Spring 2003

The BRIDGE

LINKING ENGINEERING AND SOCIETY

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

Promoting the technological welfare of the nation by marshalling the knowledge and insights of eminent members of the engineering profession.

The
BRIDGE

NATIONAL ACADEMY OF ENGINEERING

Editor-in-Chief

George Bugliarello (Interim)

Managing Editor: Carol R. Arenberg

Production Assistants: Penelope Gibbs, Kimberly West

The Bridge (USPS 551-240) is published quarterly by the National Academy of Engineering, 2101 Constitution Avenue, N.W., Washington, DC 20418. Periodicals postage paid at Washington, D.C.

Vol. 33, No. 1 Spring 2003

Postmaster: Send address changes to *The Bridge*, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Papers are presented in *The Bridge* on the basis of general interest and timeliness. They reflect the views of the authors and not necessarily the position of the National Academy of Engineering.

The Bridge is printed on recycled paper. ♻

A complete copy of each issue of *The Bridge* is available in PDF format at http://www.nae.edu/TheBridge. Some of the articles in this issue are also available as HTML documents and may contain links to related sources of information, multimedia files, or other content.

The BRIDGE

Volume 33, Number 1 • Spring 2003

LINKING ENGINEERING AND SOCIETY

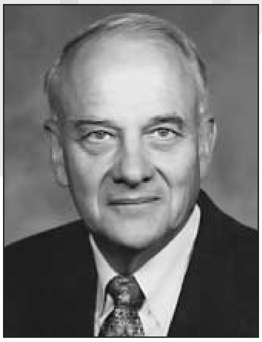
Editorial

Features

NAE News and Notes

(continued on next page)

Editorial



Wm. A. Wulf is president of the National Academy of Engineering.

The Future of Computing

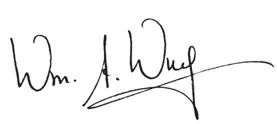
As many of you know, my field is computers. I wrote my first computer program in 1960 for the Illiac I—a one-of-a-kind computer built at the University of Illinois in the 1950s. I sent my first transcontinental email in about 1972, and by the mid-1970s I was involved in an active, email-enabled research project with a colleague 2,000 miles away. In short, for more than 40 years, I have been privileged to have a seat on the 50-yard line, witnessing changes in information technology (IT) and, more importantly, witnessing the resulting changes in society.

Many of the advances in IT have fit the predictions of "Moore's law"—the observation by NAE member Gordon Moore that the number of transistors per unit area doubles about every 18 months. That translates roughly into a doubling of memory capacity and processing speed and a halving of size, cost, and power consumption every year-and-a-half. There have been about 25 such doublings since I wrote my first program, an increase of a factor of about 32 million. That is, roughly speaking, the difference in speed, memory capacity, power consumption, size, and cost between Illiac I and the laptop on which I am typing this paper.

Some think that in another decade or so Moore's law will no longer apply—that we are approaching "fundamental physical limits" that will prevent the continuation of this remarkable phenomenon. Maybe so; maybe not. Obviously, at some point that must happen, but previous predictions of the end of Moore's law were based on assumptions that clever engineers were able to circumvent. In any case, the important thing is not Moore's law but whether IT will continue to improve our lives as it has for the last 40 years. I for one don't think the benefits will end abruptly or even taper off soon.

Significant computing advances have often been made because of applications to new problems rather than because of the forward march of Moore's law. The papers in this issue of *The Bridge*, which are adapted from talks presented at the technical session (Computing Meets the Physical World) of the 2002 Annual Meeting, present a sampling of application domains in which the uses of IT are just beginning to be explored—from robotics to research tools to medical assists. Even with today's technology—much less tomorrow's—they illustrate applications where IT has the potential to make our lives safer, healthier, and more enjoyable and to enrich our understanding of nature.

From my 50-yard-line seat, even if Moore's law were to fail tomorrow, which it won't, a future that includes improvements in our quality of life through applications of IT looks very bright.



Wm. A. Wulf

Rapid changes in computing will continue for the foreseeable future.

Computing Meets the Physical World

Butler Lampson is Distinguished Engineer at Microsoft Corporation. He is an NAE member.

Butler Lampson

The field of computing has always changed rapidly, and it is still doing so. The changes are driven, more than anything else, by Moore's law. Many people think the pace of change is slowing, or even that because we already have the Internet and Google, there is not much left to do. I hope these papers will convince you that this view is entirely wrong.

For the last 50 years, new applications of computers have followed a pattern, as one manual activity after another has become automated. In the 1940s, it became possible to automate the calculation of ballistic trajectories and in the 1950s of payrolls and nuclear weapon simulations. By the 1970s, it was possible to create reasonably faithful representations of paper documents on computer screens. In the 1990s, we had the equivalent of a telephone system for data, in the form of the Internet. In the next two decades we will have embodied computers, machines that can interact with the physical world.

Hardware and Software

The factor that determines whether or not an activity can be automated is whether the hardware is up to it. According to Moore's law, the cost performance of computers improves by a factor of 2 every 18 months, or a factor of 100 every 10 years; this applies to processing, storage, and communication. Moore's law is not a law of physics, but it has held roughly true for several decades and seems likely to continue to hold true for at least another decade. Indeed, today some things are developing much faster than that. Storage capacity, for example, is doubling every 9 months, not every 18 months. Wide-area communication bandwidth is also improving faster than Moore's law. Sometimes, with speech recognition and web search engines, for example, the cheaper cycles or bytes can be applied directly. Often, however, by spending more hardware resources, we can minimize programming effort; this is true for applications that use web browsers or database systems.

Hardware is the raw material of computing, but software gives it form. Our ability to write software is limited by complexity. People have been complaining about the "software crisis" at least since the early 1960s, and many people predicted in the 1960s and 1970s that software development would grind to a halt because of our inability to handle the increasing complexity of software. Needless to say, this has not happened.

The software "crisis" will always be with us, however (so it isn't really a crisis). There are three reasons for this:

- As computing hardware becomes more powerful (at the rate of Moore's law), new applications quickly become feasible, and they require new software. In other branches of engineering the pace of change is much slower.
- Although it is difficult to handle complexity in software, it is much easier to handle it there than elsewhere in a system. Therefore, it is good engineering to move as much complexity as possible into software, and engineers are busily doing so.
- External forces, such as physical laws, impose few limits on the application of computers. Usually the only limit is our inability to write programs. Because we have no theory of software complexity, the only way to find this limit is by trial and error, so we are bound to overreach fairly often.

A lot of software today is built from truly gigantic components: the operating system (Windows or Linux), the database (Oracle or DB2), and the browser (Netscape or Internet Explorer). These programs have 5 million to 40 million lines of code. By combining them with a little bit of new code, we can build complex applications very quickly. These new applications may use a hundred or a thousand times the hardware resources custom-built programs would use, but they can be available in three months instead of five years. Because we have plenty of hardware resources, this is a good way to use them. It is programmers and time to market that are in short supply, and customers care much more about flexibility and total cost of ownership than about the costs of raw hardware.

Another way to look at this is that today's PC is about 10,000 times bigger and faster than the 1973 Xerox Alto, which it otherwise closely resembles (Thacker, 1988). A PC certainly doesn't do 10,000 times as much, or do it 10,000 times faster. Where did these cycles go? Most of them went into delivering lots of features quickly, which means that first-class design had to be sacrificed. Software developers traded reductions in hardware resources for shorter time to market. A lot of cycles also went into integration (for example, universal character sets and typography, drag and drop functions, spreadsheets embedded in text documents) and compatibility with lots of different hardware and lots of old systems. Only a factor of 10 went into faster responses.

Applications

There have been three broad waves of applications for computers, about 25 years apart (Table 1). Currently, the communication wave is in full flood, and the first signs of embodiment (relatively unrestrained interactions with the physical world) are starting to appear. Of course the earlier waves do not disappear, simulation continues to be an important class of applications.

TABLE 1 Applications for Computers

Category	Starting Date	Examples
Simulation	1960	Nuclear weapons, payroll, games, virtual reality technology
Communication (and storage)	1985	E-mail, online airline tickets, books, movies
Embodiment	2010	Vision, speech, robots, smart dust

Usually a computer application begins as a fairly close simulation of a manual function. After 10 or 20 years, people begin to explore how the computer can do the job in a radically different way. In business, this is called "business process reengineering." The computer no longer does the same things as a bookkeeper; instead, it makes it possible to close a company's books two days after a quarter ends. Boeing builds airplanes in a very different way because computers can model every mechanical detail.

The earliest computers in the 1950s were used for simulation. Simulations of nuclear weapons, astrophysics, protein folding, payrolls, project scheduling, games, and virtual realities all fall comfortably into this category.

The next great wave of computer applications, embodiment, is just beginning.

The communication wave became apparent outside of research laboratories around 1980, and we are now in the middle of it. Today, we have e-mail, search engines, and the ability to buy airline tickets, books, movie tickets, and almost anything else online. TerraServer, gives us access to publicly available satellite telemetry of the world. The Library of Congress' catalog is online, and you can buy any one of a million and a half books on Amazon.com. Conduct a search on Google today, and in half a second you can research a database of about 3 billion pages that is updated every two weeks—and will soon be updated in real time.

The next great wave, which is just beginning, is embodiment. Of course, computers have been used in process-control systems for a long time, but that is comparatively uninteresting (albeit of considerable economic importance). We are now seeing the first computer systems that can function effectively in the real world—computerized cars, robots, smart dust. They are still in their infancy, but the most interesting developments in computing in the next 30 years will be in this domain.

A Boston company called iRobot has just introduced what seems to be the first plausible domestic robot, a vacuum cleaner that crawls around a room in a vaguely spiral pattern, bouncing off of things (see it at *www.roombavac.com*). The price is $199. In fact, with only 14k bytes of ROM and 256 bytes (not kilobytes) of RAM, it's barely a computer.

What's Next?

In a recent paper, Jim Gray (2003) countered the widely held perception that most of the important developments in computing have already happened and that the future holds little more than refinements and cost reductions. Gray predicted that the next 50 years would be much more exciting than the last 50, both intellectually and in practical applications. Here are some of the challenges he raises.

Win the impersonation game. The classic Turing test asks whether a person sitting at a keyboard and display can distinguish between a conversation with a computer and a conversation with another person. To win, roughly speaking, a computer must able to read, write, think, and understand as well as a person. The computer will need some facility with natural language and a good deal of common sense. Anyone who has tried using natural language to interact with a computer knows that we still have a long way to go; and we don't even know how far.

Hear, speak, and see as well as a person. Meeting this challenge will be much more difficult. Today's best text-to-speech systems, given enough data, can do a pretty good job of simulating a person's voice, although they still have trouble with intonation. In a quiet room, you can dictate to a computer a little faster than a person can type, at least if, like me, the person types fairly fast but makes a lot of errors. If there is any background noise, however, the computer does much worse than a person. To see as well as a person is even more difficult. People first learned to parse two-dimensional images on the retina and construct a model of a three-dimensional world so they could detect tigers in the jungle and swing from tree to tree. Today's best systems do a fair job of recognizing buildings on a city street, but not in real time.

Answer questions about a text corpus as well as a human expert. Then add sounds and images. A computer can't yet read and absorb Google's 3 billion web pages and then answer questions about them in a sensible way. It can find documents where words occur or documents with a lot of other documents pointing to them, but it can't understand content.

Be somewhere else as observer (tele-past), participant (tele-present). Videoconferencing represents the first feeble step in this direction. Can virtual presence equal real presence? We don't really understand what makes real presence good, so this is an open question—one that has implications for medicine, transportation, education, and social relations. Remote surgery is just one valuable, but extremely demanding application.

Devise a system architecture that scales up by 10^6. Computer systems on the Internet often serve millions of users, sometimes hundreds of millions, and the demand can change rapidly. After September 11, for example, the main web news sites collapsed because traffic was 10 to 100 times higher than normal. In addition, the same architecture must be used across a wide range of systems to ensure compatibility and consistency. The Internet has met this challenge for transporting data, but storage, processing, and coordination over such a range of sizes are problems yet to be solved.

Given a specification, build a system that implements it. Do it better than a team of programmers. Writing an adequate specification is a daunting task, as anyone who has tried it knows. Automatically building a system to implement it means converting it into a form that can be executed reasonably efficiently. Most teams of programmers don't do this terribly well, so if we can create a system that can do it at all, we have a good shot at doing it better than a team of programmers. Today, we can do it in very limited domains; the canonical examples are certain spreadsheet and database query applications, in which the specification and the program are almost indistinguishable.

Build a system used by millions that can be administered by half a person. The operating costs of most computer systems dwarf their hardware costs. Configuration, backup, repair, expansion, and updates require a lot of human attention. There is no reason in principle why this work can't be done by machines, except for the small effort required to set policy (e.g., telling the system who the authorized users are and which tasks are most important).

Common Themes

Three themes common to these challenges are central to the way computing will develop in the next few years and decades: information, uncertainty, and ubiquity.

Information. Very soon it will be technically feasible to put everything we have online and remember it forever. But making the most of this capability will require that the information be meaningful to the machine in some sense. Even though today's web is feeble by this standard, it has already had a tremendous impact on our lives. Machines that can answer questions about the information they store and relate different pieces of information to each other would be able to do much more for us.

Uncertainty. Interacting with the physical world necessarily involves dealing with uncertainty. The computer needs a good model of what can happen in the part of the world it is interacting with, and boundaries that tell it when the model no longer applies. This is often called common sense, and it is essential not only for sensors and robots, but also for natural user interfaces, such as speech, writing, and language. For each of these, the machine often has to guess meaning; it needs to guess well, and the user needs to know what to do when the guess is wrong.

Ubiquity. Computers are getting so cheap and so small that we can begin to think about having a computer on every fingernail, a computer inside every manufactured physical object. We could have guardian angels, for example, that monitor the state of our health and safety, call for help when it's needed, and so forth. Every manufactured object in the world could respond to us and interact with its fellows. How can all of this be done reliably and conveniently? How can people tell all of these computers what to do?

These are just a few examples of the opportunities before us. The papers that follow focus on physical ways computers might interact with the world.

References

Gray, J. 2003. What next?: a dozen information-technology research goals. Journal of the ACM 50(1): 41–47.

Thacker, C. 1988. Personal Distributed Computing: The Alto and Ethernet Hardware. Pp. 267–290 in A History of Personal Workstations, edited by A. Goldberg. Reading, Mass.: Addison-Wesley.

Soccer-playing robots could lead to completely autonomous intelligent machines.

Autonomous Robot Soccer Teams

Manuela Veloso is professor of computer science at Carnegie Mellon University.

Manuela Veloso

The idea of autonomous robot soccer teams invariably inspires images and expectations that, ironically, remove us somewhat from the real concept they embody. Indeed, the underlying research goes well beyond entertaining soccer fans to the creation of completely autonomous intelligent robots. I am in the fortunate position of pursuing research in artificial intelligence (AI), a fascinating field of research started by Allen Newell and Herb Simon at Carnegie Mellon. In the late 1980s, Allen Newell announced that it was time for the subareas of AI to merge and create "complete intelligence agents" capable of perception, action, and cognition. I fully embraced this challenge as the subject of my research.

Robot soccer teams compete in matches called RoboCup, which set itself a challenge of creating a robot team that could beat a human soccer team in the World Cup in 2050. RoboCup competitions are organized in a way that advances the state of the art of AI and robotics. Every year, the leagues are revised and moved closer to reality. The final goal is for robots to coexist with humans in a common physical environment.

The research platforms defined for the RoboCup international competitions present many challenges: (1) the environment is only partially observable; (2) the effects of a player's actions in the presence of opponents are uncertain and difficult to model; and (3) the cycle of perception, cognition, and action must run in real time. Soccer differs from other adversarial scenarios in fundamental ways. In chess, for example, there are no uncertainties about the effects of a player's actions. When Kasparov played chess against Deep Blue, there was no uncertainty in the execution of the moves—no tables were shaken; no pieces fell accidentally. Real-time response required only a combination of deliberative planning and reactive execution.

Autonomous playing robots face many technical challenges. The robots function today in a color-coded world. The floor is green; the goals are yellow and blue; the ball is orange; the uniforms are red and blue; the field is marked with unambiguous colored landmarks. Unlike the real world, the entire environment is customized. The real world in all of its complexity will be incrementally addressed over time. Each time the leagues are revised, the teams move a bit closer toward realization of the final goals. This year, for example, black and white balls will replace orange balls to determine whether robots can cope without the color.

Eventually robots will be able to cope with the real world—run in grass, function in rain or shine, and do all kinds of beautiful kicks through the air. The objective is to develop robots that can perceive and model the environment with which they are interacting and then respond to problems or changes in that environment in real time. Even in the color-coded world, we had to develop new segmentation and object-recognition algorithms capable of reliably and continuously processing images in real time.

To function as a true approximation of human intelligence, AI must encompass the idea of thinking forever, of deliberative planning, of when to stop thinking and start executing, and of assessing and learning from an execution to improve future executions. In other words, the goal is the integration of thinking, perceiving, and acting. Realization of the goal is decades away, but significant progress has been made in many dimensions, ranging from hardware and strategic teamwork to intelligent response to the world and other robots.

In the 2002 RoboCup competitions, in the laboratory, and in many demonstrations, our robots were active all the time, which represents a huge leap forward in terms of their reliability and robustness. The robots also move much more quickly today than they did even a few years ago. They are capable of maneuvering around obstacles, scoring goals, and localizing themselves, all autonomously (i.e., without remote control). Our robot team can cope with a large degree of uncertainty. Indeed, unlike real-world sports teams, they must because they do not see their opponents prior to play. They have no videos of games, do not know what their opponents look like, and do not know if their opponents are adept at finding the ball, blocking, or any other aspect of the game. It's easy to get caught up in the excitement of the game, but we can also appreciate their performance from a technical view—their ability to play different roles as a team, to search continuously for the ball and chase it, to localize themselves and navigate in the field without getting lost, even if they are occasionally picked up by a referee.

A soccer robot's view of the world is utterly different from ours.

In 2002, we were able to gather a complete sequence of images of a robot's view of the world. The images left the research team at Carnegie Mellon speechless. The bouncing vision camera on the four-legged body of the robot captures an utterly different view of the world than the one we see: the field is upside down; the ball is not always round; objects change position and size radically with the motion of the robot; the ball actually disappears from view when it is near the robot. Overall, the images illustrate the challenge of processing perceptual data to be used by intelligent robots. Through our CMVision processing algorithm, robots effectively process such images and act based on the objects they recognize (Bruce et al., 2000).

One of the main functions of the robot is localizing itself on the field. Localization involves determining its position in the world. Human beings take for granted that they know where they are. Robots have no clue where they are unless algorithms have been written to help them filter the world and try to predict where they are going. How is this accomplished? The classical approach to localization uses a probability distribution for the robot's belief of its position. The distribution includes an a priori model of the robot's movement and a model of the field as a function of the sensory input (e.g., the fixed colored landmarks). When the robot moves, it updates its belief using the a priori model of its own movement. When the robot senses the landmarks, it further updates the distribution according to the a priori model of the environment. When we tried this classical approach, however, the robot could not handle the large errors in the robot movement model.

At RoboCup'98, in Paris, the robots often became entangled with each other, so the referee lifted them up and put them down in a different location. At that point, the robots became completely lost because their perceptions of a different location did not match their locale belief because they had been moved but had not moved themselves (Veloso et al., 1998).

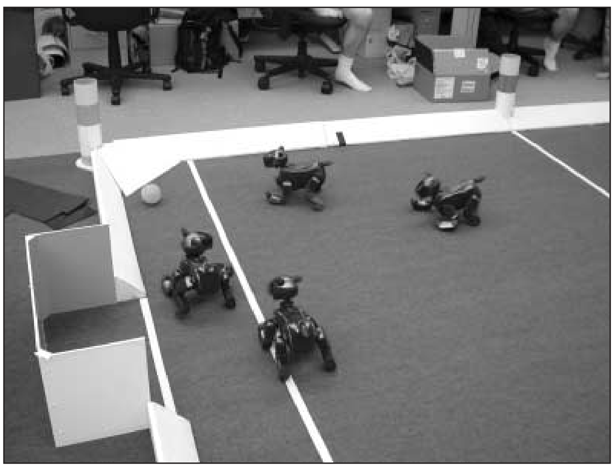


FIGURE 1 Robot soccer players on the playing grid.

In the classical approach to localization, robots being lifted up, pushed, or falling down are not accounted for. Earlier robots were big and were not moved around manually, so there was no need to localize algorithms. Robot soccer created the first small robots that execute a complete task. We devoted a great deal of research time to devising a new localization algorithm, called sensor resetting localization (SRL) that is capable of detecting "failure" in localization updates when the sensory information contradicts belief above a set threshold (Lenser and Veloso, 2000). SRL then abruptly creates a new hypothesis for the robot's position based on the sensory data. With SRL, the robots can localize themselves despite inevitable errors in their movement models.

Once the robots have been equipped with robust vision and localization, they need to act to achieve their goals. Now that they see the world and they know where they are, they need to kick the ball in the right direction. How do they know what they are supposed to do? We call this a planning-behavior-based approach, which our research has revealed must be a function of the robot's confidence in its world model. This discovery led to "multifidelity behaviors," in which a robot scores with different procedures as a function of how much it trusts its sensors (Winner and Veloso, 2000). If, for example, the robot has low confidence in its position on the field, it approaches the ball by a straight path. If it knows its position well, it can vary its approach to the ball to set itself behind the ball facing the opposing goal. Multifidelity behaviors are an innovation; no previous behavior architectures had explicit procedures for behavior as a function of a robot's confidence in its world model.

The behavioral states transition among each other upon verification of conditions that test the visual perceptual input for specific environment states. For example, the robot transitions from searching for the ball to approaching it, if it can see the ball. Any image other than the ball is ignored. General perception becomes, therefore, "purposeful perception," as the robot's behavior-state machine focuses its attention only on specific perceptual conditions. Considering the images the robot actually sees, this purposeful perception explains how the robot can perform well. Even if it sees a series of apparently confusing images, it ignores everything except the specific conditions set at each state (e.g., the presence of the ball in the searching state).

Individual robots with real-time object recognition, effective SRL, and multifidelity behaviors can function as autonomous individual creatures. The next question to address is forming a team of robots. The first step in team organization is assigning roles, different behaviors to different members of the team (e.g., goalie, midfielders, offensive players, and defensive players). Robots can then be organized in formations. A team member, as a single robot, executes a particular role through a behavioral-state machine. Coordination among team members during real-time execution may require communication among them. However, communication may be expensive or not available, so we have devised coordination approaches that do not depend on real-time communication. We introduced predefined team plans, which we call "locker room agreements," that encode coordination plans the robots can carry out as a team, triggered by universal world features that all of the robots can detect without communication (Stone and Veloso, 1999). Time and score, for example, are special world features the robots can perceive without communicating with other team members. So, if a team is winning by more than two goals and there is only one minute left in the game, then the team moves to a defensive formation. The robots have been equipped with alternative, predefined plays they can execute as a team. They can actually assess the success of each play in the presence of different opponents and adapt to using the play most likely to succeed against a particular opponent.

Before 2002, the robots could not talk to each other and could see each other only in terms of recognition of the colors of their uniforms, which they could perceive. In 2002, the robots acquired wireless communication. Communication among members of a team creates opportunities for sharing information and for dynamic coordination. In a communicating team, the model of the environment does not have to be inferred from one robot's view of the world. Team members can share their views of the world to create a global world model. Therefore, even if one robot cannot see the ball, perhaps because the ball is too far away or is occluded, the robot may know the position of the ball through communication with its teammates.

Asynchronous communication in a highly dynamic environment like robot soccer inevitably leads to inconsistencies in the information shared. Two robots may communicate different ball positions, for example. Therefore, we developed an approach in which each individual robot keeps two separate world models, one that corresponds to its view of the world and one that merges information received from its teammates in terms of their positions and the position of the ball, as well as of the confidence in the shared information (Roth et al., 2003). The robot relies mostly on its individual world model and invokes the shared world model only when its confidence in its model is below a preset threshold.

Except for the goalie, which has a fixed role, the robots are prepared to switch roles dynamically and opportunistically during the course of a game. For example, the CMPack'02 team of Sony legged robots consists of four robots. One is a goalie, and the other three play the roles of primary attacker, offensive supporter, and defensive supporter. The robots coordinate in two separate phases. First, they assign roles to each other; then they position themselves on the field according to their assigned roles. For example, a primary attacker would move toward the ball; the offensive supporter would position itself in a supportive attacking position; the defensive supporter would move closer to its own goal. Role assignment is achieved by the introduction of values functions computed based on the world model. Each robot can compute the value of each role for all of the robots as a function of their distance to the ball and their positions on the field. Roles are hence assigned through local computations based on the shared world model, thus eliminating the need for additional negotiations.

After a role has been assigned, the robots must position themselves as a function of their roles. We have devised two similar solutions for strategic positioning: a constraint-based objective optimization and a gradient-based potential field. For the supportive attacker, the objective function finds a position that maximizes the distance to the opponents and teammates and minimizes the distance to the ball and to the goal, under constraints (e.g., do not block the goal, do not compromise passes, etc.) (Veloso et al., 1999). The primary attacker goes to the ball, and the supporter moves to a good open position trying to maximize the chances of an emerging pass. Recently, we developed a similar potential-field-based approach that combines multiple repulsion and attraction points and allows the robots to navigate in the direction of the gradient of the field (Vail and Veloso, in press). Using this approach, our CMPack'02 team successfully coordinated and positioned itself, becoming the RoboCup'02 World Champions.

Communication among team members creates opportunities for sharing information and dynamic coordination.

Other research we are pursuing includes dynamic multirobot path planning, coaching, and multiagent learning. The algorithms we devised for path planning probabilistically combine past plans into the generation of new plans and allow for a smooth real-time execution of planned trajectories (Bruce and Veloso, 2002). Coaching addresses the challenging question of providing and following advice (Riley and Veloso, 2002). Multiagent learning enables an agent to learn in the presence of other learning agents. We have introduced a learning principle that changes the learning rate as a function of whether the learner is winning or losing (Bowling and Veloso, 2002).

Human responses to robot behavior can be fascinating. Spectators, as well as researchers, cheer the robots on and get truly caught up in the game. This year, we wired a victory dance into the robots. The dance, which of course exists because humans programmed it to exist, does not represent consciousness on the part of the robots, nothing they see, perceive, or plan. Nevertheless, people respond to the victory dance because the robots appear to be expressing their emotions. By 2003, we plan to have five or six different dances the robots can select randomly, which will increase the illusion that they are creative and will elicit a stronger response. At a demonstration last year, a child asked if the robots wonder why people pick them up. Based on their autonomous behavior, people often infer that robots can do much more than they actually can. Indeed, they are currently only little soccer-playing robots. But in time they will surely become much more efficient.

The first RoboCup American Open for all the Americas will be held April 30 thru May 4, 2003, at Carnegie Mellon in Pittsburgh. The cognition and action involved in competitions between multirobot teams continues to be challenging scientifically and at the engineering level and will provide opportunities for research and development for years to come.

Acknowledgment

This research is part of Cooperate, Observe, Reason, Act and Learn (CORAL), a large research project at Carnegie Mellon. Videos and publications are available at *http://www.cs.cmu.edu/~coral*.

References

Bowling, M., and M. Veloso. 2002. Multiagent learning using a variable learning rate. Artificial Intelligence 136: 215–250.

Bruce, J., T. Balch, and M. Veloso. 2000. Fast and inexpensive color image segmentation for interactive robots. Pp. 2061–2066 in Proceedings of the IEEE International Conference on Intelligent Robots and Systems. Piscataway, N.J.: IEEE.

Bruce, J., and M. Veloso. 2002. Real-time randomized path planning for robot navigation. Pp. 2383–2388 in Proceedings of the IEEE International Conference on Intelligent Robots and Systems. Piscataway, N.J.: IEEE.

Lenser, S., and M. Veloso. 2000. Sensor resetting localization for poorly modeled mobile robots. Pp. 1225–1232 in Proceedings of the International Conference on Robotics and Automation. Piscataway, N.J.: IEEE.

Riley, P., and M. Veloso. 2002. Planning for distributed execution through use of probabilistic opponent models. Pp. 72–81 in Proceedings of the Sixth International Conference on Artificial Intelligence Planning Systems, M. Ghallab, J. Hertzberg, and P. Traverso, editors. Menlo Park, Calif.: American Association for Artificial Intelligence.

Roth, M., D. Vail, and M. Veloso. 2003. A world model for multi-robot teams with communication. Submitted for publication.

Stone, P., and M. Veloso. 1999. Task decomposition, dynamic role assignment, and low-bandwidth communication for real-time strategic teamwork. Artificial Intelligence 110(2): 241–273.

Vail, D., and M. Veloso. In press. Dynamic multi-robot coordination. In Multi-Robot Systems, A. Schultz, L. Parker, and F. Schneider, editors. New York: Kluwer Academic Publishers.

Veloso, M., P. Stone, and M. Bowling. 1999. Anticipation as a key for collaboration in a team of agents: a case study in robotic soccer. Pp. 134–141 in Proceedings of SPIE Sensor Fusion and Decentralized Control in Robotic Systems II (Volume 3839), G.T. McKee and P.S. Schenker, editors. Bellingham, Wash.: SPIE Press.

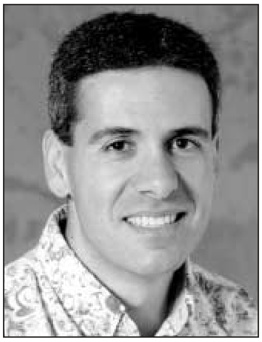
Veloso, M., W. Uther, M. Fujita, M. Asada, and H. Kitano. 1998. Playing soccer with legged robots. Pp. 437–442 in Proceedings of the IEEE International Conference on Robotics and Automation. Piscataway, N.J.: IEEE.

Winner, E., and M. Veloso. 2000. Multi-fidelity behaviors: acting with variable state information. Pp. 872–877 in Proceedings of the National Conference on Artificial Intelligence of the American Association for Artificial Intelligence. Menlo Park, Calif.: American Association for Artificial Intelligence.

Neurobiologists want to understand how neurons control animal behavior.

Flying with Animals

Part One: Linking Artificial Information-Processing Machines and Living Information-Processing Machines



Chris Diorio is an associate professor of computer science and engineering at the University of Washington.

Chris Diorio

A key goal of neurobiology is understanding how neurons control behavior. Neurobiologists probe and examine the activities of brain cells involved in sensory inputs, integrative processes, and motor outputs to understand the neural bases of behavior. They also probe the components of neuronal control circuitry to understand the plasticity and dynamics of control. But to make significant progress, neurobiologists need methods of recording the activity of single neurons or assemblies of neurons for long time scales at high fidelity in animals that are free to interact with their sensory world and free to express normal behavioral responses.

Although both silicon electronics and nerve tissue process and communicate information using primarily electrical (voltage and current) signals, there has been no large-scale integration of silicon electronics with nerve tissue either for investigatory or medical purposes. Although the electronics for recording from and stimulating neurons already exists as bench-top equipment, it hasn't been miniaturized in the form of a stand-alone, implantable computer. My goal is to build miniature computers that we can implant into or onto animals without damaging the computer or the animal that can interface directly with nerve tissue.

One step toward achieving this broad objective is understanding how animals control movement, a fundamental problem we can readily study because we can probe the structures, muscles, and nerves that enable movement.

However, understanding neuronal control itself has remained beyond our grasp, partly because of our inability to study in sufficient detail the dynamics of this control in intact, freely behaving animals. Consequently, our first effort in implantable electronics is to study the mechanisms of sensorimotor integration and the control of locomotion in freely behaving animals.

FIGURE 1 Hawkmoth (*Manduca sexta*) on pliers.

This interdisciplinary project encompasses biologists, engineers, chemists, and others. Choosing the animal was easy; my colleague, Tom Daniel, already had a fantastic model system: *Manduca sexta*, or hawkmoth. *Manduca* is one of the largest flying insects, and its flight circuits are relatively well understood in the context of constrained laboratory environments. Tom and others have studied this animal extensively, including its flight dynamics, neuromuscular control, and visual and mechanosensory signaling. In addition, *Manduca* has accessible recording sites with high signal fidelity.

We had several options for computer-based studies: tethering the animal to a host computer; mounting simple electronics on the animal and communicating the recorded information via radio frequency to a host computer; or using a stand-alone microcomputer on the animal itself. We chose the third option, for several reasons. First, the technology is totally autonomous. Second, it can be used on other animals—for instance, we are using it underwater to study the nudibranch *Tritonia*. In addition, as electronics advances, the amount of computational circuitry on a single chip will increase amazingly, and implantable computers will become commonplace. Single-chip computers today have sufficient power for biologists to perform complex experiments on an animal in real time.

Our immediate goal is to choose a biology experiment, write the experiment in software, download the software to the implantable computer before the experiment, run the experiment on the untethered animal, and then upload the data to a desktop computer when the experiment is over. For the actual interfacing, the input side needs amplification and an onboard central processing unit—the little microcomputer (actually a microcontroller)—to run the experiment, plus onboard memory and a battery. The output side needs an interface to a desktop computer.

Eventually, we will increase our experimental capabilities. We'll add an accelerometer to record flight forces on the animal as it flies. We'll add onboard optical sensors so we can correlate the experiment with the high-speed video we are taking externally. And we'll need outputs for direct muscle stimulation to do stimulus-response experiments.

The constraints on an implantable computer are size and power consumption. The electronics must operate at incredibly low current because the power comes from onboard batteries, and a moth cannot carry much weight. Our first prototype was a printed circuit board—a test bench for validating designs before we committed them to silicon. The board used off-the-shelf components, which are incredibly capable. We used a small programmable system-on-a-chip, basically a little microcomputer with some amplifiers and a bit of memory. We added more memory and amplifiers. Just for calibration, this tiny microcontroller on a tiny printed-circuit board is an 8-bit processor running at 24 megahertz, roughly the same power level as the old 8088s in the first IBM PCs. But the main challenge was and remains the battery. Our goal is power consumption of less than 15 milliwatts. Right now, we are using a zinc silver-oxide battery because it works in any environment, but it has some disadvantages—low current density, short lifetime, and heavy packaging. Eventually, we would like to have thin-film, rechargeable batteries, which may be available commercially soon, that could handle an extended experiment that includes recording and stimulating.

Our first proof-of-concept implant was not very elegant, but we learned a lot from it. The little board we used was about 1 by 3 centimeters and weighed about 1.5 grams—too heavy for the moth to fly with. Still, we discovered that by having the amplifiers and the batteries right on the moth we got incredible signal fidelity at very low power consumption because the length of the wires from the amplifiers into the moth was so short. Although the moth couldn't lift this prototype, that wasn't the purpose. The purpose was to integrate all of the electronics on a little board, put it right next to a moth, and run actual experiments collecting information, compressing and storing it, and later downloading it to a PC.

Our next goal is miniaturization, both in size and in power consumption. By the time you are reading this article, we will have a board about 1 centimeter in diameter, a little hybrid ceramic substrate—no packaging, no soldering, no plastic—just chips on a board, weighing roughly 0.75 gram including batteries. The animal will be able to fly with this board glued to its thorax. We will conduct implant experiments and record during free flight. Our future goal is to put all of the capabilities on a single chip and eliminate the ceramic board entirely. Using current technology, that chip would be about 6 millimeters by 6 millimeters and would weigh about 0.4 grams with a battery.

In addition to the implantable electronics, my colleague Karl Bohringer is developing intracellular silicon probe arrays with micromachined submicron tips to penetrate and record from inside nerve cells. Unlike glass pipettes that require bench-top micromanipulators for placement, his arrays will be stand-alone devices that attach to the neural ganglion using microfabricated hooks or clamps built on the array itself. When we combine our implantable computers with his microprobes, we will be truly able to study and explore integrative processes within animal brains. Dr. Bohringer's work is incredibly challenging, but, if it is successful, it will change the way we do biology.

As we begin to explore animals in their natural environments using stand-alone computers, many technologies will come together: low-power microelectronics; new battery technologies; MEMS probes; new surgical procedures; and software algorithms. Initially, the goal is to record from the animals. Eventually, we hope to close the loop—to stimulate the animal and measure its response. In short, we want to build a smart electronic system that interacts in a smart way with an animal brain. The possibilities that derive from linking artificial information-processing machines (computers) to living information-processing machines (animal brains) defy prediction.

Acknowledgment

This research was funded by the Office of Naval Research and the David and Lucile Packard Foundation.

Flight control in the hawkmoth is being analyzed by reverse engineering.

Flying with Animals

Part Two: Interfacing Computer Electronics with Biology

Thomas Daniel is chair and Komen Professor of Biology at the University of Washington.

Thomas Daniel

Animal movement emerges from the complex interplay of aerodynamic forces, nonlinear muscle forces, a massive flow of sensory information, and enigmatic information processing. In nearly all biological systems, the flow of sensory information is so massive that, at first glance, it appears to be redundant. We know, for example, that insects acquire sensory data for the strain distribution and position of a wing, chemical information from the environment around them, visual pattern data, and gyroscopic data. All of this information is integrated, stored, and processed by the insect's nervous system. Interestingly, if one were to reach in and randomly remove a few neurons anywhere in this system, the chances are good that there would be no noticeable difference in the animal's capacity to fly. By contrast, if one were to remove a few connections at random from the standard CPU design, the likelihood of functionality would be very low. This difference suggests redundancy in the design of neuronal systems, but our understanding of complex neural systems is still too primitive for us to draw that conclusion.

Overlying the issue of information processing is that the insect moves in spatially complex and uncertain environments. The flight of small insects in a naturally turbulent environment is particularly interesting in that the spatial and temporal scales of stochastic variations are large relative to the spatial and temporal scales of their control concerns. One of our central concerns is how biological systems deal with this combination of massive information flow and uncertainty.

To address this concern we have focused on a reverse engineering analysis of flight control in the hawkmoth, *Manduca sexta*. One of the fastest insect fliers, the hawkmoth is capable of navigating in low levels of light (even in starlight!), hovering while feeding on flowers moving in a breeze in turbulent eddies, and doing so with wings beating at about 25 Hz. How it controls its position in space, how it processes sensory information, and how we might affect direct computer-assisted control of its motion are central issues in our research.

We have, therefore, a challenging reverse engineering problem for a very successful, fast, tiny, self-replicating "robot" capable of flying autonomously, refueling in midair, and adapting to uncertain environments within milliseconds. From previous and parallel research, we know that these animals are inherently unstable devices that require a tremendous amount of very fast sensory information to control their position in space. Interestingly, the time demands occasionally exceed the rate at which data can be provided by the visual system. This suggests not only that fast information processing and transmission are extremely important, but also that parallel processing takes place between the slow, yet powerful, visual systems and the rapid, yet highly specific, mechanosensory systems.

The best way to picture the underlying control system is as a feedback loop between sensory information flow into the central nervous system and mechanical output in the form of a flight trajectory. Visual data pass to the central nervous system where motion detection is processed in visual centers of the brain. Their output is passed along a central nerve chord in the form of a motor pattern, some of which drives wing motions and some of which drives steering and compensatory motions in the abdomen and head. Moving wings propel the animal in ways that determine the flow of visual information; so too do steering motions from the abdomen; so too do head rotations (much the way our eyes track moving targets). By this scheme, the loop between visual data flow and motion is closed.

Insects spend a great deal of time processing images—cell-by-cell—and a great deal of innovative research is being done, largely by postdoctoral researchers and graduate students, to understand this processing in detail. For example, some cells in the visual processing centers of the brain of hawkmoths have been shown to be tuned to a specific direction and velocity of movement in the visual world of the insect and that this direction and velocity tuning appears in the motor pattern in the central nerve chord. In addition, muscles responding to these motor outputs operate in a nonlinear manner in ways that mimic mammalian cardiac cells. Like hearts, insect flight muscles commonly drive a structure in which elastic energy storage plays a key role in how motion is maintained and controlled. These muscles actively deform the thorax, which, indirectly, drives the up and down motions of the wings. In moths, the thorax muscles are activated for each wing stroke, sometimes reaching frequencies in excess of 30 Hz. In other insects, muscle activation is less coupled, with many wing strokes following each stimulus. In mosquitoes and fruit flies, for example, wing beat frequencies can exceed 200 times per second—much higher than the rates at which muscles can turn on and off—and follows from a resonant oscillation of the thorax to which wings are attached.

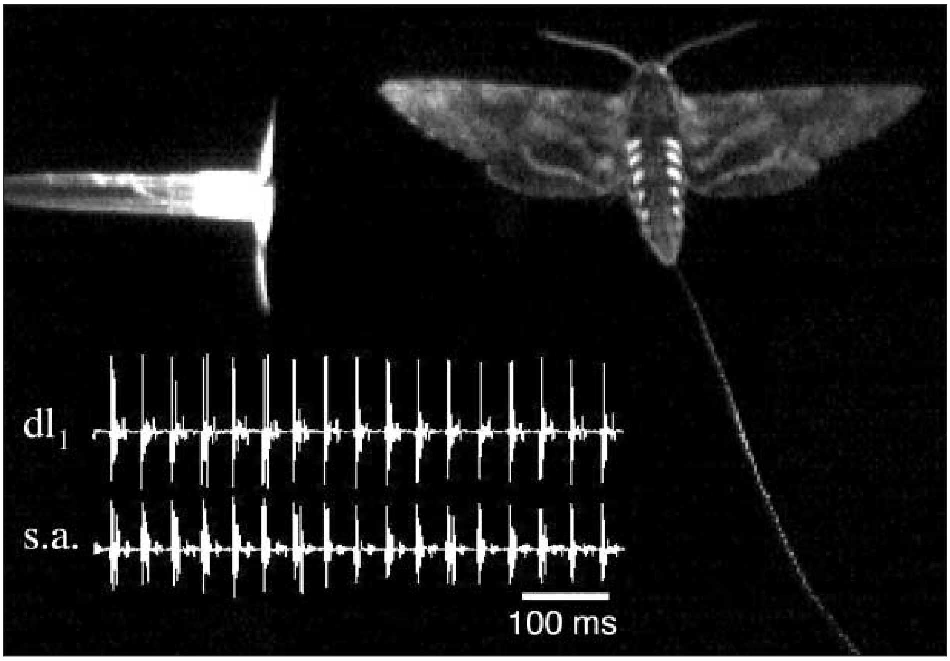


FIGURE 1 Hawkmoth in flight with simultaneous neuronal display.

To explore this complex control system, we use a wide variety of experimental and theoretical approaches, from intracellular recordings to computational models of aeroelastic behavior of oscillating wings and analyses of quasisteady aerodynamic flight forces. High-speed digital videography, combined with simultaneous recordings of neural information during flight, links these experimental and theoretical approaches and sets the stage for a formal systems analysis of the control circuit of flight.

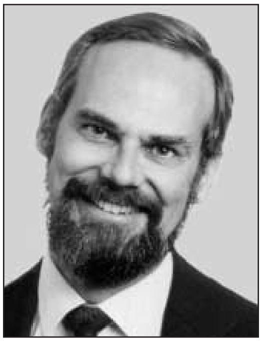
In our project, we hope to equip freely flying insects with onboard microcomputers (i.e., programmable systems-on-a-chip) that can track neuronal systems and enable us to eavesdrop on the control circuit. In theory, microcomputers can also send digital information to neural centers of the animal where local processing may enable us to delve more deeply into the feedback control of these very successful "robots."

Although this study heralds an exciting new approach to the reverse engineering of biological systems, we remain mindful of the challenges that lie ahead. Can we use the digital world of CMOS electronics to control motion in biological systems? Do neural systems adapt to such digital control events? Can we implement learning algorithms in implantable microcomputers? New data suggests that we can make significant progress toward answering these questions.

Noninvasive technology allows surgeons to see beneath the surface of the brain.

Entering the Brain: New Tools for Precision Surgery

Eric Grimson



Eric Grimson is the Bernard Gordon Professor of Medical Engineering at Massachusetts Institute of Technology and a lecturer on radiology at Brigham and Women's Hospital.

Standard approaches to removing a brain tumor today are not necessarily refined. Suppose you have the misfortune of having a brain tumor near the motor cortex. You'd like the surgeon to remove it without paralyzing you, but with the standard approach, the surgeon is only able to see the surface of the brain. He has to cut through to find the piece he wants to remove. I would just as soon not have someone blindly rooting around in my brain looking for the right spot. I'd like him to be able to see it.

Imagine, instead, that we are able to show the neurosurgeon an augmented-reality visualization—in effect, letting him look at a patient and see through skin and bone to the interior structure in exact alignment, so he or she can home in on a precise target. Suppose, moreover, that we can enable the surgeon to see a variety of internal structures, a patient-specific anatomical reconstruction showing the exact location of all key structures. Even better, we can provide the surgeon during the surgical procedure with a visualization of the patient's anatomy—that highlights where the tumors lie, as well as where the critical structures are, including vessels, motor cortex, and other connections, and how their positions change during surgery. That is our goal. We want to build models of all of these structures to identify surgical targets, so that surgery will become minimally invasive.

Our approach marries computer vision and machine learning techniques. The result, I like to say, is to give the surgeon the capabilities of Superman—

the ability to sense critical information that is not normally visible. The goal is to build a 3-D model of the individual patient, rather than a generalized prototype, because an individual model provides much more information to the surgeon. On top of that, we want to fold in data on tissue properties and use our adaptable patient model for surgical visualization, surgical planning, and actual surgical navigation.

Our research has concentrated primarily on neurosurgery, but this technology has applications for many other kinds of surgery. For instance, it would be enormously useful in treating prostate cancer. Brachytherapy involves implanting small radioactive seeds around the cancer. First, however, the patient is scanned to determine the ideal locations for the seeds; then needles are driven in to place the seeds correctly. To do this, it is necessary to know where the target tumor is. Currently, an open magnetic resonance system is used to guide the placement of the needles. This new technology could use a preoperative scan of the patient to build a model of the prostate; during the procedure, the surgeon would then use the scan as a guide to placing the seeds.

The technology could also be used for vascular surgery. For instance, a patient with vessel problems in the chest could undergo a CT scan; then a computer algorithm could be used to create a detailed model showing what the structure looks like and, ideally, would automatically measure—without any invasion—the width of the vessel, enabling the surgeon to identify trouble spots.

The algorithm finds the same answer every time. But is it the correct answer?

Different tissue types respond differently to magnetic fields, revealing different intensities. We are striving for a technology that automatically identifies where particular tissue structures are in the individual brain. We have begun by modeling prototypes, but we would ultimately like to be able to identify automatically where the tissue structures are in each individual patient.

In the standard approach to brain surgery, a radiologist produces a set of visual slices of the brain, then manually traces out the significant structures—an incredibly time-consuming process. It must be done one slice at a time, and most radiologists don't have the time to do it. In addition, thin structures that pass through the slice—vessels or nerves—are very hard to spot, so the approach does not always work well. An alternative is to let the radiologist, by clicking with the mouse, highlight a small set of recognized points, building a little statistical distribution of what intensity response looks like from magnetic resonance. Ideally this statistical distribution could then be used to label all the other elements in the medical scan, using the nearest known intensity to determine the label.

But problems can arise. When a patient is put into the magnetic field, there is a very significant nonlinear gain artifact inside the field that affects the intensity responses of different tissues, so that the same type of matter may appear different in different locations, thus shifting the statistics in a nonstationary way. If we knew the gain field, we could correct for it and measure the tissue type. But we do not. If we knew the tissue type, we could predict the image and use the difference to solve for the gain field. But we do not.

Fortunately, a statistical tool called expectation maximization enables us to solve both problems. It allows us to go through the iterative sequence of estimating one, solving for the best estimate of the other, and coming back. That produces a nice segmentation that allows us to identify tissue types very well. To verify our results, we applied our algorithm to 50 scans of 35 patients, each taken by a radiologist two or three weeks apart. Although there were significant variations in labeling over time, even by the same radiologist, our algorithm produced solid, repeatable measurements.

But we are still addressing the wrong question. True, the algorithm finds the same answer every time, but is it the correct answer? To find the right answer requires ground truth.

We asked six Harvard radiologists to segment each scan by hand and noted how much the labeling by two radiologists varied and how the algorithm compared to the ground truth. We found that two radiologists differ by 22 per cent and that the variations occur at the boundaries of tissues, where it is very difficult to see differences. When the algorithm is thrown into the mix, its performance is similar to a radiologist's. To get ground truth, we said that if five out of six radiologists labeled a voxel the same way, we would be confident that the tissue identification was correct, and we could compare it to the algorithm's identification. Within the intercranial cavity, the algorithm's identification was correct about 98 percent of the time.

However, there were two other key considerations: (1) we were working in the intercranial cavity; and (2) we were working on normal brains. Brains with abnormal structures, such as tumors, could cause tissue-response problems. There are two quick methods of addressing these issues.

The first is to do what a radiologist does. Radiologists know where structures belong in the brain, and if they see something in the wrong place, they know there is a problem. The same principle applies to this modeling technology. The system starts with a small amount of anatomical knowledge and builds a very detailed atlas of the brain. We then elastically compare new scans to the atlas, taking into account the different sizes and shapes of heads, and we use that information to set a prior probability on tissue types. The system can take over from there. Over a period of eight months, we built a very detailed neuroatlas that is now available on the web from Brigham and Women's Hospital.

When we get a new scan, we run a rough classification using our first method, then warp it to the atlas using an elastic registration to set a guideline for what things should look like. We then take a new scan, segmenting out certain structures, such as skin or ventricles, to gradually map the location of the tumor. We are basically bringing anatomical knowledge to bear so the system can find the pieces it wants and highlight the location of the tumor.

This works well for most structures, but a few are still difficult to locate, especially in places where the boundaries between the edges of objects are very subtle. To deal with that, we build a machine learning system into the algorithm so it can learn the differences in shapes across populations; then we bias the segmentation toward a likely shape. For instance, by giving it a set of corpora callosi from a sequence of subjects, the algorithm learns the average shape of a person's corpus callosum and, more importantly, the standard modes of variation. Then we fold the information into a system that automatically performs the segmentations. I use statistical information to tell me where to look, use the atlas to refine that, then use shape to fill in across the narrow boundaries. As a consequence, this system is able to find very subtle boundaries.

What is the result? We can now let the system segment out structures and build models. Its performance is indistinguishable from the performance of a human, and it generates plenty of information for the surgeon to use. We build models like this for our surgeon friends.

In the case of neurosurgery, we now have the ability to find all of the structures, including white matter, gray matter, cerebral spinal fluid—and all of the structural pieces. In some cases, that is sufficient. In others, however, it is also important to know the connections because they could be sites of the malfunction. To do that, we are building on a new technique from medical imaging called diffusion-tensor MRI, a way of taking a quick sequence of images to measure how water diffuses in different directions. This is useful because in brain cellular tissue water is likely to diffuse in any direction; but if there are fiber bundles, the water is likely to diffuse along them. In other words, by treating this as a fluid-flow problem, we can build a surgical model that uses the diffusion to show connections between different brain structures, thus enabling the surgeon to identify disruptions and determine where to start.

FIGURE 1 Patient with computer overlay.

Once we have built models of the patient's anatomy, we want to apply that to actual surgery. To do this, we gather information about the position of the patient in the operating room and use that to align our model with the actual patient position (Figure 1). We can then use augmented reality visualization to present information to the surgeon. We render a synthetic view of the patient's interior anatomy, then create a video mix that shows the surgeon the interior structures exactly overlaid on a live view of the surgical cavity. We then put markers on the surgical instruments to track their position relative to the model as the surgeon inserts them. That way, we can show the surgeon in real time exactly where the tip of his instrument is in relation to the reconstructed model of the patient, and in relation to the preoperative scans.

We use this technology for visualizations, for surgical guidance, and for simulation. In a colonoscopy, for example, we use the technology to show the surgeon precisely where worrisome sites are located, so he can take a look and decide whether they require surgery. I hope by the time I have my next colonoscopy, this technique will be ready for general use.

These reconstructions are useful for planning surgeries, but the real question is how the model can be used during surgery as a guide. We can create wonderful 3-D models, incredibly accurate, registered to the patient to submillimeter accuracy. But the minute the surgeon picks up the scalpel, the model is no longer accurate because the tissue moves, and sometimes the shift is huge. For the models to remain accurate, we need intraoperative sensing to guide the surgeon.

One way to create computer-assisted surgery would be to incorporate another new technology, open MR, which was developed at Brigham and Women's Hospital in collaboration with General Electric. Open MR is basically an MR scanner that allows a surgeon to stand in its center. The patient is placed within the scanner and surgery proceeds normally. At any point in time, however, the surgeon can obtain an image of what is going on inside the patient, not a full scan—that would take 20 minutes—but a little slab of data. Starting with one of our preoperative models, as the surgeon works, at regular intervals he uses a trackable probe to monitor tissue changes, receiving a new image and a little slab of data within a few seconds; then the new piece of data wraps into the original model to reflect the changes in what the surgeon sees.

In another case, we created a visualization; the surgeon planned the surgical path, then, during surgery, used this technology to acquire images on the fly and warp them into the model. Part of the image came from the original model, part came from intraoperative acquisitions. He was able to use the plan to get to the exact location he wanted and extract the piece he wanted.

How well does this work? Several years ago we built a system like this, called a neuronavigator system, for use at the Brigham and Women's Hospital. The system was retired after it had been used in several hundred neurosurgical cases with no side effects. Only a formal outcomes analysis can accurately assess the impact, but anecdotal information can highlight the utility of the system. Surgeons using the system report that they now take half the time to complete many surgeries. In neurosurgery, a lot of time is spent getting to the target without damaging anything along the way, so it makes perfect sense that, you can see through tissue, see where the structures are that you want to avoid, you can get there much more quickly. Perhaps the most striking thing the surgeons note is that they are now doing surgeries that three years ago they would have considered inoperable.

I'd like to close with a comment from my colleague, another surgeon, who thinks the next generation of surgeons will be accustomed to hand-eye coordination, to dealing with graphics, and to manipulating things while looking at screens. The surgeon of the future, he said, will be sort of a "Nintendo surgeon." I particularly like this comment, because now, when my sons, ages 12 and 14, spend too much time in front of the PlayStation or the Nintendo, I can assure my wife, "They're not wasting time. They're practicing to be surgeons. Really."

NAE News and Notes

Class of 2003 Elected

Class of 2003 Elected

In February, the National Academy of Engineering elected 77 members and nine foreign associates, bringing the total U.S. membership to 2,138 and the number of foreign associates to 165. Election to the National Academy of Engineering is one of the highest professional distinctions accorded an engineer. Academy membership honors those who have made "important contributions to engineering theory and practice, including significant contributions to the literature of engineering theory and practice," and those who have demonstrated accomplishment in "the pioneering of new fields of engineering, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education." The newly elected members and foreign associates, their primary affiliations, and a brief statement of their principal engineering accomplishments are listed below.

New Members

Linda M. Abriola, Horace Williams King Professor of Civil and Environmental Engineering, University of Michigan, Ann Arbor, for advancing our knowledge of contaminant fate and transport in groundwater and subsurface systems.

Rod C. Alferness, senior vice president, Optical Networking Research Division, Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey, for contributions to the development of electro-optic devices and circuits for light-wave transmission and switching systems.

James R. Asay, research professor, Institute for Shock Waves, Washington State University, Pullman, for leadership in engineering research and management of shock waves and for the development of tools that have contributed to national security.

Thomas W. Asmus, senior research executive, DaimlerChrysler Corporation, Auburn Hills, Michigan, for contributions to the design, analysis, and control of heat engines of all types.

Georges Belfort, professor of chemical engineering, Rensselaer Polytechnic Institute, Troy, New York, for advances in bioseparations using membrane filtration, affinity processes, and membrane bioreactors for biotechnology.

Philip A. Bernstein, senior researcher, Microsoft Corporation, Redmond, Washington, for contributions to transaction-processing and database systems.

Anjan Bose, dean, College of Engineering and Architecture, Washington State University, Pullman, for the development of training simulators and computational tools for reliable power-system operation and for contributions to education and research on power systems.

Daniel S. Bricklin, founder and chief technology officer, Trellix Corporation, Concord, Massachusetts, for the invention and creation of the electronic spreadsheet.

Randal E. Bryant, head, Computer Science Department, Carnegie Mellon University, Pittsburgh, Pennsylvania, for contributions to symbolic simulation and logic verification.

Jeffrey P. Buzen, consulting scientist, BMC Software, Waltham, Massachusetts, for contributions to the theory and commercial application of computer system performance models.

Gonzalo Castro, principal, GEI Consultants, Inc., Winchester, Massachusetts, for contributions to geotechnical earthquake engineering, soil dynamics, and the seismic safety of dams.

Corbett D. Caudill, vice president and general manager, Engineering Division, GE Aircraft Engines, Cincinnati, Ohio, for technical leadership in the design of gas-turbine engines for military and commercial aircraft.

Paul Citron, vice president, Technology Policy and Academic Relations, Medtronic, Inc., Minneapolis, Minnesota, for innovations in the monitoring of cardiac rhythm and patient-initiated cardiac pacing and for outstanding contributions to industry-academia interactions.

Bernard L. Cohen, Professor Emeritus, University of Pittsburgh, Pittsburgh, for fundamental contributions to our understanding of low-level radiation.

Glen T. Daigger, senior vice president and chief technology officer, CH2M Hill, Inc., Greenwood Village, Colorado, for combining the theory and practice of wastewater-nutrient control and for improving the practice of environmental engineering worldwide.

Christine A. Ehlig-Economides, global account manager and consultant, Schlumberger Oilfield Services, Houston, Texas, for contributions to the testing of wells and the characterization of reservoirs, including the management, integration, and visualization of data from multiple disciplines.

Thomas J. Engibous, chairman, president, and chief executive officer, Texas Instruments Inc., Dallas, for recognizing the potential of DSP + analog systems-on-a-chip for Internet products and for pioneering this new and developing technology.

Robert E. Fenton, Professor Emeritus, Department of Electrical Engineering, Ohio State University, Columbus, for pioneering systems research and engineering on the design and operation of automated highway systems.

Stephen R. Forrest, professor, Electrical Engineering Department, Princeton University, Princeton, New Jersey, for advances in optoelectronic devices, detectors for fiber optics, and efficient organic LEDs for displays.

Glenn H. Fredrickson, professor of chemical engineering and director of the Mitsubishi Chemical Center for Advanced Materials, Department of Chemical Engineering, University of California, Santa Barbara, for advancing our understanding of the behavior of block copolymers and other polymeric and complex fluids.

Robert Q. Fugate, senior scientist for atmospheric compensation, Air Force Research Laboratory, Kirtland Air Force Base, New Mexico, for the experimental demonstration of laser beacons and the development of adaptive optical systems.

Mauricio Futran, vice president, Process Research and Development, Bristol-Myers Squibb Company, New Brunswick, New Jersey, for technical leadership in pharmaceutical process design and development, especially in the engineering of Crixivan, an HIV protease inhibitor.

Hector Garcia-Molina, chair, Computer Science Department, Stanford University, Stanford, California, for contributions to distributed-information systems.

Joseph E. Greene, professor, Department of Materials Science and Engineering, University of Illinois, Urbana-Champaign, for pioneering studies in the synthesis and characterization of epitaxial and highly ordered polycrystalline materials.

Lawrence G. Griffis, president, Structures Division, Walter P. Moore and Associates, Inc., Houston, Texas, for contributions to the structural design and wind engineering of composite buildings and open, covered, and retractable-roof sports arenas.

Jeff Hawkins, chairman and chief product officer, Handspring, Inc., Mountain View, California, for the creation of the hand-held computing paradigm and the creation of the first commercially successful example of a hand-held computing device.

Thomas P. Hughes, Mellon Professor Emeritus, University of Pennsylvania, Philadelphia, for contributions to, and the effective dissemination of, the history of technology.

Mary Jane Irwin, Distinguished Professor, Department of Computer Science and Engineering, Pennsylvania State University, University Park, for contributions to VLSI architecture and automated design.

Tatsuo Itoh, TRW Professor of Electrical Engineering, University of California, Los Angeles, for advances in electromagnetic engineering for microwave and wireless components, circuits, and systems.

Charles V. Jakowatz, Jr., manager, Signal Processing and Research Department, Sandia National Laboratories, Albuquerque, New Mexico, for innovations in synthetic-aperture radar-image processing critical to military applications and environmental monitoring.

Edward H. Kaplan, William N. and Marie A. Beach Professor of Management Sciences and professor of public health, Yale School of Management, New Haven, Connecticut, for assessment of needle-exchange programs and for generally bringing engineering perspectives to the design of public health policies.

Karl G. Kempf, fellow and director, Decision Technologies, Intel Corporation, Chandler, Arizona, for the development and implementation of control and decision systems that have improved the performance and cost effectiveness of semiconductor manufacturing systems.

Sung Wan Kim, Distinguished Professor, Department of Pharmaceutics and Pharmaceutical Chemistry, University of Utah, Salt Lake City, for the design of blood-compatible polymers with human applications, including drug-delivery systems.

Michael D. King, senior project scientist, Earth Observing System, NASA Goddard Space Flight Center, Greenbelt, Maryland, for advancing our understanding of the effects of aerosols and clouds on Earth's radiation and for leading programs to improve climate prediction.

R. Peter King, professor and

chairman, Department of Metallurgical Engineering, University of Utah, Salt Lake City, for the development of techniques for quantifying mineral liberation and for leadership in Internet education about mineral processors.

Oliver D. Kingsley, Jr., senior executive vice president, Exelon Corporation, Chicago, Illinois, for leadership, technical management skills, and setting standards that have transformed the operation of U.S. nuclear plants.

David C. Larbalestier, David Grainger Professor and L.V. Shubnikov Professor, Materials Science and Engineering Department, University of Wisconsin, Madison, for advancing our understanding of the materials science of high-field superconductors and for developing processing techniques that incorporate this knowledge.

Ronald G. Larson, chair, Department of Chemical Engineering, University of Michigan, Ann Arbor, for elucidating the flow properties of complex fluids at the molecular and continuum levels through theory and experiment.

Victor B. Lawrence, vice president, Lucent Technologies, Holmdel, New Jersey, for contributions to data communications.

Carroll N. Letellier, vice president (retired), Jacobs Engineering/Sverdrup, Charleston, South Carolina, for leadership in the planning, design, and construction of major civil infrastructure and military facilities that meet and serve the highest societal values.

John H. Lienhard, M.D. Anderson Professor Emeritus, Mechanical Engineering Department, University of Houston, Houston, Texas, for creating the awareness of engineering in the development of cultures and civilizations and for the development of basic burnout theories in boiling and condensation.

R. Noel Longuemare, Jr., president, Longuemare Consultants, Ellicott City, Maryland, for significant contributions to the modular-architecture, affordability, and real-time imaging capability of airborne/space radar and for important innovations in Department of Defense acquisition practices.

Tso-Ping (T.P.) Ma, professor and chairman, Department of Electrical Engineering, Yale University, New Haven, Connecticut, for contributions to the development of CMOS gate dielectric technology.

Alfred U. MacRae, president, MacRae Technologies, Berkeley Heights, New Jersey, for advancing our understanding of ion implantation, its application to the fabrication of electronic devices, and its introduction into manufacturing.

David K. Matlock, director, Advanced Steel Processing and Products Research Center, Colorado School of Mines, Golden, for fundamental and applied contributions in the uses of advanced steels, including the development of micro-alloyed steels for critical vehicle applications.

Richard A. Meserve, chairman, Nuclear Regulatory Commission, Washington, D.C., for leadership in the development of national and international programs for strengthening nuclear safety and safeguards.

Debasis Mitra, vice president, Mathematical Sciences Research, Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey, for contributions to the modeling, analysis, and design of communication networks.

Sanjit K. Mitra, professor, Department of Electrical and Computer Engineering, University of California, Santa Barbara, for contributions to signal and image processing, for research supervision, and for writing pioneering textbooks.

Haydn H. Murray, Professor Emeritus of Geology, Indiana University, Bloomington, for pioneering work on the mineralogy and industrial applications of clays.

Eugene W. Myers, professor, Computer Science Department, University of California, Berkeley, for pioneering research and leadership in the development of computational methods of genome sequencing and assembly.

Roy E. Olson, professor emeritus, Civil Engineering Department, University of Texas, Austin, for furthering our understanding of the properties of clays and for contributions to geotechnical engineering design.

Elaine S. Oran, senior scientist for reactive flow physics, U.S. Naval Research Laboratory, Washington, D.C., for unifying engineering, scientific, and mathematical disciplines into a computational methodology to solve challenging aerospace combustion problems.

Victor L. Poirier, chief technology adviser, Thoratec Corporation, Woburn, Massachusetts, for the design, development, clinical trial, and commercialization of first-generation left-ventricular assist systems for treating heart failure.

Charles W. Pryor, Jr., chief executive officer, Nuclear Utilities Group, BNFL, Inc., Cheshire, United Kingdom, for setting and achieving exemplary standards for nuclear equipment and fuel performance and for worldwide leadership in advanced nuclear power concepts.

Richard F. Rashid, senior vice president, Research, Microsoft

Corporation, Redmond, Washington, for advances in operating systems and leadership in industrial research.

Emery I. Reeves, consultant, Palos Verdes Estates, California, for pioneering contributions to the design and development of spacecraft and attitude-control and navigation systems for ballistic missiles.

Thomas E. Romesser, vice president, Technology Development, Northrup Grumman Space Technology, Redondo Beach, California, for pioneering contributions to high-power laser technology and isotope separation.

Alton D. Romig, Jr., vice president, Science, Technology, and Partnerships, and chief technology officer, Sandia National Laboratories, Albuquerque, New Mexico, for outstanding contributions to the science and technology of materials and for innovative research and development for defense systems.

Yoram Rudy, professor of biomedical engineering, physiology, biophysics, and medicine, Case Western Reserve University, Cleveland, Ohio, for leadership in the engineering sciences of cardiac excitation at the genetic and molecular levels and for introducing new methods in clinical diagnosis and therapy.

Vinod K. Sahney, senior vice president of planning and strategic development, Henry Ford Health System, Detroit, Michigan, for the development and use of industrial and operational-systems engineering to improve health care.

Henry Samueli, cochair and chief technical officer, Broadcom Corporation, Irvine, California, for pioneering contributions to academic research and technology entrepreneurship in the broadband communications system-on-a-chip industry.

Adel F. Sarofim, Presidential Professor, Combustion Research Group, University of Utah, Salt Lake City, for advancing our understanding of the mechanisms and modeling of processes that control radiation in and pollutant emissions from combustors.

Peter W. Sauer, Grainger Chair Professor of Electrical Engineering, University of Illinois, Urbana-Champaign, for technical contributions to the modeling, simulation, and dynamic analysis of power systems and for leadership in power engineering education and research.

Dudley A. Saville, Stephen C. Macaleer '63 Professor of Engineering and Applied Science, Princeton University, Princeton, New Jersey, for advancing our understanding of electrokinetic and electrohydrodynamic processes and their application to the assembly of colloidal arrays.

Stephen D. Senturia, professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, for contributions to and leadership in research on microelectromechanical systems.

Burton J. Smith, chief scientist, Cray, Inc., Seattle, Washington, for contributions to the development of parallel computer architecture.

Soroosh Sorooshian, Department of Hydrology and Water Resources, University of Arizona, Tucson, for the development of flood-forecasting models used worldwide in hydrologic services.

Gregory N. Stephanopoulos, Bayer Professor of Chemical Engineering and Biotechnology, Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, for pioneering contributions in defining and advancing metabolic engineering and for leadership in incorporating biology into chemical engineering research and education.

R. Bruce Thompson, director, Center for Nondestructive Evaluation, Iowa State University, Ames, for outstanding contributions to nondestructive evaluation, materials processing, and life-cycle management and for the development of novel ultrasonic technology.

Alan M. Title, senior fellow, Lockheed Martin Advanced Technology, Palo Alto, California, for pioneering the development of elegant optical systems that enable precise space-based studies of the sun.

Harold J. Vinegar, senior research consultant, Shell E&P Technology Company, Houston, Texas, for the invention and development of well logging, core analysis, and thermal methods of oil exploration and production and for environmental remediation.

Thomas H. Vonder Haar, University Distinguished Professor of Atmospheric Science and director, Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, for fundamental analysis of the Earth's radiation balance and its impact on climate.

J. Turner Whitted, senior researcher, Microsoft Research, Redmond, Washington, for contributions to computer graphics, notably recursive ray-tracing.

Max L. Williams, dean of engineering (retired), University of Pittsburgh, Pittsburgh, Pennsylvania, for fundamental developments in fracture mechanics and for providing guidance to industry and government that has facilitated technology transfer.

Richard D. Woods, professor, Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, for applications of soil dynamics and geotechnical earthquake engineering to the design of foundations for vibration-sensitive and vibration-robust facilities.

Richard N. Wright III, director (retired), Building and Fire Research Laboratory, National Institute for Standards and Technology, Gaithersburg, Maryland, for sustained leadership in building research, for the development of standards, and for representing the U.S. building industry and research community worldwide.

Eli Yablonovitch, professor of electrical engineering, University of California, Los Angeles, for introducing photonic band-gap engineering and applying semiconductor concepts to electromagnetic waves in artificial periodic structures.

New Foreign Associates

Kenneth J. Ives, Emeritus Professor of Civil and Environmental Engineering, Department of Civil and Environmental Engineering, University College London, London, United Kingdom, for contributions to the theory and practice of water-treatment technology throughout the world.

John F. Knott, Feeney Professor of Metallurgy and Materials, University of Birmingham, Birmingham, United Kingdom, for advancing our understanding of the mechanisms and microstructure of fracture and fracture mechanics with application to the failure of engineering alloys and structures.

Bindu N. Lohani, secretary of the bank, Asian Development Bank, Manila, Philippines, for the development of planning for integrated economic-cum-environmental sustainable development through the protection of natural and social resources.

Giulio Maier, professor of structural engineering, Technical University of Milan, Milan, Italy, for contributions to solid mechanics, including shakedown theory and bounds, softening plasticity and fracture, structural optimization and identification, and boundary elements.

Giuseppe Marrucci, professor of chemical engineering, Department of Chemical Engineering, University of Naples, Naples, Italy, for contributions to the molecular modeling and thermodynamics of polymeric systems and for furthering our understanding of their transport processes.

Raghunath A. Mashelkar, director general, Council of Scientific and Industrial Research, New Delhi, India, for outstanding engineering contributions and exceptional leadership and management of the Indian National Laboratories and for providing advice to the Indian government.

Shuji Nakamura, professor, Materials Department, University of California, Santa Barbara, for contributions to optoelectronic engineering of gallium-nitride materials, culminating in the development of violet/blue lasers and light-emitting diodes.

Gary R. Purdy, University Professor Emeritus, Department of Materials Science and Engineering, McMaster University, Hamilton, Ontario, Canada, for pioneering theoretical and experimental studies of chemical and structural effects on phase transformations and of interfacial diffusion-induced phenomena.

Evgeny P. Velikhov, president, Russian Research Center Kurchatov Institute, Moscow, for pioneering work in plasma physics, controlled nuclear fusion, and gas lasers and for advancing international scientific cooperation.

NAE Newsmakers

The American Society of Mechanical Engineers bestowed **Honorary Membership** on **Jan D. Achenbach**, McCormick School Professor, Center for Quality Engineering and Failure Prevention, Northwestern University, and **Bei Tse Chao**, professor emeritus of mechanical engineering, University of Illinois at Urbana-Champaign. Dr. Achenbach was recognized for excellence in research and teaching and for his more than 350 scholarly publications on new analytical and experimental work in quantitative nondestructive evaluation, wave propagation in elastic solids, fracture mechanics, and other subjects. Dr. Chao was honored for excellence in teaching and outstanding research in the area of heat and mass transfer, particularly his pioneering work on the thermal-physical aspects of metal cutting.

Frances H. Arnold, Dick and Barbara Dickinson Professor of Chemical Engineering and Biochemistry, California Institute of Technology, received the **2003 Carothers Award** from the Delaware section of the American Chemical Society. Dr. Arnold was recognized for her outstanding contributions to industrial applications of chemistry.

George J. Dvorak, William Howard Hart Professor of Mechanics, Rensselaer Polytechnic Institute, was awarded the **2002 ASME Daniel C. Drucker Medal**. Dr. Dvorak was recognized for his research on plasticity, material fracture and fatigue, and thermal-mechanics of heterogeneous materials.

Ira Dyer, professor emeritus of ocean engineering, Massachusetts Institute of Technology, was awarded the **2002 ASME Per Bruel Gold Medal for Noise Control and Acoustics**. Dr. Dyer was recognized for establishing research and educational programs in ocean engineering and for his original contributions to the understanding of underwater acoustics, flow-generated noise, ocean ambient noise, and structural acoustics.

Douglas W. Fuerstenau has been elected a **Foreign Fellow of the Indian National Academy of Engineering** for his many contributions to research and education in the processing of minerals and particulate materials, including applications of interfacial science and engineering to particulate systems.

Werner Goldsmith, professor of the graduate school, Department of Mechanical Engineering, University of California, Berkeley, received the **Outstanding Engineering Alumnus Award** from the College of Engineering, University of California, Berkeley, in February 2002. In June 2002, Professor Goldsmith was awarded both an **honorary doctorate** from the University of Patras, Greece, for his contributions to the field of mechanics, and the **Distinguished Academician Alumnus Award** from the College of Engineering, University of Texas at Austin, for his research, scholarship, and teaching in the field of impact and collision and for his lifelong dedication to the advancement of engineering education.

Dean Kamen, president, DEKA Research and Development Corporation, was awarded the **2002 ASME Ralph Coats Roe Medal**. Mr. Kamen was recognized for his outstanding contributions to the public understanding and appreciation of the importance of engineers to society through the development of innovative technologies and the initiation of the FIRST contest.

Arthur Kantrowitz, professor of engineering, Thayer School of Engineering, Dartmouth College, received the **International Beamed Energy Propulsion Award** at the First International Symposium on Beamed Energy Propulsion in Huntsville, Alabama. Dr. Kantrowitz, who was recognized for his role in the development of laser propulsion, also served as keynote speaker.

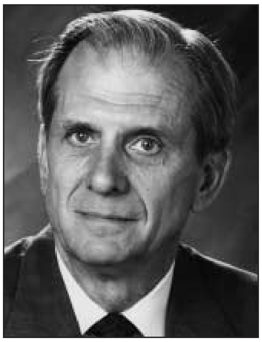
William W. Lang, president emeritus, International Institute of Noise Control Engineering, was awarded the **2002 Distinguished Noise Control Engineering Award** for his national and international leadership in establishing industrial noise-control programs, noise-control organizations, and standards for noise control.

Norbert R. Morgenstern, University Professor of Civil Engineering Emeritus, University of Alberta, received the **2003 Sir John Kennedy Medal**, which is presented biennially by the Engineering Institute of Canada to individuals who have rendered outstanding services to the engineering profession or have made noteworthy contributions to the science of engineering or to the benefit of the institute.

Shlomo P. Neuman, Regents' Professor, University of Arizona, was awarded the **2003 Robert E. Horton Medal** by the American Geophysical Union. Dr. Neuman was recognized for outstanding contributions to the geophysical aspects of hydrology.

Robert O. Ritchie, professor in the Department of Materials Science and Engineering at the University of California, Berkeley, was inducted in 2002 as a **Fellow of the Royal Academy of Engineering**.

Message from the Home Secretary



W. Dale Compton

Now that the 2003 election is over, I thought you would find some of the statistics of interest. First, we welcome 77 new members and 9 foreign associates. Second, 48 percent of our active membership cast ballots. The demographics of the 483 nominees and the 77 new members follow. This is the first year we have assembled demographic statistics, so I must caution you that they may not be reflective of subsequent years; in addition, keep in mind the problem with the statistics of small numbers. Despite these caveats, I think they are useful as we consider future elections.

- Of 483 nominations, there were approximately twice as many new nominations as renominations. The same statistic holds for the 77 new members who were elected.
- Female nominees and candidates were significantly younger than their male counterparts.
- Eighty-three percent of nominees and those who were elected hold Ph.D.s. All candidates from 7 of the 13 sections had Ph.D.s.
- Nearly 60 percent of nominees had been elected fellows of their professional societies: 81 academic, 56 business, and 88 other.
- Thirty-four percent of all nominees and 24 percent of new members are naturalized citizens.
- The percentage of nominees, per work sector, with only three references (as opposed to the maximum of four) were: 16 academic, 29 business, and 17 other. The percentages for new members were: 11 academic, 18 business, and 13 other.

These statistics suggest the following questions. Does our method of identifying the contributions of potential members favor those with Ph.D.s? Are we correct in not requiring prior election to a fellowship in a professional society? Should we retain the minimum of three references for all nominees?

The Council has asked the Membership Policy Committee (MPC) to consider a number of issues related to the election of new members, such as the process for allocating slots to peer committees; the underrepresentation of some segments of the profession; and proper recognition of interdisciplinary activities. The MPC initiated its inquiry at the meeting on January 31, 2003, and expects to offer recommendations to the Council in early 2004.

W. Dale Compton
Home Secretary

Foreign Secretary to Step Down

Betty and Harold Forsen with NAE President Wm. A. Wulf.

On February 6, the National Academy of Engineering (NAE) held its National Meeting at the Beckman Center in Irvine, California, in honor of Foreign Secretary **Harold K. Forsen**, who steps down on June 30, 2003, at the completion of the two-term tenure allowed by the NAE bylaws. Dr. Forsen, who served one-three year term as Councillor prior to his election as Foreign Secretary, has made outstanding contributions to the Academy.

As Foreign Secretary, Dr. Forsen expanded NAE's international activities, and under his leadership, the organization has become a major player in setting national and international policy. Dr. Forsen oversaw the expansion of the Frontiers of Engineering Program to include the German-American Frontiers of Engineering and Japan-America Frontiers of Engineering symposia. He also contributed to the expansion of the Council of Academies of Engineering and Technological Sciences by promoting international collaboration in engineering and the establishment of academies of engineering in other countries. Dr. Forsen was instrumental in drafting a memorandum of agreement that was signed by the presidents of the NAE and the Chinese Academy of Engineering in October 2000 to promote cooperation between engineering and technological sciences for their mutual benefit.

Together with the foreign secretaries of the National Academy of Sciences and the Institute of Medicine, Dr. Forsen provided support and guidance for the work of the National Research Council (NRC). He served on the NRC Governing Board and its Executive Committee, chaired the Committee on Classified Activities, and worked closely with divisions of the NRC, particularly the Division on Engineering and Physical Sciences and the Transportation Research Board.

During his term of service, Dr. Forsen contributed to the formulation and implementation of NAE's independent program and strategic plan. He also advocated increasing the number of foreign associates in the Academy to strengthen contacts with other countries and raise the Academy's international profile. His advice on institutional management has served the Academy well, and he played an important role in keeping NAE on course through a time of crisis in leadership, thus ensuring the continuing vitality of the institution.

The symposium topic at the National Meeting, "Technology and Policy for Disposition of Spent Nuclear Fuel," reflected Dr. Forsen's

L. to R.: Charles McCombie, Harold Ray, B. John Garrick, Lawrence Papay, Harold Forsen, J. Russell Dyer, and Ralph Bennett.

personal interest. The following background synopsis was provided to symposium participants:

> *Governments and concerned activist groups have wrestled with how to dispose safely of highly radioactive spent fuel, which poses a major obstacle to the expanded use of nuclear power. Options include storing it at reactor sites for the life of the reactor, shipping it to surface or underground storage facilities, reusing the fissionable material, and transmuting the longer-lived materials. Security of stored or transported materials is crucial, especially since the recent terrorist attacks here and abroad. The issue of spent fuel is important not only for the United States, which has the largest number of nuclear plants, but also for countries in Europe and Asia.*

The following speakers discussed various aspects of the issue: Charles McCombie, international consultant, Association for Regional and International Underground Storage; **B. John Garrick**, PLG (retired); J. Russell Dyer, Yucca Mountain Project, U.S. Department of Energy; Ralph Bennett, Idaho National Engineering and Environmental Laboratory; and Harold B. Ray, Southern California Edison.

The symposium committee was chaired by **John F. Ahearne**, Sigma Xi, The Scientific Research Society; **Michael J. Corradini**, University of Wisconsin-Madison; **James J. Duderstadt**, University of Michigan; **Lawrence T. Papay**, Science Applications International Corporation; and **Neil E. Todreas**, Massachusetts Institute of Technology.

New Interns Join NAE

On January 13, 2003, three interns began 12-week internships.

Aimee Eggler, who will be assisting with the Public Understanding of Engineering Program, earned a B.S. in chemistry from the University of California-Santa Cruz (UCSC) and a Ph.D. in biochemistry from the University of Wisconsin-Madison. For many years, Aimee has enjoyed playing ultimate frisbee; she was a member of the women's team at UCSC that won a national championship. Lately, she has traded in her frisbee for a yoga mat. She also enjoys writing songs and singing. Her career goal is to transfer scientific knowledge to others by becoming a professor of biochemistry or working outside academia with an organization that promotes public understanding of science. One of Aimee's most rewarding teaching experiences was four years of tutoring Tibetan refugee students in Madison. She is looking forward to learning how scientific knowledge is transferred at the National Academies.

Emma Seiler is the first Diversity Program intern supported through a grant from the Northrop Grumman Litton Foundation. Emma earned a B.S. in biological engineering with an environmental emphasis and recently received an M.S. in civil engineering, both from Mississippi State University. Emma's passion is inspiring young women to explore science and engineering through a hands-on and unique approach. Working with the former outreach coordinator of the Bagley College of Engineering at Mississippi State University, she developed a shoe-design activity for a high school girls' camp. Called *The Cinderella Project*, the project involved using the biomechanics of the foot and the engineering design process to create a comfortable, sturdy shoe. In addition to designing the shoe, the girls had to develop a marketing plan using a PowerPoint presentation.

Maxwell "Max" Wingert, a Ph.D. candidate in chemical engineering at Ohio State University, will be working with the Technology and the Environment Program. Max earned a B.S. in chemical engineering from the University of Notre Dame. He has exercised leadership throughout his academic career. As an undergraduate at the University of Notre Dame, he was a squad leader in the Fighting Irish Marching Band and president of the Engineering Student Council. As a graduate student, he is currently serving on the student council of his department as recruiting officer for the graduate program. He is known in the department not only for coplanning orientation activities, but also for adding a tour of the football stadium. His personal career goal is to become a leader in corporate research, probably in the field of polymer processing, the area of his research. His work is on foam extrusion, a project in the NSF-sponsored Center for Advanced Polymer and Composite Engineering (CAPCE). The goal of his research is to develop environmentally benign methods of producing polymeric foams.

The News Media Could Be Our Weakest Link

Randy Atkins is senior media relations officer for the National Academy of Engineering. This article appeared in the "Outlook" section of the *Washington Post* on Sunday, January 26, 2003.

This country isn't ready to deal with a catastrophic terrorist attack, and government preparedness may not be the biggest problem. Indeed, one of the most critical parts of our infrastructure—the nation's news media—doesn't appear near the top of anyone's list of concerns. They should be of utmost concern to those responsible for homeland security.

I suspect, though, that most defense types simply regard journalists as pests at best, maybe even a threat to national security. They generally feel the media are to be avoided as much as possible and told as little as possible. But with the country's increased focus on security here at home, I think that the strength of the news media is more important than ever.

When we think of infrastructure, we usually think of tangible things that bind us together: our water supply, transportation networks, energy pipelines. The media, too, belong in this category. They are the main communication conduit to the public, carrying valuable information from one place to another. The interconnectedness of these modern infrastructure systems allows greater efficiency, but it also creates new vulnerabilities. And the news media may be the weakest link in this system.

We need to protect the media as zealously as we protect the electric power grid and nuclear reactors, and not just their printing plants and broadcast towers. Their journalists also need to be armed to work effectively as part of the nation's response to terrorism. And to do that, they need the help of the engineering and science community.

A couple of months ago, I was on a panel at a meeting of the Associated Press Managing Editors, and I began by asking who knew anything about the place where I work—the National Academy of Engineering (NAE). Not one editor in the room raised a hand, and this was a group interested in participating in a discussion about science and technology reporting. I bet I would get the same response from an audience of government policymakers.

Here's what scares me: Neither the media nor the government value the roles of science and technology as much as the terrorists do. While terrorists see Western civilization as bad, they have demonstrated both their adeptness and willingness to take from it what they need—chemicals, computers, planes. In the same way, while calling us an entertainment-obsessed culture, they use our media, too, to full advantage—counting on journalists to dramatically present the terrorists' ghastly handiwork.

Ignorance and misinformation can be as damaging to the information infrastructure of the United States as a break in an oil pipeline. It can cause paralysis among citizens, and confuse people trying to respond to a crisis. As a local police chief recently said, "You can't build a fence around a community, but you can arm your citizens with knowledge." American journalists have few precedents for these emerging terrorist threats—it's different from traditional war reporting. Organizations like mine must work hard to get good information into the hands of the media quickly in the event of any cyber, nuclear, chemical or biological attack. Journalists need instant access to trusted experts who are good communicators.

I would go so far as to argue that getting good information to the public in the midst of a crisis can be more vital than the actions of first responders. In fact, journalists are first responders. Not only do they sometimes get to the scene first, but they are the only ones focused on and able to describe the level of risk to the public. They can save lives through the efficient delivery of good information.

With today's 24-hour coverage, journalists are under tremendous pressure to say something—anything—and to say it first. Of course, this can lead to speculation, which is not always harmless. In fact, sometimes it can cost lives. This isn't just the media's problem. It's the engineering and science communities' problem, too.

At the NAE, we have wrestled with the question of how to help the media become better informed and more conscious of their importance in the event of a terrorist attack.

The media, after all, are a vigorously independent bunch, constitutionally protected and—to the nation's benefit—outside of government control. So the NAE has decided to conduct a war game exercise that, for the first time, would focus on the media. The goal is to develop new communication strategies for cutting through the chaos of a terrorist attack, as well as to develop better connections between the journalists and the scientists and engineers.

I mentioned our war game idea to a major news organization, and the executives there replied that they felt they had already been tested by 9/11. Well, yes, to a point. But next time—which we are constantly warned will come—could be worse. Accurate and efficient communication with the public during a catastrophic attack will require more technical expertise than was needed on 9/11.

Based on past experience, I know that I'm facing an uphill climb. Shortly after the Sept. 11 attacks, for example, the NAE held a daylong briefing for senior news executives from across the country on the technical aspects of various forms of terrorism. We were pleased that the TV networks sent a camera crew over for pool coverage. The crew got there early, but didn't turn on its cameras during any of the morning briefings—and the briefers included some of the nation's premier experts. The cameras were only there to record the words of the luncheon speaker, Tom Ridge. Then they left.

Too often, journalists take the path they're most comfortable with—which often means the political angle. Even during the anthrax attacks, journalists were turning to members of Congress and their staffs for technical answers.

I think that, in part, this is because politics is a form of theater, and entertainment trumps substance in the ratings. Let's face it, news is about people and personalities. I know the journalistic importance of storytelling and of doing it in compelling ways. The public, unfortunately, has been trained to have a limited and shallow attention span. If we want it to get information at all, that information must be "packaged" correctly.

The challenge—for both scientists and journalists—is to make science, technology, and engineering more intriguing; to make it, whether in wartime or not, more a part of popular culture. The media don't take their role—their responsibility—seriously enough. They aren't just a business. They are part of this country's infrastructure and times have changed.

We need the media to keep challenging the government, because that friction makes us all stronger. But uninformed journalists can't effectively question authority. For example, well-meaning but misguided government efforts to classify too much information could harm national security by slowing the delivery of research results beneficial to society. And unless the public is well-informed, it won't know how to analyze the issues and know how to assess the information being provided by its leaders.

Before 9/11, people like me chuckled as journalists churned out their usual ratings-grabbing fare, overlooking important stories while providing full details on the psychology behind the contestants on "Survivor." Just as terrorism was not at the forefront of many journalists' minds before 9/11, I think it's being slowly overshadowed again by today's trivial obsessions.

National Academy of Engineering

2002 Private Contributions

Gifts received between January 1 and December 31, 2002.

Golden Bridge Society

The Golden Bridge Society recognizes current members who have made cumulative contributions of $20,000 or more, as well as planned gifts of any size made prior to 2000.

$1,000,000 or more

Section 1

Norman R. Augustine

Section 3

Arnold O. Beckman
Ralph Landau

Section 4

Stephen D. Bechtel, Jr.

Section 7

Bernard M. Gordon
Gordon E. Moore

Section 8

Jordan J. Baruch

$100,000 to $999,999

Section 1

Holt Ashley
William F. Ballhaus, Sr.
Thomas V. Jones
Ruben F. Mettler
Allen E. Puckett
Robert H. Wertheim

Section 2

Alejandro Zaffaroni

Section 3

William L. Friend

Section 5

John A. Armstrong
C. Gordon Bell
Anita K. Jones
Kenneth H. Olsen
Wm. A. Wulf

Section 6

Harold K. Forsen

Section 7

Robert W. Galvin
C. Kumar N. Patel
Joseph E. Rowe*

Section 8

Robert A. Pritzker

Section 10

Ronald P. Nordgren

Section 11

Richard M. Morrow

Section 12

George M.C. Fisher
Simon Ramo

$20,000 to $99,999

Section 1

William A. Anders
Daniel J. Fink
Richard L. Garwin
James N. Krebs
Jack S. Parker
Eberhardt Rechtin
Brian H. Rowe
Robert C. Seamans, Jr.
H. Guyford Stever
Sheila E. Widnall

Section 2

Dane A. Miller
George B. Rathmann
Leo J. Thomas

Section 3

W. Kenneth Davis
Robert C. Forney
Edward G. Jefferson
Gerald D. Laubach
Michael P. Ramage
Warren G. Schlinger

Section 4

Harry E. Bovay, Jr.
Edgar J. Garbarini
Charles J. Pankow
Ivan M. Viest

Section 5

Elwyn R. Berlekamp
Erich Bloch
Lewis M. Branscomb

Section 6

William F. Allen, Jr.
William Cavanaugh III
E. Linn Draper, Jr.
John W. Landis
Will H. Rowand*

Section 7

John M. Cioffi
William E. Gordon
Paul E. Gray
David A. Hodges
Kenneth G. McKay
Morris Tanenbaum
Gary L. Tooker

Section 8

Robert A. Charpie
W. Dale Compton
Donald N. Frey
Trevor O. Jones
Charles Eli Reed
Henry M. Rowan

Section 9

George A. Roberts

Section 10

Stephen H. Crandall
Robert J. Eaton
Simon Ostrach

Section 11

Thomas D. Barrow

Section 12

William W. Lang
Robert M. White

Rosette Society

The Rosette Society recognizes members and friends who contributed $5,000 or more to the National Academies in 2002.

Section 1

Holt Ashley
Norman R. Augustine
David R. Heebner*
Robert J. Hermann
Edward E. Hood, Jr.
Kent Kresa
Dale D. Myers
Jack S. Parker
Allen E. Puckett
Peter B. Teets
David W. Thompson
Edward Woll
A. Thomas Young

Section 2

David M. Lederman
George B. Rathmann
Leo J. Thomas

Section 3

William L. Friend
Robert W. Gore
Gerald D. Laubach
Michael P. Ramage
James F. Roth
Warren G. Schlinger
Arnold F. Stancell

Section 4

Stephen D. Bechtel, Jr.
Harry E. Bovay, Jr.

Section 5

John A. Armstrong

* Recently deceased

Paul Baran
C. Gordon Bell
Elwyn R. Berlekamp
Lewis M. Branscomb
Charles M. Geschke
Robert E. Kahn

Section 6

William F. Allen, Jr.
William Cavanaugh III
E. Linn Draper, Jr.
Harold K. Forsen
Lawrence T. Papay
Will H. Rowand*
Chauncey Starr

Section 7

John M. Cioffi
Thomas E. Everhart
Robert W. Galvin
Paul E. Gray
David A. Hodges
Gordon E. Moore
Joseph E. Rowe*
Steven B. Sample
Morris Tanenbaum
Gary L. Tooker

Section 8

Donald C. Burnham
Robert A. Charpie
Robert A. Pritzker
Henry M. Rowan
Laurence C. Seifert

Section 9

Spencer H. Bush
Frank W. Luerssen
George A. Roberts

Section 10

Stephen H. Crandall
Phillip S. Myers
Ronald P. Nordgren

Section 11

Lawrence B. Curtis
Richard M. Morrow
John Neerhout, Jr.

Section 12

George M.C. Fisher

Friends

Richard Evans
William T. Golden
William R. Jackson, Sr. and family

Charter Society

The Charter Society recognizes members and friends who contributed between $1,000 and $4,999 to the National Academies in 2002.

Section 1

Richard E. Adams
Oliver C. Boileau
Alan C. Brown
James R. Burnett
Robert P. Caren
Joseph V. Charyk
Aaron Cohen
Natalie W. Crawford
Ruth A. David
Coleman duPont Donaldson
Bonnie J. Dunbar
Daniel J. Fink
Joseph G. Gavin, Jr.
Ivan A. Getting
George S. Graff
George W. Jeffs
Don R. Kozlowski
James N. Krebs
David S. Lewis, Jr.
Hans W. Liepmann
Robert G. Loewy
Russell G. Meyerand, Jr.
Theodore H.H. Pian
Anatol Roshko
Robert C. Seamans, Jr.
H. Guyford Stever
John W. Townsend, Jr.
Jasper A. Welch, Jr.
Abe M. Zarem

Section 2

Earl E. Bakken
Edmund Y. S. Chao
Yuan-Cheng B. Fung
Robert M. Nerem
Hardy W. Trolander
Daniel I. C. Wang

Section 3

Andreas Acrivos
Elisabeth M. Drake
Robert C. Forney
Eduardo D. Glandt
Robert C. Gunness
Edward G. Jefferson
James R. Katzer
John P. Longwell
James F. Mathis
Morgan C. Sze
John J. Wise

Section 4

George Bugliarello
Theodore K. Galambos
Paul H. Gilbert
Delon Hampton
Charles C. Ladd
Cecil Lue-Hing
Thomas S. Maddock
James K. Mitchell
Norman A. Nadel
Celestino R. Pennoni
Richard J. Robbins
Man-Chung Tang
Richard N. White

Section 5

Joel S. Birnbaum
Barry W. Boehm
Edward E. David, Jr.
Alexander Feiner
Anita K. Jones
Robert J. Spinrad
Robert F. Sproull
Willis H. Ware
Wm. A. Wulf

Section 6

Roy H. Beaton
Philip R. Clark
John G. Kassakian
Zack T. Pate
Murray W. Rosenthal
Henry E. Stone
Willis S. White, Jr.

Section 7

David K. Barton
Malcolm R. Currie
Delores M. Etter
G. David Forney, Jr.
Shirley A. Jackson
Thomas Kailath
Robert G. Kouyoumjian
John G. Linvill
Ralph A. Logan
Morton B. Panish
William J. Perry
Thomas L. Phillips
Dennis J. Picard
Gerald F. Ross
William G. Shepherd
Joel S. Spira
Raymond S. Stata
Charles H. Townes
Andrew J. Viterbi
Paul K. Weimer
Eugene Wong

Section 8

Paul A. Allaire
W. Dale Compton
Michael Field
Louis V. Gerstner, Jr.
James F. Lardner
Donald E. Procknow
Linda S. Sanford
Maxine L. Savitz

Section 9

Hubert I. Aaronson
John C. Angus
Craig R. Barrett
Arden L. Bement, Jr.
Donald J. Blickwede
Lance A. Davis
Raymond F. Decker
Alexander F. Giacco
Mary L. Good
William D. Manly

* Recently deceased

Robert D. Maurer
Tsuneo Nakahara
Neil E. Paton
George W. Scherer
Paul G. Shewmon
Robert H. Wagoner
Johannes Weertman
Julia R. Weertman

Section 10

David B. Bogy
Francois J. Castaing
Edward E. Hagenlocker
George N. Hatsopoulos
Albert S. Kobayashi
Frederick F. Ling
C. Dan Mote, Jr.
Donald E. Petersen
Frank E. Pickering
Bernard I. Robertson
Warren M. Rohsenow
Beno Sternlicht

Section 11

Thomas D. Barrow
Robert Ray Beebe
Harry M. Conger
Stephen A. Holditch
G. Frank Joklik
J. David Lowell
Franklin M. Orr, Jr.
Robert M. Sneider
Richard J. Stegemeier
John E. Swearingen

Section 12

Harold M. Agnew
Clarence R. Allen
Ronald K. Leonard
Duncan T. Moore
John R. Moore
Simon Ramo
Ernest T. Smerdon

Other Individual Donors

Members and friends who contributed up to $999 to the National Academies in 2002.

Section 1

Lew Allen, Jr.
Irving L. Ashkenas
William F. Ballhaus, Jr.
James E. Broadwell
Richard J. Coar
George E. Cooper
Edgar M. Cortright
Earl H. Dowell
Gerard W. Elverum, Jr.
Wesley L. Harris
David G. Hoag
John C. Houbolt
Paul G. Kaminski
Bernard L. Koff
J. Halcombe Laning
Chung K. Law
Paul A. Libby
Peter W. Likins
Hans Mark
Angelo Miele
Earll M. Murman
Norman F. Parker
Bradford W. Parkinson
William H. Pickering
William R. Sears*
Maurice E. Shank
Daniel M. Tellep
Walter G. Vincenti
Irving T. Waaland
Robert H. Widmer
Holden W. Withington

Section 2

Thomas F. Budinger
Stephen W. Drew
Lewis S. Edelheit
David B. Geselowitz
James Gillin
Adam Heller
Donald L. Johnson
Raphael Katzen
Van C. Mow
Robert Plonsey
Buddy D. Ratner
Murray B. Sachs
Michael R. Sfat
Michael L. Shuler

* Recently deceased

John T. Watson

Section 3

John E. Anderson
John L. Anderson
P. L. Thibaut Brian
Nai Y. Chen
Pablo G. Debenedetti
Richard E. Emmert
James R. Fair
Liang-Shih Fan
Sheldon E. Isakoff
C. Judson King
Riki Kobayashi
Johanna M. H. Levelt Sengers
Edward A. Mason
Walter G. May
G. Alexander Mills
William B. Russel
William R. Schowalter
Reuel Shinnar
Matthew V. Tirrell
Charles R. Wilke

Section 4

William D. Alexander
David P. Billington
Lillian C. Borrone
Rafael L. Bras
John E. Breen
Jack E. Buffington
L. Gary Byrd
John L. Cleasby
G. Wayne Clough
Richard A. Conway
Albert A. Dorman
Carroll H. Dunn
Lloyd A. Duscha
Bruce R. Ellingwood
Eugene J. Fasullo
Eugene C. Figg, Jr.*
Gerard F. Fox
E. Montford Fucik
William J. Hall
Henry J. Hatch
Lester A. Hoel
Donald G. Iselin

* Recently deceased

Robert B. Jansen
Paul C. Jennings
Michael C. Kavanaugh
James L. Lammie
Herbert S. Levinson
John Lowe III
Robert C. Marini
Hudson Matlock
Ross E. McKinney
Dade W. Moeller
Benjamin F. Montoya
Thomas M. Murray
Daniel A. Okun
Charles R. O'Melia
Karl S. Pister
Leslie E. Robertson
Jerome L. Sackman
Reuben Samuels
Gurmukh S. Sarkaria
Franklin F. Snyder
Kenneth H. Stokoe II
James M. Symons
Jan A. Veltrop
Leland J. Walker
C. Michael Walton
Robert V. Whitman

Section 5

Frances E. Allen
Frederick P. Brooks, Jr.
Fernando J. Corbato
Ivan T. Frisch
Samuel H. Fuller
Robert S. Hahn
Juris Hartmanis
John L. Hennessy
Aravind K. Joshi
Barbara H. Liskov
Joel Moses
John R. Rice
Mischa Schwartz
Moshe Y. Vardi
Steven J. Wallach

Section 6

John G. Anderson
David H. Archer
Wm. H. Arnold
Robert Avery
Wallace B. Behnke

W. Spencer Bloor
James D. Callen
Melvin W. Carter
Robert W. Conn
Ralph S. Gens
Charles H. Holley
James F. Jackson
John W. Kalb
Leonard J. Koch
Richard T. Lahey, Jr.
Ludwig F. Lischer
I. Harry Mandil
James J. Markowsky
Warren F. Miller, Jr.
Frederick J. Moody
Peter Murray
Cordell Reed
Theodore Rockwell
Neil E. Todreas
Alvin W. Trivelpiece
Gregory S. Vassell
John J. Vithayathil
Harvey A. Wagner
Bertram Wolfe

Section 7

Franklin H. Blecher
Esther M. Conwell
Douglass D. Crombie
Charles A. Desoer
Frederick H. Dill
Irwin Dorros
Alan B. Fowler
Charles A. Fowler
Elsa M. Garmire
Elmer G. Gilbert
Jerrier A. Haddad
Robert C. Hansen
Alan J. Heeger
Robert W. Hellwarth
William C. Hittinger
David C. Hogg
Amos E. Joel, Jr.
Howard S. Jones, Jr.
Ivan P. Kaminow
Jack S. Kilby
James U. Lemke
Frederick J. Leonberger
Humboldt W. Leverenz
Joseph C. Logue
John C. McDonald
Alan L. McWhorter
David Middleton
James J. Mikulski
A. Stephen Morse
Venkatesh Narayanamurti
Marshall I. Nathan
Robert H. Rediker
Arye Rosen
Walter A. Rosenblith*
Roland W. Schmitt
William F. Schreiber
Freeman D. Shepherd
Arnold H. Silver
Jack M. Sipress
Elias Snitzer
Gunter Stein
Lewis M. Terman
Theodore Van Duzer
Max T. Weiss
Irwin Welber
Marvin H. White
Bernard Widrow

Section 8

Jack L. Blumenthal
Geoffrey Boothroyd
Don B. Chaffin
Robert P. Clagett
Ralph L. Disney
John S. Foster, Jr.
Thom J. Hodgson
Joseph M. Juran
William L. Maxwell
Eugene S. Meieran
M. Eugene Merchant
Gerald Nadler
Joseph H. Newman
Charles E. Reed
F. Stan Settles
J. Edward Snyder, Jr.
James M. Tien
Paul E. Torgersen
Howard S. Turner
James E. Turner, Jr.
Dennis F. Wilkie
Edgar S. Woolard, Jr.

* Recently deceased

Section 9

Peter R. Bridenbaugh
Harvey Brooks
Morris Cohen
George E. Dieter
Edith M. Flanigen
Norman A. Gjostein
Julius J. Harwood
Siegfried S. Hecker
Arthur H. Heuer
John P. Hirth
U. Fred Kocks
William J. Koros
Doris Kuhlmann-Wilsdorf
Alan Lawley
John W. Lyons
William J. MacKnight
William D. Nix
Donald R. Paul
Harold W. Paxton
Alan W. Pense
William R. Prindle
Nathan E. Promisel
Lyle H. Schwartz
Richard P. Simmons
Rangaswamy Srinivasan
Edgar A. Starke, Jr.
Dale F. Stein
Gerald B. Stringfellow
Gareth Thomas
Sheldon Weinig
Robert M. White

Section 10

H. Norman Abramson
Allan J. Acosta
Ronald J. Adrian
William G. Agnew
Charles A. Amann
Donald W. Bahr
Rodica A. Baranescu
Richard T. Baum
Arthur E. Bergles
Louis F. Coffin, Jr.
Joseph M. Colucci
James W. Dally
Robert C. Dean, Jr.
Fazil Erdogan
James A. Fay
Nancy D. Fitzroy
Ronald L. Geer
Richard J. Goldstein
William A. Gross
Daniel D. Joseph
Melvin F. Kanninen
Robert W. Mann
Simon Ostrach
David H. Pai
Albert P. Pisano
Ronald F. Probstein
Allen F. Rhodes
Herbert H. Richardson
Jerome G. Rivard
Donald E. Ross
Z. J. John Stekly
Charles E. Taylor
Charles M. Vest
Raymond Viskanta
Ward O. Winer

Section 11

Frank F. Aplan
Grigory I. Barenblatt
Robert W. Bartlett
Robert F. Bauer
Robert R. Berg
Corale L. Brierley
James A. Brierley
James P. Brill
Farouk El-Baz
George J. Hirasaki
William C. Maurer
Thomas K. Perkins
Henry H. Rachford, Jr.
Frank J. Schuh
William H. Silcox
Robert J. Weimer

Section 12

Betsy Ancker-Johnson
David Atlas
Ken Austin
Arthur B. Baggeroer
Leo L. Beranek
Harold Brown
Floyd Dunn
Helen T. Edwards
Essex E. Finney, Jr.
John H. Gibbons

Lawrence R. Glosten
Thomas E. Graedel
Carl W. Hall
Howard R. Hart, Jr.
Marvin E. Jensen
Eugenia Kalnay
Max A. Kohler
Benson J. Lamp
William W. Lang
Robert C. Lanphier III
Louis J. Lanzerotti
Margaret A. LeMone
Richard K. Moore
Stuart O. Nelson
Wesley L. Nyborg
Frank L. Parker
J. Randolph Paulling
Owen M. Phillips
Robert O. Reid
Willard F. Searle, Jr.
Robert J. Serafin
Herman E. Sheets
Charles P. Spoelhof
Richard G. Strauch
Gerald F. Tape
Valerian I. Tatarskii
Warren M. Washington
Wilford F. Weeks
Robert M. White
David A. Woolhiser

Friends

Frances P. Elliott
Thomas H. Jensen
Merrill Meadow

Corporations, Foundations, and Other Organizations

Air Products & Chemicals, Inc.
American Electric Power Company, Inc.
AT&T Corporation
AT&T Foundation
Elizabeth and Stephen D. Bechtel, Jr., Foundation
The Boeing Company
BP Amoco, Inc.
The Capital Group Companies, Inc.
ChevronTexaco Corporation
Consolidated Edison Company of New York, Inc.
Cummins, Inc.
DaimlerChrysler Corporation
Delphi Corporation
Dow Chemical Company
E.I. du Pont de Nemours & Company
Exxon Mobil Foundation
Ford Motor Company
Gannett Company, Inc.
GE Fund
General Electric Company
General Motors Corporation
Hewlett-Packard Company
Honeywell International, Inc.
International Business Machines Corporation
W.M. Keck Foundation
Lockheed Martin Corporation
Microsoft Corporation
J.P. Morgan Chase Foundation
NEC Foundation of America
Northrop Grumman Corporation
Ohio University
Parsons Brinckerhoff, Inc.
Phillips Petroleum Company
PJM Interconnection, L.L.C.
Pratt & Whitney
QUALCOMM, Inc.
Round Table
San Diego Foundation
SBC Communications, Inc.
Southern Nuclear Operating Company, Inc.
Southwest Research Institute
Stratford Foundation
Teagle Foundation, Inc.
Texas Utilities Company
TRW, Inc.
United Technologies Corporation

In Memoriam

DONALD S. BERRY, 91, Murphy Professor of Civil Engineering, emeritus, Northwestern University, died on December 16, 2002. Dr. Berry was elected to the NAE in 1966 for his work on transportation and safety technology.

W. SPENCER BLOOR, 84, retired manager, Steam and Nuclear Power Systems, Leeds & Northrup Company, died on December 8, 2002. Mr. Bloor was elected to the NAE in 1979 for contributions to the reliability and economy of electric power production through the design and application of complex control systems.

C. CHAPIN CUTLER, 87, professor emeritus of applied physics, Stanford University, died on November 30, 2002. Professor Cutler was elected to the NAE in 1970 for fundamental contributions to microwave electronics and to space engineering and applied science.

CARROLL H. DUNN, 86, retired consultant, died on January 31, 2003. Lt. Gen. Dunn was elected to the NAE in 1998 for his engineering and research in the construction industry and national defense.

VLADIMIR HAENSEL, 88, retired professor of chemical engineering, University of Massachusetts at Amherst, died on December 15, 2002. Professor Haensel was elected to the NAE in 1974 for contributions to the development of processes for oil refining, including platforming, used to produce high-octane gasoline without lead. He was the recipient of the NAE Draper Prize in 1997.

ARTHUR HAUSPURG, 77, retired chairman and chief executive officer, Consolidated Edison Company of New York, died on February 19, 2003. Mr. Hauspurg was elected to NAE in 1976 for contributions to the fields of UHV and HVDC transmission and complex interconnected power systems.

DAVID R. HEEBNER, 75, retired executive vice president, Science Applications International Corporation, died on January 3, 2003. Mr. Heebner was elected to the NAE in 1999 for his accomplishments in aerospace systems engineering that have substantially improved our national security.

LUCIEN C. MALAVARD, 79, professor emeritus, University of Paris, died on March 2, 1990. Dr. Malavard was elected a foreign associate of NAE in 1980 for contributions to the field of aerodynamics and for his original work on flow visualization.

BRYANT MATHER, 85, director emeritus, Structures Laboratory, died on December 4, 2002. Dr. Mather was elected to the NAE in 1992 for furthering our understanding of concrete durability and the use of mineral admixtures and for his worldwide leadership in concrete research and practice.

JOHN L. MCLUCAS, 82, aerospace consultant, died on December 1, 2002. Dr. McLucas was elected to the NAE in 1969 for the conception and development of electronic reconnaissance devices.

RENE H. MILLER, 86, professor emeritus, Massachusetts Institute of Technology, died on January 28, 2003. Dr. Miller was elected to NAE in 1968 for his work in aircraft engineering, especially on helicopters, other vertical-flight vehicles, and supersonic transports.

Calendar of Meetings and Events

February 18	Draper and Russ Prizes Press Conference *National Press Club* *Washington, D.C.*
	NAE Draper and Russ Prizes Dinner and Presentation Ceremony *Union Station* *Washington, D.C.*
February 20	NRC Governing Board Executive Committee Meeting
February 21	NAE Congressional Luncheon
February 25	Partnership for Public Service Meeting
March 10–11	NAE/IOM Engineering and the Health Care System Workshop
	Committee on Diversity in the Engineering Workforce Meeting
March 13	NAE Regional Meeting *University of Washington* *Seattle, Washington*
March 18	NRC Governing Board Executive Committee Meeting
April 2–3	Engineering Society Diversity Summit
April 3	NAE Regional Meeting *Rensselaer Polytechnic Institute* *Troy, New York*
April 8	NAE Regional Meeting *University of Illinois at Urbana-Champaign* *Urbana, Illinois*
April 10	NAE Regional Meeting *University of Colorado* *Boulder, Colorado*
April 12	NAE/MIT Meeting
April 15	NRC Governing Board Executive Committee Meeting
April 15–16	Committee on Assessing Technological Literacy Meeting
April 26–29	NAS 2003 Annual Meeting
April 28–29	NAE/IOM Committee on Engineering and the Health Care System Meeting
	Foreign Associates Meeting *Stockholm, Sweden*
May 1–3	German-American Frontiers of Engineering Symposium *Ludwigsburg, Germany*
May 5–6	Convocation of Professional Engineering Societies
May 8	NAE Regional Meeting *Massachusetts Institute of Technology* *Cambridge, Massachusetts*
May 9	NAE/ASCE Engineers Forum on Sustainability
May 13	NRC Governing Board Executive Committee Meeting
May 13–14	NRC Governing Board Meeting
May 16–17	NAE Council Meeting *Hollywood, California*
May 18–21	15th Council of Academies of Engineering and Technological Sciences (CAETS) Convocation *Hollywood, California*
May 22	CAETS Council Meeting *Hollywood, California*
May 27	NAE Finance and Budget Committee Meeting
May 29	Founders and Arthur M. Bueche Awards Conference Call
June 10	Center for the Advancement of Scholarship on Engineering Education Advisory Committee Meeting
June 12	NRC Governing Board Executive Committee Meeting
June 16–17	NAE/IOM Committee on Engineering and the Health Care System Meeting
July 8	Charles Stark Draper Prize Committee Meeting
July 15	NRC Governing Board Executive Committee Meeting

All meetings are held in the Academies Building, Washington, D.C., unless otherwise noted. For information about regional meetings, please contact Sonja Atkinson at *satkinso@nae.edu* or (202) 334-3677.

The National Academies Update

Presidents' Statement on Current Visa Restrictions

On December 13, 2002, NAE President **Wm. A. Wulf**, *National Academy of Sciences President Bruce Alberts, and Institute of Medicine President Harvey Fineberg issued the following statement, "Current Visa Restrictions Interfere with U.S. Science and Engineering Contributions to Important National Needs":*

To make our nation safer, it is extremely important that our visa policy not only keep out foreigners who intend to do us harm, but also facilitate the acceptance of those who bring us considerable benefit. The professional visits of foreign scientists and engineers and the training of highly qualified foreign students are important for maintaining the vitality and quality of the U.S. research enterprise. This research, in turn, underlies national security and the health and welfare of both our economy and society. But recent efforts by our government to constrain the flow of international visitors in the name of national security are having serious unintended consequences for American science, engineering, and medicine. The evidence we have collected from the U.S. scientific community reveals that ongoing research collaborations have been hampered; that outstanding young scientists, engineers, and health researchers have been prevented from or delayed in entering this country; that important international conferences have been canceled or negatively impacted; and that such conferences will be moved out of the United States in the future if the situation is not corrected. Prompt action is needed.

Under current rules, consular officials send many visa applications back to the United States for sequential security clearances by several agencies, leading to long delays and backlogs. In addition, consular officials in some countries are denying visas by telling applicants—even high-ranking officials from major research institutions—that there is fear that they may try to remain in the United States. Consular officers are subject to criminal penalties if they grant a visa to someone who subsequently commits a terrorist act in the United States. Unfortunately, there are currently no offsetting incentives for consular officers to serve the national interest by facilitating scientific exchanges.

The list of those who have been prevented from entering the United States includes scholars asked to speak at major conferences, distinguished professors invited to teach at our universities, and even foreign associates of our Academies. It includes research collaborators for U.S. laboratories whose absence not only halts projects, but also compromises commitments made in long-standing international cooperative agreements. It includes scientists from countries such as Iran and Pakistan whose exclusion from this country blocks our efforts to build allied educational and scientific institutions in those parts of the world. Perhaps most seriously, the list also includes large numbers of outstanding young graduate and postdoctoral students who contribute in many ways to the U.S. research enterprise and our economy.

In order to correct these problems as rapidly as possible, we pledge the help of the U.S. scientific community and urgently call upon the U.S. government to implement an effective and timely visa screening procedure for foreign scientists, engineers, and medical researchers, one that is consistent with the twin goals of maintaining the health of science and technology in the United States and protecting our nation's security. We ask the Department of State and its consular officials to recognize that, in addition to their paramount responsibility to deny visas to potential terrorists, the long-term security of the United States depends on admitting scholars who benefit our nation.

Possible mechanisms for streamlining the process without compromising security might include:

- Reinstating a procedure of pre-security clearance for scientists and engineers with the proper credentials;
- Instituting a special visa category for established scientists, engineers, and health researchers; and
- Involving the U.S. scientific and technical community in determining areas of particular security concern.

The U.S. research community can assist consular officials by providing appropriate documentation for those foreign citizens who are engaged in collaborations with our scientists and engineers.

An approach that welcomes qualified foreign scientists, engineers, health professionals, and students serves three general purposes in support of national goals. We outline these briefly below.

Harnessing international cooperation for counterterrorism. The National Academies have been working with foreign scientists and engineers on several efforts directly related to combating terrorism. Last September visa restrictions came within one day of forcing the cancellation of an important meeting in Washington of our Committee on U.S.-Russian Cooperation on Nuclear Non-Proliferation. This committee's responsibilities include assuring that nuclear weapons-grade materials are under control and out of the hands of terrorists. It required intervention at the highest levels of the State Department to gain the needed visas. Similar collaborations are under way in many other venues, and these require that we welcome qualified foreigners to our nation without restrictions or delays.

Building stronger allies through scientific and technological cooperation. It is clearly in our national interest to help developing countries fight diseases such as AIDS, improve their agricultural production, establish new industries, and generally raise their standard of living. There is no better way to provide that help than to train young people from such countries to become broadly competent in relevant fields of science and technology. Yet our new visa restrictions are making this more difficult. For example, several hundred outstanding young Pakistanis, carefully selected by their government as potential leaders of universities there and accepted for graduate training in U.S. universities, experienced a 90 percent denial rate in applying for U.S. visas.

Maintaining U.S. global leadership in science and technology. Throughout our history, this nation has benefited enormously from an influx of foreign-born scientists and engineers whose talents and energy have driven many of our advances in scientific research and technological development. Over half a century ago, Albert Einstein, Enrico Fermi, and many others from Western Europe laid the foundations for our global leadership in modern science. More recently, immigrants from other parts of the world—most notably China, India, and Southeast Asia—have joined our research institutions and are now the leaders of universities and technology-based industries. Many others have returned to take leadership positions in their home countries, and now are among the best ambassadors that our country has abroad.

Approximately half of the graduate students currently enrolled in the physical sciences and engineering at U.S. universities come from other nations. These foreign students are essential for much of the federally funded research carried out at academic laboratories.

Scientific and engineering research has become a truly global enterprise. International conferences, collaborative research projects, and the shared use of large experimental facilities are essential for progress at the frontiers of these areas. If we allow visa restrictions to stop international collaborations at our experimental facilities, then these facilities will cease to attract international support. Moreover, our scientists and engineers will no longer enjoy reciprocal access to important facilities abroad. And if we continue to exclude foreign researchers from conferences held in the United States, then those meetings may cease to take place in this country in the future, depriving many American scientists of the opportunity to participate in them.

In short, the U.S. scientific, engineering, and health communities cannot hope to maintain their present position of international leadership if they become isolated from the rest of the world. We seek the help of the U.S. government in implementing effective and timely screening systems for issuing visas to qualified foreign scientists and students who bring great benefit to our country. We view this as an urgent matter, one that must be promptly addressed if the United States is to meet both its national security and economic development goals.

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at <*http://www.nap.edu*> or by phone at (800) 624-6242. *(Note: Prices quoted by NAP are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

An Assessment of Non-Lethal Weapons Science and Technology. The U.S. Department of Defense (DOD) created the Joint Non-Lethal Weapons Directorate, under the purview of the U.S. Marine Corps, to oversee the development and deployment of nonlethal weapons, which are valuable in a variety of military operations, such as urban peacekeeping, counterterrorism, and force protection. Up to now, DOD's focus has been on mature technologies, with little investment in the development of new capabilities. The report recommends four high-priority science and technology areas for research and development: calmatives and malodorants that are compatible with treaty obligations for controlling crowds and clearing facilities; advanced directed-energy systems for stopping vehicles or vessels; novel and rapidly deployable marine barrier systems to stop attack vessels and protect perimeters; and unmanned or remotely piloted vehicles and sensors to provide warnings and to localize and track potential enemies. Paper, $41.25.

Eighth Annual Symposium on Frontiers of Engineering. This collection includes summaries of presentations given at the September 2002 symposium. Topics include: chemical and molecular engineering in the twenty-first century, technology for human beings, the future of nuclear energy, and engineering challenges for quantum information technology. Paper, $33.50.

Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics. This report offers a vision for the systematic evaluation of teaching practices and academic programs and provides recommendations for various stakeholders in higher education about how to achieve change. The report discusses ways to evaluate the undergraduate teaching of science, mathematics, engineering, and technology, characterizes effective teaching in these fields, explores the implications of differences between research and teaching cultures and describes how practices for rewarding researchers could be transferred to the teaching enterprise. The report provides a blueprint for institutions that are ready to develop effective evaluation programs for teaching in science fields. Paper, $39.95.

The Internet Under Crisis Conditions: Learning from September 11. Although telecommunications issues were secondary to the human tragedy of September 11, the problems were significant, in terms of both damage and of mounting response and recovery efforts. The National Research Council Computer Science and Telecommunications Board was asked to organize an exploratory workshop to gather data and personal accounts of experiences pertinent to the impact of September 11 on the Internet and to prepare a report summarizing the performance of the Internet that day. The report, which suggests how telecommunications can be better prepared for future emergencies, focuses on three issues related to the Internet: (1) the local, national, and global consequences of the destruction that occurred in New York City; (2) the impact of the crisis, including the actions of users and the effects of physical damage; and (3) the uses of the Internet during the crisis. Paper, $18.00.

One Step at a Time: The Staged Development of Geologic Repositories for High-Level Radioactive Waste. The authoring committee coined the term "adaptive staging" to describe how nuclear-waste disposal programs should be implemented. Adaptive staging has seven characteristics: (1) continuous and systemic learning; (2) flexibility; (3) reversibility; (4) "auditability"; (5) transparency; (6) integrity; and (7) responsiveness to public concerns. Adaptive staging would give project managers the latitude to make adjustments throughout the disposal process based on operational experience or scientific advances, taking into account safety, environmental concerns, and cost. In the case of Yucca Mountain, adaptive staging would allow the U.S. Department of Energy to retain the option of reversing a decision or action while moving forward with disposal. Paper, $42.00.

Personal Cars and China. In its most recent five-year plan (2001–2005), the Chinese government set a goal for its automotive industry of producing more than 1 million cars a year. The plan calls for massive restructuring of the industry and encourages the production of a Chinese economy car, independently of foreign manufacturers. Assuming that economic growth continues, it is highly likely that China's vehicle fleet will increase rapidly from the 18 million vehicles (including 5 million cars) in the country in 2001. Rapid growth will bring many benefits but will also present serious challenges to China's social, environmental, and economic systems. Recommended actions for the Chinese government and automotive industry include: keeping abreast of ongoing research and development on promising technologies in other countries; making substantial investments to achieve capability in technologies; maintaining a balance between short-term and long-term needs; and developing partnerships with foreign producers that offer Chinese companies access to evolving product and process technologies. Paper, $55.25.

Preparing for the Revolution: Information Technology and the Future of the Research University. Research universities are of great importance to our economic strength, national security, and quality of life. The report identifies information technologies that are likely to evolve in the near future and examines the possible implications of those technologies for research universities and for the broader higher education enterprise. The report describes the functions, values, and characteristics that are most likely to change as well as those most important to preserve. The conclusions should provide a useful guide for future activities by research universities and their stakeholders. Paper, $25.50.

Raising Public Awareness of Engineering. The public has little awareness or appreciation of engineering as the source of technology, even though the engineering community spends mightily to try to improve public awareness. A survey commissioned by the National Academy of Engineering of activities intended to raise public awareness found that these activities are not well coordinated and that most of their sponsors have not developed measures of their success. This report provides the results of the survey, explains why it was needed, and recommends what the engineering community can do to communicate the importance of engineering more effectively to the public. Paper, $25.75.

Review Procedures for Water Resources Planning. The U.S. Army Corps of Engineers (USACE) conducts planning studies to determine if there is federal interest in projects proposed for America's waterways and, if so, whether those projects can be justified on technical, economic, and environmental grounds. Recent public controversies over the assumptions and analyses in certain USACE studies prompted Congress to ask the National Research Council to review the process USACE uses. The report concluded that Congress should direct the secretary of the Army to establish a small professional staff to administer the review process and decide, on a case-by-case basis, whether reviews of USACE planning studies should be conducted externally or internally. Congress should also create a review advisory board to provide periodic advice to the project review group. The report recommends that external reviews be conducted of all projects that are expensive, controversial, affect a large geographic area, or involve a high degree of environmental risk and that the reviews be overseen by an independent organization. Paper, $12.00.

The
BRIDGE

(USPS 551-240)

National Academy of Engineering
2101 Constitution Avenue, N.W.
Washington, DC 20418

Periodicals
Postage
Paid