist-child can pound a toy, throw it into the corner, put it into its mouth, examine it from many different angles, and bang it together with other toys, both similar and dissimilar. The visual and interactive nature of these new human-machine interfaces allows people to revert to what they do best. Consequently, human creative mechanisms can operate to their full and natural potential.

SUMMARY

Information technology has provided us with tremendous amounts of information and extensive capabilities to manipulate that information. While this informating capability is good; it also has its down side. The human-machine interface has been strongly biased toward the capabilities of the machine and not the needs and skills of the human element. Abstract symbols, e.g., tables of numbers or graphs of relationships, are unable to convey the richness of expression that we receive from the real world in terms of physical cues. Many of these cues are visual. Anything that we can do to duplicate this visual nature in computer interfaces for natural resource managers will enable the managers to work in their natural mode and to focus less on how to operate the technology and more on the resource problems facing them.

Traditional information technology and human endeavor have, in some sense, been moving orthogonally to one another. Technology has been informating us, but it has not been providing the referential context that allows us to attach physical meaning to that information. Because the human element is more adaptable, it has been asked to conform to the culture of the technology. However, as computer hardware and software have become more sophisticated and we understand better how people think and work, it is becoming increasingly obvious that the technology can be made to conform to the human factor instead. One thing seems certain. If we just drop technology at the feet of resource managers, it is much more likely that they will stumble over it than that they will grasp it and run with it.

LITERATURE CITED

Boden, M. A. 1991. *The creative mind: myths & mechanisms.* New York: Basic Books, Inc.

Burk, T. E., and M. N. Nguyen. 1992. Visualizing the operation of a distance-dependent tree growth model. *The Compiler*. (In Press).

Cleese. J. 1991. And now for something completely different. *Personnel* 68: 13-15.

Friedl, M. A., J. E. Estes, and J. L. Star. 1988. Advanced information-extraction tools in remote sensing for earth science applications: AI and GIS. *AI Applications* 2(2/3): 17-31.

Greenberg, D. P. 1991. Computers and architecture. *Scientific American* 264(2): 104-109.

Hogue, J. R., W. A. Johnson, R. W. Allen, and D. Pierce. 1991. A smokejumpers' parachute maneuvering training simulator. In Proceedings of the American Institute of Aeronautics and Astronautics 11th Aerodynamic Decelerator Systems Technology Conference. April 9-11, 1991, San Diego CA. 9 p.

Host, G. E., H. M. Rauscher, and D. L. Schmoldt. 1992. An integrated framework for forest landscape simulation. *Landscape and Urban Planning*. (In Press).

Jacobson, L. 1991. Virtual reality: a status report. *AI Expert* 6(8): 26-33.

Johnson, R. C. 1992. Virtual reality: a preview of the 21st century? *PC AI* 6(1): 18-22.

Kline, D. E., E. M. Wengert, P. A. Araman, and P. Klinkhachorn. 1992a. Hardwood lumber edger and trimmer training system. *Forest Products Journal* 42(1): 53-57.

Kline, D. E., J. K. Wiedenbeck, and P. A. Araman. 1992b. Management of wood products manufacturing using simulation/animation. *Forest Products Journal* 42(2): 45-52.

Krueger, M. 1974. Computer controlled responsive environments. Ph.D. dissertation, University of Wisconsin-Madison. (Unpublished).

Langley, P., H. A. Simon, G. L. Bradshaw, and J. M. Sytkow. 1987. *Scientific discovery*. Cambridge MA: The MIT Press.

McKim, R. H. 1980. *Thinking visually*. Belmont CA: Lifelong Learning Publications.

McRoberts, R. E., D. L. Schmoldt, and H. M. Rauscher. 1991. Enhancing the scientific process with artificial intelligence: forest science applications. *AI Applications* 5(2): 5-26.

Michalski, R. S., and R. E. Stepp. 1982. Revealing conceptual structure in data by inductive inference. Pages 173-196 in J. E. Hayes, D. Michie, and Y-H Pao (eds.) *Machine Intelligence 10*. Chichester England: Ellis Horwood Ltd.

Mintzberg, H. 1973. *The nature of managerial work*. New York: Harper and Row.

Montgomery, D. 1979. *Workers' control in America, studies in the history of work, technology, and labor struggles*. Cambridge: Cambridge University Press.

Newquist, H. P., III. 1991. A computer-generated suspension of disbelief. *AI Expert* 6(8): 34-41.

Occeña, L. G., and J. M. A. Tanachoco. 1988. GSS--A CAD-based graphic sawing simulator for hardwood logs. *Comput. & Graphics* 12(3/4): 565-578.

Olson, R. L., and J. D. Hanson. 1987. A knowledge-based deduction system for curve shape analysis. *AI Applications* 1(2): 3-12.

Pagels, H. R. 1988. *The dreams of reason*. New York: Simon and Schuster.

Parsye, K., M. Chignell, S. Khoshafian, and H. Wong. 1989. *Intelligent databases: object-oriented, deductive hypermedia technologies*. New York: John Wiley & Sons, Inc.

Piaget, J. 1954. *The construction of reality in the child*. (Translated by Margaret Cook) New York: Basic Books, Inc.

Pierce, D. 1990. People's Republic of Mongolia: parachute maneuvering simulator assistance program. U. S. Dept. of Agric., Forest Service, Technology & Development Program, Missoula MT. 9151-2803-MTDC.

Rauscher, H. M. 1987. Increasing scientific productivity through better knowledge management. *AI Application* 1(2): 21-34.

Rheingold, H. 1991. *Virtual Reality*. New York: Summit Books.

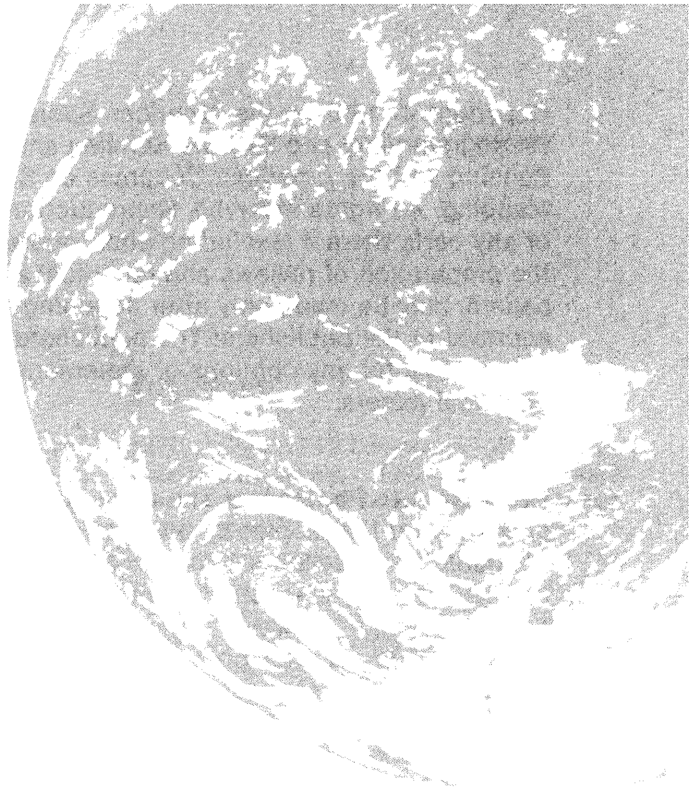
Welty, J. J., J. W. Moser, Jr., and M. J. Bailey. 1985. Timcogs: an educational, computer graphics timber-marking simulator. *IEEE Computer Graphics and Applications* 5(1): 61-67.

Zhu, D. P., R. W. Conners, D. L. Schmoldt, P. A. Araman. 1991. CT image sequence analysis for object recognition--a rule-based 3-d computer vision system. Pages 173-178 in Proceedings of the 1991 IEEE International Conference on Systems, Man, and Cybernetics. October 13-16, 1991, Charlottesville VA.

Zuboff, S. 1988. *In the age of the smart machine: the future of power and work*. New York: Basic Books, Inc.

ASPRS/ACSM/RT 92

TECHNICAL PAPERS



VOLUME 5

Resource

Technology 92