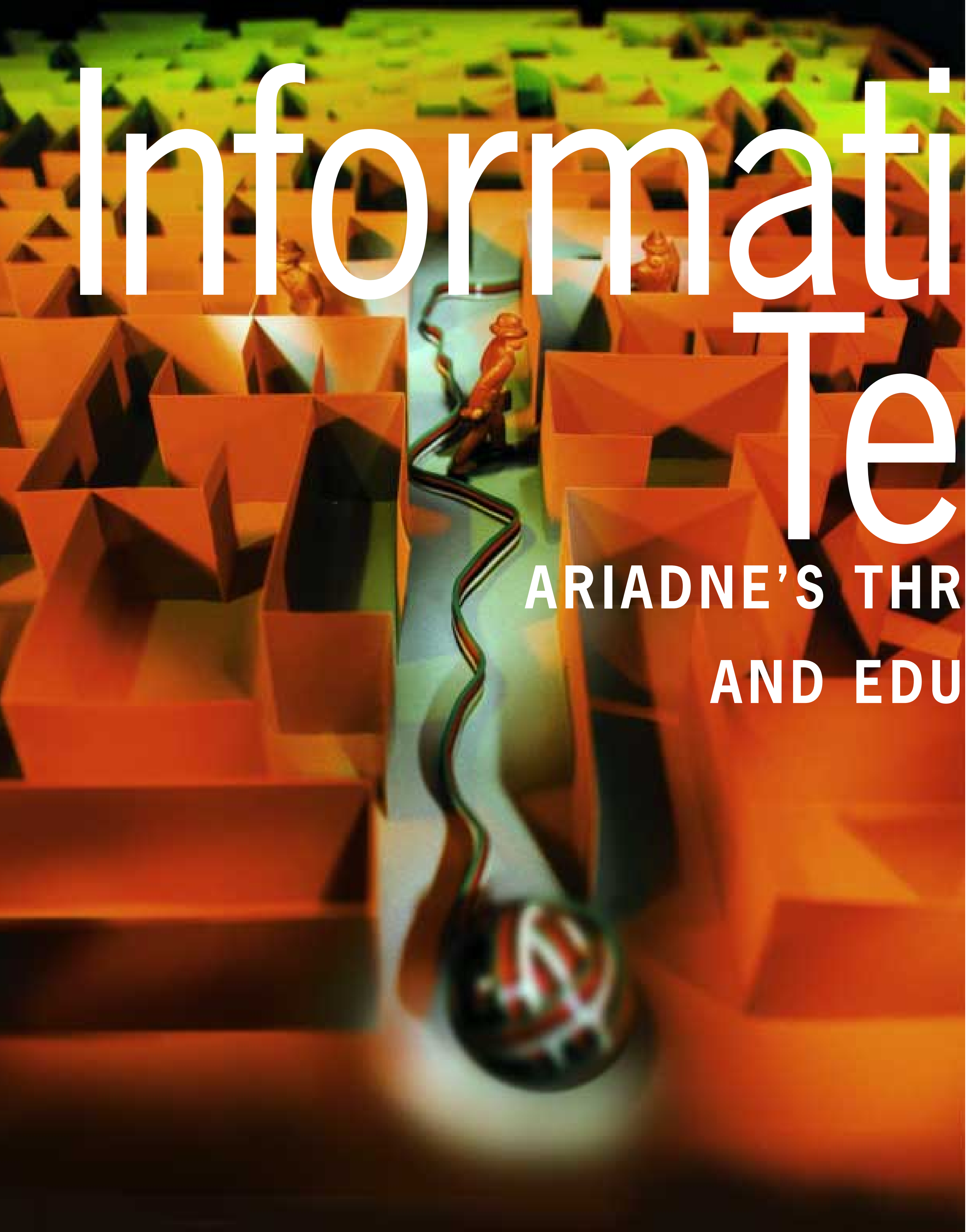

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Information Technology

ARIADNE'S THREAD THROUGH THE RESEARCH AND EDUCATION LABYRINTH

By Rita Colwell

Information technology is absolutely vital to our future. It can guide us to new frontiers in fundamental research and draw different disciplines together. It can integrate research and education, and most of all, it can link science and society in ways that we have never imagined.

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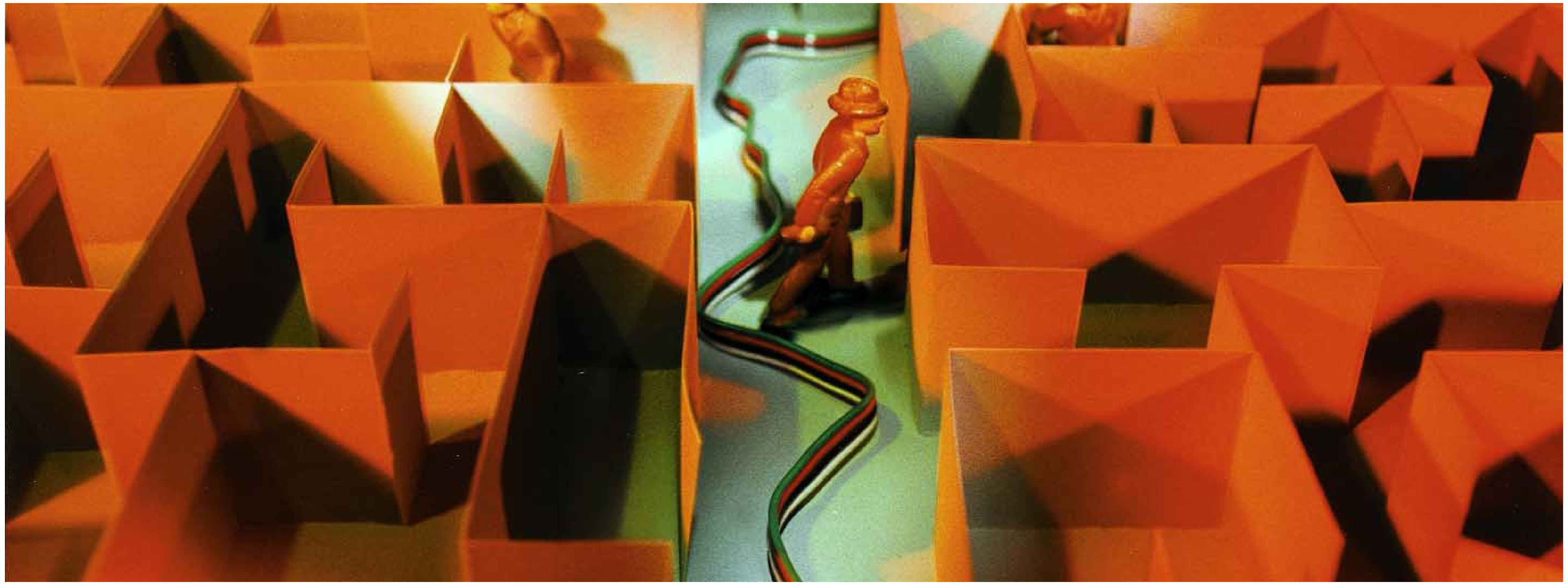


Science used to be composed of two endeavors—theory and experiment—but today it has a third component: computer simulation.

The role of information technology is, I think, analogous to the wonderful thread of Ariadne in Greek mythology. You may recall the tale: King Minos of Crete had built a massive labyrinth to contain the horrible beast, the Minotaur. Ariadne, the king's daughter, possessed a magical device, a thread, that allowed her to navigate the maze without mishap. She gave this thread to Theseus, the young hero from Athens, to guide him safely through the labyrinth.

In modern terms we can follow this metaphorical thread of information technology in two directions: back to the beginning of the Internet, and then forward to glimpse some revolutionary future scenarios. Along the way we can reflect on three major guideposts. The first is the unifying role that information technology plays for all research disciplines today. The second guidepost is how information technology can revolutionize education—that is, if we manage this momentous transformation with care and attention. The third is the very unfortunate situation we know as the "digital divide," the unequal access to information technology in different sectors of our society.

Guidepost 1: Information Technology and Research

Let me begin with my own experience with computing as a young researcher. I conducted my doctoral research on the IBM 650. (By the way, the very model of the computer that I used has an honored place in the Smithsonian Institution.) My research was an early example, actually the first, of using computers to classify marine bacteria, and early on, computing became indispensable in my research. It allowed me to draw on the insights of other disciplines, whether through modeling or remote sensing or by linking sociology and epidemiology.

Now, years later, we're poised for the beginning of a new campaign to strengthen the fundamental thread, the very fiber of information technology and its links to all fields. No field of research will be left untouched by the current explosion of information and information technologies. Indeed, science used to be composed of two endeavors—theory and experiment—but today it has a third component: computer simulation, which links the other two.

In fact, scientific questions are growing more complex and interconnected. We know that the greatest excitement in research often occurs at the borders of disciplines—at that interface with other disciplines. Materials engineering is a good example, through its blending of synthetic and biological materials. As a result, we have artificial skin that is partly biodegradable and is already helping burn victims. Another example is complexity theory from mathematics, which is being applied in biology and social science. We gain new insights into the way fish school and into how animals herd together—patterns that reveal the secrets of rather sophisticated systems.

We're supporting a new research thrust at the National Science Foundation (NSF), one that we call *biocomplexity*. To understand this characteristic of our planet's systems, we gather information at scales ranging from the subatomic to the astronomical. The solid foundation of information technology is fundamental for these fields to fuse and to flower. We're already watching discrete scientific cultures come together. In this way we can better reflect and probe the wholeness of the world that we live in and that we study.

Another example of research aided by information technology is the project called SHEBA—the Surface Heat Budget of the Arctic Ocean. In the fall of 1997, a ship was frozen into the Arctic Ocean and allowed to drift. It served as a sort of "floating research station" for climate, ice, and ocean research. The streams of data were regularly posted to the Internet, and most of the researchers, wherever in the world that they were at the time, did not have to be at the North Pole themselves. (I suspect they were grateful for that.)

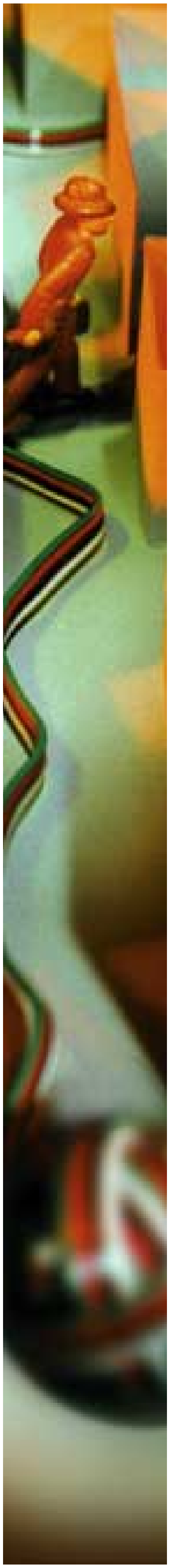
Astronomy also gives a very striking example of the convergence of research streams. The NSF-supported Gemini telescope, sited in both Hawaii and Chile, is an earth-bound instrument, but the clarity of its images will surpass those from the Hubble telescope, which is up in space. In fact, these sorts of imaging technologies that let astronomers see through the blurry atmosphere are now being applied in vision research to study the living retina. In addition, the software that is used by astronomers to discern a celestial object against a cluttered background of stars has also been applied to mammograms to pinpoint the calcified crystal that may be, in fact, a beginning cancer.

Astronomy and physics are also in convergence. Michael Turner, the noted astrophysicist from the University of Chicago, lectured at NSF recently. He described the coming together of particle physics and astrophysics—the extremes of scale in our study of the universe. In his words, the deepest answers lie in the connection between inner space and outer space. He also noted the almost unimaginable deluge of data that astronomers will need to mine in order to find those answers.

Other examples are found in the biosciences. An article in *The Economist* magazine recently proclaimed a "shotgun marriage" between biology and information technology because biology has realized that it is itself an information technology. The data onslaught that is flooding the biosciences is just the beginning. One representation of the riches of information pouring from just one area, genomics, is demonstrated by the cholera vibrio. It has been only about four years since we first mapped the entire genome of an organism. Today we know the entire genetic sequences of twenty-five organisms. Twenty-four are microorganisms; most are human pathogens, which will give us a better understanding of disease. The twenty-fifth is a nematode. Many similar challenges in biology will be conquered only in lockstep with advances in information technology. We need this computing power to put it all together—to process the volumes of data, to visualize results, and to collaborate.

Guidepost 2: Information Technology and Education

The ability to see, to sense, to visualize, is one way the thread of information technology wraps around and draws the sciences together. This is a wonderful capability with equal potential benefit for education. Researchers can use tele-immersion, sharing the same virtual reality across distances to study, for example, the temporal bone of the inner ear. Collaborations across distance can and



should include students, giving them access to the latest research. This educational transformation with information technology is the second guidepost on our way through the maze.

Information technology may be able to revolutionize the way we teach and the way we learn. One example is a project based at the University of Minnesota. In a simulation of an orbiting planet, students can change the mass of the planet and watch the orbit change. I hear that the simulation is just as exciting, fast-moving, and interactive as a video game, which makes it fun for the students. The project leaders specifically sought out kids from disadvantaged areas to do the programming and to provide the technical support for the teachers who used these materials in the classroom.

That is one of the success stories, but it's no secret that we have a great deal of ground to make up. A book entitled *The New Renaissance,* by Douglas Robertson, looks at the social revolution caused by the computer revolution. The greatest challenge of our age, according to Robertson, is to create a system of individualized and inspiring education. Robertson states, "By far the worst failing of our educational system is that it develops only an insignificant fraction of the abilities of most individuals."

To inspire learning, we need to understand learning. Until the learning process is better understood, it will be very difficult for teachers, parents, and the public to make informed choices about the theory and practices that could make the education of K through 12 more effective for all students. Our universities and colleges, both four-year and two-year institutions, need to form equal partnerships with school systems. At NSF we've just established K-through-12 teaching fellowships, which link the graduate student, the teacher, and the children. This is just one way to bridge the chasms that divide our educational system, that divide the institutions of higher education from the K-12 schools. The two groups must be brought together.

Guidepost 3: The Digital Divide

We can follow the thread of information technology to a final stop, where we find ourselves on a precipice looking down into another chasm: that yawning gap known as the "digital divide." Most of us believe in the power of information technology to bring about the most democratic revolution in literacy and numeracy the world has ever known. We also know that if we're not careful, this same power could be economically divisive. Although we imagine universal connectedness, with talk of tetherless networks that anyone could tap into anytime and anywhere, information technology could also broaden the gap between the information-rich and the information-bereft. In our own nation, sociologists have identified groups whose access to telephones, computers, and the Internet lag far behind the national averages.

These information gaps appear among nations as well. Most of those who live in the Third World have never used a telephone. Our World Wide Web is a very thinly stretched one. Less than 2 percent of the world is actually on the Web, and if we subtract the United States and Canada, the number is less than 1 percent. A 1998 report by the President's Information Technology Advisory Committee (PITAC) spells out some of these gaps. For instance, the committee points out, whites are more likely than African-Americans to have Internet access, at home or at work. Similar gaps probably exist for other minority groups, such as Hispanics and Native Americans, and recent research suggests that the racial gap in Internet use is increasing. Finally, the report notes that the Internet may indeed provide equal opportunity and help level the playing field—but only for those with access.

Although these facts remind us that we are still in the depths of the labyrinth, we have nevertheless taken some promising steps toward the way out. One such innovative step is the NSF Advanced Networking Project With Minority-Serving Institutions (AN-MSI), directed by EDUCAUSE. AN-MSI will help to broaden the participation of educational institutions in the information technology revolution by embracing historically black colleges and universities, Hispanic-serving institutions, and tribal colleges. Leaders of these institutions will have help, from EDUCAUSE and EOT-PACI (the Education, Outreach, and Training Partnership for Advanced Computational Infrastructure), to improve networking and, most important, to enhance their institutions' participation in the many opportunities for education and research that are now emerging on the Internet.

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Our three guideposts mark the common ground we share and the common thread we all follow. It will take joint participation—by the federal government, the universities, and the private sector—to see our way through the maze and to connect the thread of information technology throughout research and education and beyond to all of society. Our future as a nation rests on extending participation in the best-quality education and collaborative research, as fully as we can. We can succeed only by continuing to work together. *e*