

Summer 2007

VOTING TECHNOLOGIES

The

BRIDGE

LINKING ENGINEERING AND SOCIETY

**Bridging Science, Technology, and Politics
in Election Systems**

R. Michael Alvarez and Erik K. Antonsson

E-Voting and Democracy in America

Gracia Hillman

What Happened in Sarasota County?

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**Legal Issues, Policy Issues, and the Future
of Democracy**

Rush Holt

Voter Assurance

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Voting as an Engineering Problem

Michael Ian Shamos

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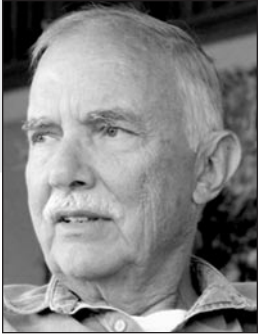
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Editor's Note



Lewis M. Branscomb is Professor Emeritus, John F. Kennedy School of Government, Harvard University, Visiting Faculty, School of International Relations and Pacific Studies, and an NAE member.

Elections and the Future of E-Voting

In February, we honored Bill Wulf with a symposium on a subject of his choosing, *The Impact of Technology on Voting and Elections in the 21st Century*. Bill has been a tireless advocate before Congress and the nation for improving our capability and increasing our knowledge in all the areas of cyber security. When he says, “engineering is design under constraints,” he understands that the most important

constraints are not imposed by the laws of physics. They are the constraints that arise from the limitations of human individuals, of socioeconomic institutions, of human preferences, fears, and sentiments such as elation and outrage. Nowhere in our society does engineering confront these human constraints more seriously than in the functions that sustain our democracy—registering to vote, voting, tallying the vote, reporting exceptions and results, and accepting the certified outcome with confidence that it reflects the collective intent of eligible voters.

The Constitution leaves the rules and means by which elections are conducted largely to the states, rather than the federal government. Elections often have not only federal impact (for presidential electors, senators, and representatives) but also state and local impacts (for governor and many other offices), and they usually take place on the same day and even the same ballot.

Almost every important decision about elections is made by state governments (mostly by secretaries of state, who certify election results in many cases with no oversight). Other elected officials at the local level also have important responsibilities, sometimes conflated with their own candidacies. We depend on their commitment to free and fair elections, as well as their competence and ability to administer rules, processes, certification of equipment, and training of election workers.

Most election officials, even though they have been appointed by a particular party, have been fair and sincere. They understood the tools used to interpret and count votes, and these functions were carried out without discrimination or fraud. But today, with more complex computer-based election technologies and bitterly contested elections, the burdens of objectivity and competence and the need for constant learning have increased dramatically. To add to these burdens, the financing of election processes is often inadequate. The training of poll workers and the testing, recounting, and auditing of votes—in fact, almost everything to do with the administration of voting systems—has been left to counties or parishes (in New England to townships) with their hundreds of precincts and different ballot styles.

Elections were never perfect, even in the world of paper ballots stuffed into boxes and lever machines with outputs read off of dials. Today, volunteers are faced with electronic voting machines manufactured and maintained by private firms that have software that hasn’t been rigorously tested and source code that is not available to experts of all political persuasions. A few years ago one of those companies was reportedly led by an executive who made no secret of his intention to do whatever he could to re-elect the president.

Voting technology must also make voting accessible to people who speak dozens of languages, have a wide range of handicaps, or may be serving overseas. They must present understandable ballots for voting on local judges, numerous propositions, and candidates for federal and all levels of state and local government. These non-partisan requirements present many difficulties for election officials, who are always trying to minimize expenditures of cost and time.

Add to this list of constraints an issue on which Democratic and Republican state legislators agree: that gerrymandering is a great way to keep all of them in office. Only the fairest, least corrupt, most understandable, and least discriminatory voting system can give voting minorities in these districts a chance to vote incumbents protected by name recognition and gerrymandered districts out of office.

Can new technologies improve the situation? Can they ensure that the intent of the voters is reflected in the official tally of the vote? What requirements

should we place on voting technologies and procedures to ensure they are credible when margins of victory may be as small as a fraction of a percent? Voters must have a substantive reason for trusting that their intentions have been correctly interpreted and recorded, and that their votes have been counted correctly. But voter confidence is not enough. The machines and procedures must be proven to perform reliably.

And if the vote in an election is certified by partisan election officials with the result that their party's candidate wins by a few hundred votes out of a quarter of a million (as happened last fall in the 13th Congressional District of Florida), the candidate certified to have lost will surely demand a recount if allowed to do so. But who will pay for this recount and how will it be done? If the election used touch screen technology, with or without a paper record, will an electronic recount more accurately reflect voter intent? Or will the machine's computer memory repeat the same questioned total each time?

What if repeated recounts—of paper or electronic ballots—give a random variation of a few hundred votes each time? Many election officials believe that if human beings do their best, there is a minimum below which non-repeatable errors cannot be reduced. But there are techniques for interpreting and counting that can provide more precise results with each iteration. These are rarely used, sometimes because of the expectation of fallibility in hand counting. In New Mexico, I am told, a poker hand played by the contesting candidates has been used to determine the outcome in a “tie.” How should voting procedures deal with such “ties” or near misses?

A related question arises about systematic errors in technological voting systems. These errors are not reduced by repetition. Only human intervention involving further study and analysis and a hand count can reduce them. Are some voting technologies, highly accurate in the absence of undiscovered software errors, vulnerable to being sufficiently perturbed to tip an election? Are election officials willing to permit public oversight to ensure that the public believes an election is fair and not that information has been hidden or simply overlooked? Can the public be confident that technology and election procedures combined can handle a very close election, such as the recent contest in Florida, with

accuracy, transparency, verifiability, reliability, security, anonymity, and privacy?

The papers in this issue address many of these concerns. An early technical response to the razor-thin margin of victory for President Bush in 2000 was the creation of the Voting Technology Project (VTP), a collaborative initiative by Caltech and MIT. Michael Alvarez, professor of political science and co-director of the project, and Erik Antonsson, professor of mechanical engineering at Caltech and a participant in the project, address the importance of bridging the gap between technology and politics in voting. Commissioner Gracia M. Hillman describes the work of the Election Assistance Commission, which was established by Congress in 2002 to assist states and ensure that elections in 2004 and thereafter would be free and fair.

David Jefferson, computer scientist at Lawrence Livermore Laboratory and chair of the California Secretary of State Voting Systems Technology Assessment and Advisory Board, addresses the mysterious undervote of about 18,000 in the 2006 congressional election in one county in Florida's 13th Congressional District. Congressman Rush Holt describes his bill, HR 811, which he introduced in February 2007, to develop requirements for electronic voting technology and reform current federal election laws.

Eugene Spafford, professor of computer science and electrical and computer engineering at Purdue University, discusses how voter confidence can be increased through better verification of voting systems. Michael Ian Shamos, Distinguished Career Professor in the School of Computer Science at Carnegie Mellon University, argues that the most serious problems with voting technologies can be addressed by better engineering design.

Our hope is that these articles will contribute to the realization of an election and voting environment that satisfies the needs of voters and election officials. Under rules like those proposed by Congressman Holt, a voting technology might emerge that is acceptable to all of the states. New rules and reliable, trustworthy voting systems might win over voters and become known as the solution that overcame the constraints and saved our democracy from itself.

Levon Branscomb

Dear Readers

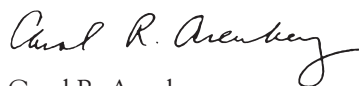
We want to call your attention to a special moment in the history of NAE that coincides with this issue of *The Bridge*. We are about to bid farewell to Bill Wulf, who will be stepping down as president of NAE on June 30, and welcome Charles M. Vest, who will take up the mantle on July 1. Beginning on p. 40, you will find some parting thoughts from Bill and some reminiscences on his remarkable presidency.

Charles M. Vest, President Emeritus of MIT, who will be taking over as NAE president in a time of transition for this organization and for our nation, is profiled briefly on p. 44. His presence and personality will surely be felt in future issues of *The Bridge* and in the direction and activities of our academy.

We thank Bill for his leadership and integrity during his 11 years as NAE president, and we look forward to continued accomplishments and progress under the leadership of President Vest.



George Bugliarello
Editor in Chief (interim)



Carol R. Arenberg
Managing Editor

After the 2000 presidential election, Caltech and MIT initiated the Voter Technology Project to address problems with voting systems.

Bridging Science, Technology, and Politics in Election Systems



R. Michael Alvarez



Erik K. Antonsson

R. Michael Alvarez
Erik K. Antonsson

Shortly after the tumult of the evening of November 7 and the morning of November 8, 2000, the presidents of Caltech and MIT challenged us to solve the technological problems that had arisen in the election, especially with the punch-card voting systems that were widely disparaged after Florida's presidential contest. Our initial research team spanned the continent and involved two campuses with different research and administrative cultures. The team also spanned many disciplines—computer science, economics, human-factors research, mechanical engineering, operations research, and political science. In addition to taking advantage of the faculty resources on both campuses, the group included staff and students, both undergraduate and graduate.

For better or worse, the more our research team studied what happened in the 2000 presidential election, the more we became convinced that the problems could not be easily resolved because, in addition to technology, they involved people, procedures, and politics. The work of the Caltech/MIT

R. Michael Alvarez is senior fellow, USC Annenberg Center for Communication; professor of political science, California Institute of Technology; and co-director, Caltech/MIT Voting Technology Project. Erik K. Antonsson is professor of mechanical engineering, California Institute of Technology; director of research, Northrop Grumman Space Technology; and a member of the Caltech/MIT Voting Technology Project. This article is based on a presentation given on February 8, 2007.

Voting Technology Project (VTP) in the immediate aftermath of the 2000 presidential election was controversial, but it served as a platform for research and reform in the years that followed. In this article, we discuss how we undertook this research project, how it has evolved over the past seven years, and the issues we believe are critical to advancing the science of elections.

Historical Background

Prior to the 2000 presidential election, little academic research had been done on voting technology or election administration (Alvarez and Hall, 2004). In addition, most of the work conducted prior to the turn of the twenty-first century was not multidisciplinary. Research was primarily published by historians, political scientists, scholars of public administration, or technologists—written primarily for specialists in their fields of interest. Thus, when the public controversy over the 2000 presidential election arose and the presidents of Caltech and MIT called upon us to initiate a major research and policy project, we found there was not much literature about research on voting technology to draw upon and almost nothing on voting as an interrelated system of equipment, people, media, laws, and regulations.

Perhaps not surprisingly, we found this situation profoundly troubling. Voting and elections have been described as the “DNA of democracy,” and, clearly, the system of government in the United States depends on fair and open elections. Nevertheless, no systematic understanding of elections or voting systems had been developed. The situation was, and to a significant degree still is, analogous to medicine at the end of the nineteenth century—based largely on empiricism, not backed by science, supported by ad hoc apparatus, and practiced by individuals with a wide range of competency levels and training. Fortunately, our republic has been protected by diligent, hardworking election officials, people of extraordinary good will, and a diversity of election apparatus and technologies. The latter—the current (and historical) patchwork of election equipment used in the United States—kept problems confined to local areas, rather than causing systemic harm.

In many ways, the 2000 presidential election revealed the potential for the development of a new field of academic research, the study of voting technology, which could have a profound impact on the understanding, conduct, and credibility of elections. Even relatively simple questions, such as the criteria that should be used

to evaluate the performance of voting technologies and the metrics that might be used in such an evaluation, had not been addressed in readily available, established, peer-reviewed, research literature. Obtaining information about voting technologies turned out to be not only difficult, but, in a distressingly large number of cases, impossible. We could not even determine how much states and lower-level election jurisdictions spend annually to administer their elections. Not surprisingly, this made our research much more difficult than we initially imagined. Thus most of our early work immediately after the 2000 election was focused on data collection.

In 2000, no systematic understanding of elections or voting systems had been developed.

We struggled to define appropriate criteria by which to evaluate the performance of voting technologies, especially in light of the difficulties of determining voter intent in Florida counties that used pre-scored punch cards (where overvotes, undervotes, and partially separated “chads” bedeviled attempts to establish a single, accurate vote count). Finally, members of the VTP research team came up with an important metric—the “residual vote”—the percentage of ballots cast in an election jurisdiction that did not produce a valid vote in a specific race, most importantly in the top-of-the-ballot race, usually for president or governor (Ansolabehere, 2004; Ansolabehere and Stewart, 2006; Sinclair and Alvarez, 2004).

The residual-vote metric, as used in our preliminary study of the accuracy of voting machines, indicated that punch-card voting systems performed relatively poorly. But, to our surprise, we also found that the electronic voting systems in use in 2000 and earlier elections also had relatively high residual-vote rates (a finding that subjected us to much public criticism).

In the years since, the residual-vote metric has been used in many peer-reviewed studies and has become a standard in studies of the performance of voting systems across time and space (e.g., Stewart, 2006). But this

metric is far from perfect. First, it aggregates overvotes and undervotes, thus making it impossible to differentiate two distinct phenomena. Second, data for overvotes and under-votes are rarely reported by election jurisdictions.

Despite these limitations, the residual-vote metric is extremely useful. It can be used to compute votes across election jurisdictions and for more than one election. So, even though it is flawed, it currently provides the best source of comparative data for studying the performance of voting technologies. These data, for example, enabled VTP researcher Charles Stewart III to examine the effects of changes in voting technologies, both specifically, in states such as Georgia, and throughout the nation (Stewart, 2006).¹

The residual-vote metric can provide comparative data on the performance of voting technologies.

Despite the challenges we faced, the VTP has made considerable progress in developing and sustaining a productive research agenda. We issued a series of major policy reports, beginning in June 2001 and continuing to the present. We helped shape the Help America Vote Act (HAVA) in 2002, and since then we have provided many forms of assistance to governments across the nation working to implement the provisions of HAVA. We have hosted a number of research- and policy-oriented conferences and workshops (including three in the past year, one on voter registration and authentication, one on studying election fraud, and a unique workshop to help researchers and vendors identify research opportunities on voting technologies).² To date, VTP researchers have published two books (two more are forthcoming in the next

year), 19 journal articles, 24 policy reports, more than 50 working papers, and five student theses. We have also studied election processes in the United States (e.g., in California, Georgia, Massachusetts, New Mexico, and Utah) and abroad (e.g., in Argentina, Estonia, and Ireland).

Difficulties of Studying Voting Technology

As we determined early in our research, we expect voting systems to perform many tasks, including authenticating voter legitimacy, recording voter intent accurately, enabling confidential and anonymous voting, providing equal protection and equal access, preventing fraud, tallying votes accurately, complying with standards and legal requirements of voting systems, and inspiring public confidence in elections. However, we also determined early on that these functions could not be analyzed based solely on the perspectives, theories, and methodologies of a single academic discipline.

Analyses of each function of a voting system require multidisciplinary research. For example, voter authentication, a procedural issue, is a matter of state law and local practice. It may influence the behavior of voters and the strategies of candidates, and it will increasingly be a subject for the development of new technologies. To fully understand voter authentication, then, requires that researchers break out of traditional academic disciplines and collaborate with researchers in other disciplines—for example, Michael Alvarez (a political scientist) working with Erik Antonsson (a mechanical engineer)! Analyzing voter authentication might involve scholars who specialize in law, political behavior, public administration, and technology.

We have also learned since 2000 that studying these problems requires complex collaborations that reach beyond the academic sector altogether. We must learn from, and work with, three other stakeholder groups—election officials and policy makers, vendors of voting systems, and advocates and other political groups and individuals—to produce research results that can effectively resolve the problems observed in the American electoral process.

Each of these groups has knowledge and resources that we need for our research to be effective. Election officials and voting-system vendors have intimate knowledge of how elections are run in America; election officials in particular have the kinds of statistical data we need to study election results. Advocates and political entities (candidates, parties, and other groups

¹ See also *Residual Vote by State*, 1996 and 2000, on p. 89 of *Voting: What Is, What Could Be*, which shows that VTP researchers could not produce estimates of residual-vote rates for a number of states (VTP, 2001). See also Alvarez et al., 2005.

² For a complete list of events sponsored and organized by VTP since 2000, see <http://www.vote.caltech.edu/events.htm>.

organized for political purposes), who either aspire to elected office or are using the electoral process for policy or political purposes, have a direct stake in the way elections are conducted. Although we must remain entirely neutral and uninvolved in partisan or ideological political struggles, the advocate and political communities often have knowledge and resources we can use to make our work more effective.

Building a Science of Elections

After looking back at how our research project has evolved since 2000 and looking ahead to the daunting research problems that still need work, we advocate focusing on the development of a new science, the study of elections. This new science must be multidisciplinary, will require nontraditional research collaborations (spanning academic institutions and bridging the academic-private sector divide), and will require the development of a scientific infrastructure. We have already discussed the need for collaborations and multidisciplinary research. In this section we address the issue of infrastructure.

Developing a new scientific infrastructure will be difficult, and the primary issue that must be addressed is research funding. To date, VTP has been funded primarily by grants from two private-sector foundations, the Carnegie Corporation of New York and the John L. and James S. Knight Foundation. These foundations, and a few others, have also supported research and policy projects on voting technology.

To date, the primary public-sector research-funding entity, the National Science Foundation (NSF), has issued only two sizeable grants for the study of voting technology—one to a University of Maryland-led group on the usability of voting technologies and one to a Johns Hopkins study of voting-technology security. Despite a long list of required research areas listed in HAVA, the U.S. Election Assistance Commission (EAC), the other main government funding entity, has not sponsored any major research projects that involve basic research on voting technology or election administration. Limited by a lack of funds, EAC has only supported a few small, narrowly focused research projects (e.g., the collection of election-administration survey data for recent federal elections).

The lack of large-scale funding, especially from the federal government, has made it extremely difficult for academic researchers to engage in the sustained, focused research necessary for meaningful studies of

voting technology. Given the many mandated studies listed in HAVA and the clear need for large-scale, sustained research on basic questions, such as voting-system usability, security, reliability, and accuracy, the federal government must provide funding, through both NSF and EAC, for the study of voting technology and election administration.

In addition, the academic research community engaged in the study of voting technology and election administration sorely needs highly visible, highly credible research outlets. Not a single peer-reviewed journal exists for studies of voting technology and election administration. Therefore, research studies in this new field are being published in a multiplicity of outlets, ranging from non-refereed websites and blogs and non-refereed conference proceedings and professional publications to highly credible, peer-reviewed academic journals. However, our experience (and the experience of many colleagues) shows that publication in the latter is extremely difficult (even though these are the kind of outlets that could establish the credibility of a research report) because all submissions are subject to the usual type of academic review, replication, and discourse. Reviewers in political science journals, for example, often demand a strong theoretical rationale for an empirical analysis of residual-vote rates; but, because there is no strong theory to draw upon, it is nearly impossible to satisfy this otherwise typical demand in the political science peer-review process. At the other end of the spectrum, voting systems are not close enough to the cutting edge of technology to generate research results suitable for publication in scholarly engineering journals.

There are no peer-reviewed journals for studies of voting technology or election administration.

The lack of credible, peer-reviewed publication outlets is not just an academic concern. Under the present circumstances, it is difficult for policy makers and election officials to distinguish between legitimate

and illegitimate research. We have heard this complaint frequently from election officials and policy makers in recent years. They clearly need access to a publication or research distribution system that identifies credible research.

Thus the second important step toward building a scientific study of elections is the development of new, scholarly, peer-reviewed journals for the publication of research results in voting technology and election administration. These publication and distribution outlets should take advantage of new technologies, such as web-based review and publishing, to shorten the time from submission to publication and provide readers with identifiably credible research.

Another alternative is for an entity, such as NSF, EAC, or even the National Academies, to develop an equivalent of the National Institutes of Health “PubMed”—a digital archive of biomedical and life-sciences research (especially government-sponsored research)—in the area of election science. This initiative, which might be called “PubVote” or “Election Science,” could collect digital copies of research related to voting systems and election administration by researchers and peer-reviewed academic research outlets. Thus it would be a one-stop destination for anyone searching for research results on these topics.

Finally, to facilitate collaboration and the dissemination of research results, we need better channels of communication among scholars and between the research community and the many other stakeholders mentioned earlier. One important function of VTP has been to convene periodic conferences and workshops on special topics (e.g., studies of voting technology, voter authentication, and voter registration). Recently, VTP sponsored a small workshop at Caltech of about two dozen researchers and representatives of the voting-technology industry for an intense one-day discussion of research questions and collaborations. These gatherings, however, have been difficult to put together, difficult to facilitate, and, frankly, have used up scarce financial resources that could have supported more research.

We must find ways to initiate these conversations and to ensure the free flow of research ideas among researchers and between researchers and other stakeholders. Such conversations will improve academic research and will ensure that results get into the hands

of those who can take action to improve the American electoral process.

Conclusion

The good news is that election systems, and elections themselves, are improving. The harsh light that illuminated the flaws in the 2000 national election led to academic research, provoked legislative action, spurred innovation in the marketplace, and educated the public about the strengths and weaknesses of elections in the United States. But as a nation, we can, and we must, do better. We need a better understanding of the interrelationships between voter registration and authentication systems and voter turnout. We need to develop clear standards for counting or disqualifying ballots. We need to understand how to reliably determine voter intent. In short, we need to understand election systems, and that understanding will come about with the establishment of a legitimate field of election science.

Acknowledgment

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The U.S. Election Assistance Commission was established in 2002 to ensure that elections are accurate, accessible, and auditable.

E-Voting and Democracy in America



Commissioner Gracia Hillman is a member of the U.S. Election Assistance Commission. This paper is based on a presentation by the author on February 8, 2007, at the NAE Symposium on the Impact of Technology on Voting and Elections in the 21st Century.

Gracia Hillman

American democracy depends on two things—citizen participation and fair and accurate elections—and both of these depend on how well elections are conducted. Administering an election is a complex undertaking that involves numerous people, processes, and machines. The underpinning of fair and accurate elections is voting systems that have been rigorously tested for reliability and accuracy to ensure that every vote on every ballot is counted and reported correctly.

Another important element is an election administration process overseen by skilled management and supported by trained poll workers to minimize errors and maximize security and accessibility. Myriad federal, state, and local laws, policies, regulations, and procedures must be taken into account for there to be accurate, open, accessible, and secure elections.

Election processes are only one part of what makes a democracy work. The other part is citizen participation, which requires that the public have confidence that the election system has a high level of integrity and minimal error. To that end, citizens must be educated about election administration processes, including the systems used for casting and counting votes. The public should have the opportunity to learn about the processes, such as how voting systems are set up and how votes are counted. At a time when electronic voting (e-voting) and other technological advances are transforming elections—creating opportunities for improvement but also raising new

challenges—voter confidence in the election system is critical. To ensure that the American election system remains strong, all of these factors must be addressed.

Voting Systems

Election integrity requires accurate, reliable, accessible, and auditable voting systems. The recount of votes in Florida following the November 2000 presidential election exposed the shortcomings of punch-card and lever voting systems. To address these and other concerns about election integrity, the Help America Vote Act (HAVA)¹ was signed into law in 2002.

HAVA establishes a number of requirements for voting systems used in federal elections:

- an opportunity for a voter to change his or her selections independently and privately prior to casting a vote
- notification of an overvote and the consequences of casting an overvote before the vote is cast
- a permanent, auditable paper record of votes
- access for individuals with disabilities, including people who are blind or visually impaired
- access for people whose first language is not English (when required by Section 203 of the Voting Rights Act)
- an error rate of no more than one error in 500,000 positions, as established in the 2002 Voting System Standards developed by the Federal Election Commission (FEC)

To comply with HAVA, states now use one or more of the following voting systems—direct record electronic systems (DREs), with or without a voter-verifiable paper audit trail, optical scans, or hybrid systems that function like DREs but mark and produce paper ballots to be scanned. Congress appropriated \$3 billion in funding to help states² meet these and other HAVA mandates.

The passage of HAVA marked the first time the federal government assumed responsibility for the testing, certification, decertification, and recertification of

voting system hardware and software. That responsibility is assigned to the Election Assistance Commission (EAC), an independent, bipartisan commission created by HAVA and established in December 2003. EAC administers payments to states, develops guidance for meeting HAVA requirements, adopts voluntary voting-system guidelines, accredits voting-system test laboratories, certifies voting equipment, and serves as a national clearinghouse and resource for information about election administration.

HAVA requires that EAC develop guidelines and establish a program for testing voting systems that includes the accreditation of independent test authorities (or test laboratories). The guidelines, testing, and accreditation processes (described below) provide a means of determining whether voting systems meet the HAVA baseline requirements, as well as the more descriptive and demanding standards of the voluntary voting-system guidelines developed by EAC to assure election officials and voters that voting systems are accurate, reliable, accessible, and auditable.

Voluntary Voting-System Guidelines

The first set of national voting-system standards was created in 1990, and updated in 2002, by the FEC. HAVA transferred responsibility for setting standards to EAC that same year and mandated that a new iteration of the standards be developed to address (1) advancements in information security and computer technologies, (2) issues related to error rates, and (3) accessibility for disabled voters. HAVA also required that the standards be called voluntary guidelines, rather than voting-system standards.

Since 2004, EAC has been working with a federal advisory committee, the Technical Guidelines Development Committee (TGDC),³ and the National Institute of Standards and Technology (NIST)⁴ to develop updated voluntary voting-system guidelines that prescribe technical requirements for performance and identify testing protocols for determining how well systems meet these requirements.

¹ A copy of the Help America Vote Act of 2002 (HAVA), signed into law by President George W. Bush on October 29, 2002, can be found at www.eac.gov.

² HAVA requires that the Election Assistance Commission provide payments to states to help them meet the federal requirements in Title III of HAVA. A payment chart showing how much money has been allocated can be found at www.eac.gov.

³ TGDC provides recommendations on voluntary standards and guidelines related to voting equipment and technologies. The committee has 14 members selected from various standards boards and individuals with technical and scientific expertise related to voting systems and equipment. A list of committee members can be found at www.eac.gov.

⁴ HAVA assigned NIST, which chairs TGDC, a key role in realizing nationwide improvements in voting systems. More information about the role of NIST can be found at www.vote.nist.gov.

In consultation with experts in technology and accessibility and election officials, TGDC and NIST completed the first draft of the new two-volume *Voluntary Voting System Guidelines*⁵ in May 2005 (VVSG 2005). To ensure compliance with the time limitations imposed by HAVA, EAC, TGDC, and NIST agreed that this first set of guidelines would be an update of the 2002 voting-system standards. EAC then took the guidelines further to address security and accessibility issues.

Volume I, *Voting System Performance Guidelines*, includes requirements for the human factors of accessibility and usability, the distribution of voting-system software, validation of systems set-up, and standards for wireless communications. This volume provides an overview of the requirements for independent verification systems, including requirements for voter-verifiable paper audit trail (VVPAT) for states that require this feature for their voting systems. Volume I also includes a requirement that all voting-system vendors submit software to a national repository so that local election officials can be sure that the software they purchase is the same software that was certified by EAC. Volume II, *National Certification Testing Guidelines*, describes the components of the national certification testing process for voting systems, which will be performed by independent test laboratories accredited by EAC (described below).

Before adopting VVSG 2005, EAC conducted a thorough, transparent process that included releasing the proposed guidelines for a 90-day period of public comment. During this time, EAC received, catalogued, and reviewed more than 6,000 comments⁶ and held public hearings⁷ in New York City; Pasadena, California; and Denver, Colorado.

Significant work remains to be done to develop comprehensive guidelines and testing methods for assessing voting systems and ensuring that they keep pace with technological advances. EAC expects to receive a draft document from the TGDC in July 2007 that will

completely update the standards of 2002 and significantly revise and expand the requirements in VVSG 2005.

Testing and Certification of Voting Systems and Laboratory Accreditation

To fulfill its responsibility for certifying voting systems, EAC has developed a comprehensive program to provide rigorous, thorough testing of all voting systems against the guidelines in VVSG 2005. The laboratories that test voting systems are certified by EAC under a national program for accrediting voting-system testing laboratories. NIST's National Voluntary Laboratory Accreditation Program⁸ does the initial screening and evaluations of testing laboratories. Once NIST determines that a laboratory is competent to test systems, the NIST director recommends that EAC accredit that laboratory. EAC then makes the determination about accrediting the lab, issues an accreditation certificate, maintains a register of accredited labs, and posts this information on its website. NIST will perform periodic reevaluations to verify that the labs continue to meet the accreditation criteria.

*Much work remains
to be done on guidelines
and voting systems.*

In January 2007, EAC implemented the permanent Voting System Testing and Certification Program,⁹ which includes assessment of quality control, field monitoring, criteria for the decertification of voting systems, and provision of public access to certification information. Under this program, EAC receives requests for manufacturer registration, which must be completed before a manufacturer can submit a system for testing by an EAC-accredited testing laboratory. If EAC technical experts determine that the lab's assessment report is in order and the system conforms to the applicable voting-system guidelines, they recommend that EAC grant the

⁵ HAVA Section 202 directs EAC to adopt voluntary voting-system guidelines that provide specifications and requirements against which voting systems can be tested to determine if they have all of the required functionality, accessibility, and security capabilities. In addition, the guidelines establish evaluation criteria for the national certification of voting systems. A copy of the VVSG 2005 can be found at www.eac.gov.

⁶ To view comments, go to www.eac.gov.

⁷ This requirement in the process of adopting the guidelines appears in HAVA, Section 222A(3). The text is available at www.eac.gov.

⁸ The National Voluntary Laboratory Accreditation Program provides third-party accreditation for testing and calibration laboratories. More information can be found at www.ts.nist.gov.

⁹ A copy of the *Voting System Testing and Certification Program Manual* can be found at www.eac.gov.

system certification. Once certified, a system may bear an EAC certification sticker and may be marketed as having obtained EAC certification.

As the EAC testing and certification program is developed further, it will establish uniform methods for testing voting equipment. Currently, accredited laboratories develop their own methods. Once uniform test methods have been adopted, however, every accredited lab will use the same methods to determine if a voting system conforms to VVSG 2005. The development of uniform test methods for each type and make of voting system will begin in 2007 but is likely to take several years because of the complexity of the task and the length of time required to develop each method.

These hallmark federal programs will shed light on the rigorous processes that ensure accurate and reliable voting systems. Information about EAC-accredited laboratories and systems tested through EAC's programs are available on the EAC website. EAC has developed these programs with the understanding that public confidence is critical to the election process and that public confidence must be based on public knowledge of that process.

The development of uniform test methods is likely to take several years.

State Testing of Voting Systems

Federal and state governments must work together to ensure election integrity. Under HAVA, every state retains responsibility for how federal elections are administered in that state. In addition, states determine the type of voting equipment and the testing and certification protocols they prefer. EAC's voting system guidelines and testing and certification programs were established to give states an opportunity to adopt them voluntarily. If a state decides to adopt them, the federal programs usually become mandatory throughout that state and apply to local jurisdictions.

Most states have elected to require federal certification of their voting systems. However, many states also have their own testing and certification processes, which they continue to perform in addition to the federal processes.

This redundancy ensures the accuracy and reliability of voting systems. Thus some states test voting systems only to their state requirements, while others re-test to the standards required under the federal programs.

Testing protocols at the state and local jurisdiction levels include acceptance testing when a voting system is received from the manufacturer to determine that the system functions properly and has been configured to the specifications in the purchase contract. Acceptance testing is generally rigorous and, ideally, is conducted with the assistance of a third-party technical advisor who understands the technology and is independent of the manufacturer. Acceptance tests should include the functions the equipment will be required to perform in an election. If the equipment does not perform properly, it should be rejected and returned to the manufacturer.

State and local election officials also conduct logic and accuracy testing on voting equipment prior to each election. This testing involves loading the system with an actual ballot that will be used in a pending election and testing to determine that the system accurately records the votes on that ballot. Although logic and accuracy testing should be performed on every piece of voting equipment used in an election, resources do not always permit testing at that level.

Many election jurisdictions rely on the manufacturer or vendors to conduct these tests. However, the election jurisdictions will have greater independence and the public will have greater confidence in the equipment if independent third-party technical advisors are involved. One model for such an arrangement is a cooperative agreement between the Georgia secretary of state and the Election Systems Center at Kennesaw State University.¹⁰

Commitment to detail, continuous improvements in technology, and vigilance in all areas affecting election integrity are necessary to reinforce public confidence in the election process.

Election Management and Administration

Focusing solely on the reliability of voting systems is not enough to ensure accuracy in an election. Accurate, reliable election results require not only thorough testing of the equipment at multiple levels, but also training and adequate resources for election officials

¹⁰The core functions of the Elections System Center at Kennesaw State University include outreach, education, training, consultation, technical support, and ballot building. More information can be found at www.elections.kennesaw.edu.

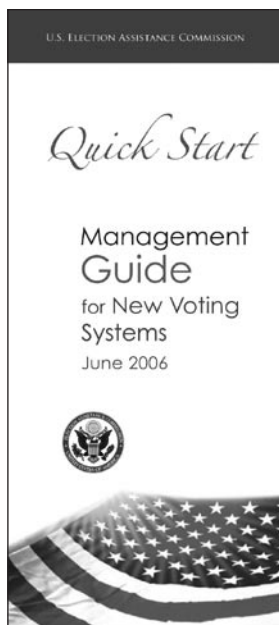


FIGURE 1 *Quick Start Guide for New Voting Systems*. This guide provides a summary of processes and procedures for introducing a new voting system. Topics include receiving and testing equipment; tips for implementation, such as conducting a mock election and developing contingency plans; system programming; and management strategies for election day, including opening the polls, processing voters, and closing the polls.

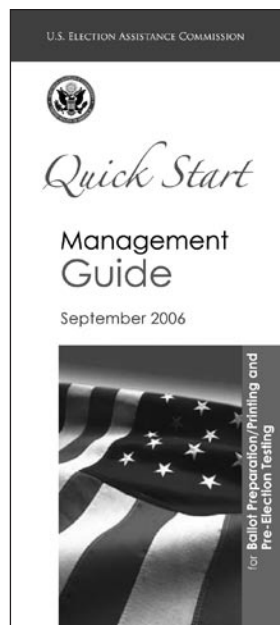


FIGURE 2 *Quick Start Guide for Ballot Preparation/Printing and Pre-Election Testing*. Ballot preparation and logic and accuracy testing are essential to ensuring a smooth election. This guide offers tips for preparing and printing ballots to ensure compatibility with the voting system and pre-election logic and accuracy testing for hardware and software.



FIGURE 3 *Quick Start Guide for Voting System Security*. This guide highlights priority items essential to ensuring the security of electronic voting systems and recommendations for maintaining passwords, physical security, personnel security, and procedures for securing equipment.

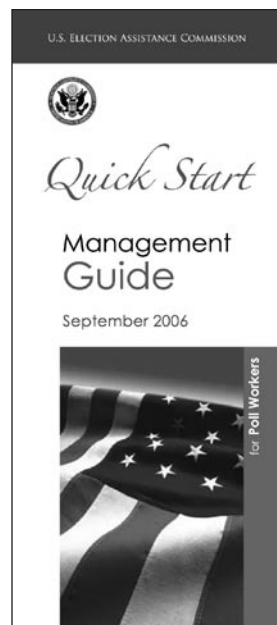


FIGURE 4 *Quick Start Guide for Poll Workers*. This guide provides information to help election managers identify, recruit, train, and assign poll workers who can take responsibility for the care, custody, and use of voting systems on election day.

and poll workers. Federal and state certification of a system cannot replace solid, thorough management procedures for every aspect of election administration at the state and local levels.

Voting System Management Guidelines

In 2005, EAC began work on comprehensive management guidelines to supplement VVSG 2005. The management guidelines, which will be completed in 2007, focus on procedures related to the use of voting equipment and related aspects of election administration.

Four *Quick Start Guides*¹¹ were distributed to election officials prior to the 2006 election to provide some guidance until the comprehensive guidelines are completed. These guides, summaries of chapters in the

management guidelines, cover the introduction of a new voting system (Figure 1), ballot preparation (Figure 2), voting system security (Figure 3), and training for poll workers (Figure 4).

Reviewing Voting System Operation

Proper administration of elections requires reviewing the operation of voting systems before, during, and after an election. Recounts, audits, and parallel testing can help ensure that voting equipment performs properly and calculates votes accurately.

Recounts and Audits

Recounts are a common method of reviewing the performance of voting equipment. Many states require recounts only under certain conditions, such as a close race. Other states mandate recounts of a certain percentage of ballots after every election regardless of the outcome. Some states call these automatic recounts audits. Both audits and recounts are often done manually.

HAVA requires that all voting systems produce a form of paper record that can be audited or recounted.

¹¹ The *Quick Start Guides* can be found at www.eac.gov.

Optical-scan systems use paper ballots, which provide a paper record that can be audited or recounted. DREs are required to produce a paper record that shows every vote that was cast on the voting system. This record is produced in randomized order to avoid association with particular voters and is obtained from the internal memory of the DRE. Some DREs can produce a VVPAT; this is also produced from the computer's internal memory but is generated contemporaneously with voting and prior to the casting of a ballot. Thus the voter can verify that the computer-generated image on the screen is the same as the computer-generated print-out. The quality of the paper used for VVPAT records is important, especially for manual recounts.

Parallel Testing

Parallel testing, a relatively new practice in monitoring the accuracy of an election, is usually conducted during the election. Several voting systems are set up as "sample systems" on which election personnel cast votes during the regularly scheduled election. Some states and local jurisdictions prefer to conduct parallel testing prior to the election. Either way, the process is the same. Known votes are entered onto the DRE system and counted. The system is deemed to be operating properly if the hand count of the ballots matches the computer tally.

Transparency and Accountability

Implementing these extensive and rigorous procedures and standards for the entire spectrum of election

processes is crucial to ensuring that elections are accurate and secure. They also make it possible for an informed electorate to determine accountability for the conduct of an election. Most voters are not familiar with the entire election-administration process; they are not engaged in the "behind the scenes" work and months of planning required to make an election run smoothly. Few voters see ballots being laid out, equipment being programmed; poll workers being trained in election laws, voters rights, and the intricacies of how the voting equipment works; or the election results being tabulated, reported, recounted, and certified.

Nevertheless, the public must be provided—either directly or indirectly via the media—with access to information on all aspects of the process of conducting elections. This openness and transparency encourages voter confidence in the system—and, by extension, in American democracy.

Conclusion

Since 2000, the process of conducting elections in America has been going through a period of transformation with the introduction of new and improved voting systems and implementation of various requirements of HAVA. Commitments to excellence by voting-system manufacturers, commitments to high standards and rigorous testing protocols by federal and state governments, commitments to open, accurate, and accessible elections by public officials, and commitments to voter participation by citizens can ensure that future elections will meet the highest standards of integrity.

The cause(s) of the undervote in the 2006 congressional race in Sarasota County, Florida, are still a mystery.

What Happened in Sarasota County?



David Jefferson is a computer scientist at Lawrence Livermore National Laboratory and chair of the California Secretary of State Voting Systems Technology Assessment and Advisory Board. This article is based on a presentation given on February 8, 2007, at the NAE National Meeting Symposium.

David Jefferson

On November 7, 2006, there was an electoral disaster in Sarasota County, Florida. Almost 18,000 people, about one in seven of the people who voted electronically, left the polls without recording a vote in the congressional race, the hottest race on the ballot. Most observers agree that few of these voters deliberately skipped voting in that race. Instead, they were either misled into not seeing that race or the voting machines somehow failed to record their votes. There is consensus on one point, however. Although Republican Vern Buchanan was certified the winner by only 369 out of more than 238,000 votes and is now representing the 13th Congressional District of Florida (CD13) in the U.S. House of Representatives, if the “missing” votes had been recorded, Democrat Christine Jennings would almost certainly have been elected (Stewart, 2006).

This election illustrates in dramatic fashion not only the complex problems that arise with the use of all-electronic voting systems, but also the deep concerns of computer scientists and security experts about total reliance on software to capture and count votes in public elections. A considerable amount of technical investigation has been done into the circumstances of this election, and many hypotheses have been eliminated. But to date (April 2007), the exact cause(s) are not known with complete certainty—indeed, they may never be known.

CD13 is comprised of four counties (Sarasota, Manatee, Hardee, and Desoto)

and part of a fifth (Charlotte). The district as a whole has leaned Republican in recent years, although the most populous county, Sarasota, where the problem occurred, leans Democratic. There was no incumbent in the 2006 CD13 election, and both candidates for the seat had won very bitter primaries against multiple opponents. For these reasons, and because control of the House of Representatives was considered a toss-up between the two major parties, the race was hotly contested, and the candidates had blanketed the media with massive advertising. The race cost \$13.1 million, including the costs of the primary contests, making it the single most expensive House race in U.S. history (Wallace, 2007).

Statistical Analysis

Sarasota County used iVotronic voting machines built by Election Systems and Software, the largest voting system vendor in the United States. The iVotronic, which has a touch-screen interface (Figure 1), is one of a class of voting machines, paperless, direct-recording electronic devices (DREs), that was widely adopted after the 2000 presidential election. Since then, paperless DREs have been the target of widespread criticism from technical experts, primarily because the vote counts they produce are not verifiable or auditable in any meaningful way.

Table 1 shows certified election returns from Sarasota County for the electronic votes cast in the three top races on the ballot—U.S. senator, U.S. representative, and governor. The table shows just the number of electronic votes for each race and each candidate (including early votes and those cast on election day), along with the number of *undervotes* (i.e., ballots that did not

TABLE 1 Electronic Vote Counts and Undervote Rates for Three Top Races in Sarasota County

	Total Electronic Votes	Electronic Undervote
United States Senator		
Katherine Harris	47,899	
Bill Nelson	68,376	
4 Others plus write-ins	2,092	
<i>Undervotes</i>	1,392	1.2%
U.S. Representative		
Vern Buchanan	47,509	
Christine Jennings	54,439	
<i>Undervotes</i>	17,811	14.9%
Governor & Lieutenant Governor		
Charlie Crist	62,825	
Jim Davis	51,380	
4 others plus write-ins	3,889	
<i>Undervotes</i>	1,665	1.4%
Total of electronic ballots cast	119,759	

show a vote for any candidate in that race). Note that only the returns for Sarasota County are shown. When the other counties in the district are included, the final count shows Buchanan winning by 369 votes.

The key statistic in Table 1 is the percentage of electronic undervotes in the congressional race, shown in the far right column. The undervotes for the senate and gubernatorial races were 1.2 and 1.4 percent, respectively, which is typical for top-of-ballot races nationwide. The undervote in the congressional race was more than 10 times higher—14.9 percent of the electronic votes. The undervote rate, which varied from precinct to precinct, was almost 30 percent in some areas.

In a statistical analysis of the pattern of undervotes in Sarasota County, Professor Charles Stewart III of MIT estimated that the number of undervotes beyond the number expected was between 13,209 and 14,739. He further projected that, if those votes had been successfully cast and counted, Jennings would have won the election “by at least 739 votes, and possibly by as many as 825 votes” (Stewart, 2006). No one, not even Buchanan’s team, has disputed that conclusion, adding drama and political significance to what might otherwise be just a technical puzzle.

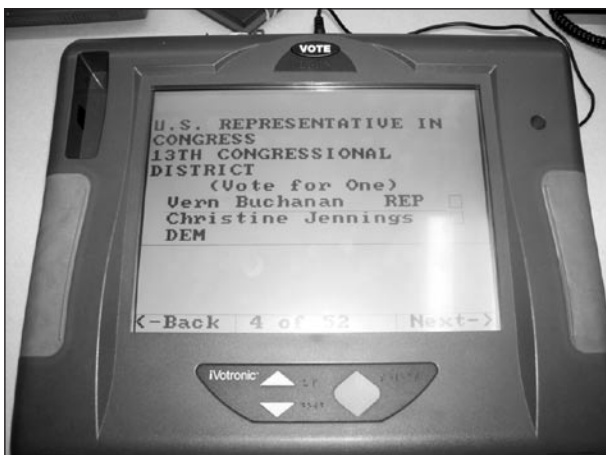


FIGURE 1 The iVotronic voting machine.

What Went Wrong?

Why did the number of electronic voters who did not record a vote in this race exceed expectations by about 18,000? Many hypotheses have been proposed, some of which can be discarded almost immediately. Election officials in Sarasota County initially suggested that most of those voters had deliberately not voted in the CD13 race, perhaps to protest the ugliness of the campaign or because they disliked both candidates. There is strong evidence, however, that this is not what happened.

If voters in general had been “turned off” by the campaigns or the candidates, we would expect that absentee and provisional voters (who voted on paper ballots) would have a similarly high undervote. But among absentee and provisional voters in Sarasota County the undervote rate was about 2.5 percent in the congressional race. The same was true for all voters in the other counties in CD13, who were exposed to the same campaigns. The undervote in those counties in the congressional race was in the normal range, less than 2 percent, nothing like the 14.9 percent in Sarasota County. These numbers strongly suggest that, whatever the problem was, it was specifically related to the votes cast in Sarasota County on the iVotronic machines.

Three primary hypotheses for the cause of the problem have been advanced:

1. *Malicious Code*: The software in the iVotronic machines might have contained logic that was deliberately designed not to record some votes in a way that would benefit Buchanan. (This would constitute election fraud.)
2. *A Software Bug*: The software (or hardware) in the iVotronic machines may have had a subtle bug of some kind that caused some votes to go unrecorded.
3. *Ballot Layout*: The layout of the ballot on the screen was misleading in a way that caused many voters to inadvertently skip the congressional race.

The rest of this paper is devoted to reviewing the evidence for and against each of these hypotheses and to a general discussion of the underlying security issues in electronic voting illustrated by the Sarasota County election.

The Malicious Code Hypothesis

The most unsettling hypothesis is that malicious logic, which caused the machines not to record the missing votes, was somehow injected into the iVotronic code

in Sarasota County. Security experts consider insider attacks in general, and malicious code in particular, a grave danger because of the potential damage of such attacks and the difficulty of detecting them, let alone repairing the damage. In this specific case, however, no evidence of malicious code has been found. In fact, several lines of evidence indicate that malicious code was probably *not* involved.

A malicious code attack designed to produce a large undervote is not very likely, because it would certainly be detected and would thus be less effective than a more direct, less noticeable attack, such as switching votes from one candidate to another. Still, the possibility of malicious code cannot be dismissed without further investigation.

*So far, no evidence of
malicious code has been
found in Sarasota County
voting machines.*

The Florida Department of State conducted a variation of a test protocol known as “parallel testing” first used in California that was designed specifically to detect malicious code in voting systems (FDOS, 2006). The test is based on the idea that the primary problem facing a would-be attacker is to design the attack code to cheat during a real election but avoid detection by conventional functionality testing during federal or state certifications of the voting system or during the immediate pre- and post-election “logic and accuracy” testing. Parallel testing involves putting a random sample of voting machines through a mock election that is so much like a real election, even down to the statistical pattern and timing of the votes cast, that the potentially malicious software has no possible cue it is undergoing a test. Thus the software is tempted to cheat as it would in a real election. A very large number of variables have to be carefully controlled to avoid giving the potentially malicious software a clue that it is being tested. But if, at the end of the test, the vote totals from the machines match the mock votes that were cast on them, simple malicious code attacks can probably be ruled out.

The results of parallel testing by the Florida Department of State were clear. No unexplained anomalies were found, and hence no evidence of malicious code was discovered, either in a sample of the machines used in the election (and kept under seal by court order) or in a sample of identical machines prepared for testing as they would have been for the real election. Although the test protocol has been criticized for some imperfections (Dill and Wallach, 2007), the test as conducted does set a lower bound on the sophistication of any malicious code that might have been responsible for the undervote problem.

Voting machines have much more complex software than one might imagine.

The Software Bug Hypothesis

Voting machines have much more complex software than one might imagine given the apparent simplicity of their vote-collecting function. The iVotronic probably has on the order of 100,000 lines of code. Thus it is quite possible that a subtle program bug might have contributed to the undervote problem. For example, a bug might have caused the congressional race not to be presented on the screen to some voters; or it might have failed to notify voters on the summary screen that they had not voted in that race; or it may simply have failed to record some votes. Any reasonable hypothesis must, of course, be consistent with the facts observed in the election and must explain, for example, why only the congressional race appeared to be affected.

To investigate the possibility that software errors may have caused the problem, the Florida Department of State engaged the Security and Assurance in Information Technology (SAIT) Laboratory at Florida State University in Tallahassee. The lead investigator, Alec Yasinsac, a professor of computer science, assembled a panel of nationally prominent software, security, and election experts to study the hardware, software, audit logs, and other data of the CD13 race. On February 23, 2007, the panel issued a 67-page technical report in which numerous flaws, bugs, and vulnerabilities found in the software were discussed. The key summary paragraph of the report follows (Yasinsac et al., 2007):

The team's unanimous opinion is that the iVotronic firmware, including faults that we identified, did not cause or contribute to the CD13 undervote. We base this opinion on hundreds of hours of manual code review complemented by automated static analysis and extensive study of the problem symptoms and the execution environment. We traced program execution from terminal initialization, through voter selection, to ballot image creation, to ballot image collection. We also investigated the possibility of asynchronous system faults not associated with any particular phase of voting. Our investigation provided no evidence that an iVotronic software malfunction caused or contributed to the CD13 undervote. [Emphasis in the original]

The panel acknowledges, of course, that no study could absolutely rule out the possibility that a very subtle bug had escaped notice. But extraordinary pains had been taken to look for all conceivable problems in the source code, and none had been found. The conclusion also indicates that no evidence of malicious code was found, which is consistent with the finding from the parallel testing.

Since the publication of the SAIT report, two other prominent computer scientists and election experts, Dan Wallach and David Dill, have published a paper detailing a number of limitations of the SAIT study and the parallel testing conducted by the Florida Department of State (Dill and Wallach, 2007). They call for further investigation to address a number of concerns, such as limitations in the parallel testing protocol, verification that the binary code actually loaded on the iVotronic machines used in the election was consistent with the source code examined by the SAIT team, and further examination of touch-screen calibration procedures and of a previously known bug in the “smoothing filter” of the iVotronic touch-screen driver. (The smoothing filter filters out anomalous touch-screen inputs, such as finger bounces and multi-finger touches.)

The Ballot Layout Hypothesis

The layout of the ballot, on paper or on screen, can greatly influence voter behavior. Candidates are well aware that whoever is listed first in a race has a measurable advantage. The format of the infamous “butterfly ballot” in Palm Beach County, Florida, in the 2000 election led many voters who intended to vote for Al Gore to mistakenly vote for Pat Buchanan. Various almost

unknown candidates in the gubernatorial recall election in California in 2003 got an unexpectedly large number of votes because their names on the multi-column ballot happened to be next to that of Arnold Schwarzenegger.

In hindsight, the layout of the ballot in the Sarasota County election looks especially problematic. Figure 2 shows the first two pages, with the U.S. Senate race on the first page and the congressional and gubernatorial races on the second. To understand why this layout might be confusing, we must remember that even people who never miss an election only vote about once a year for about 10 minutes. Thus, from one election to the next, voters do not generally remember the layout and interaction conventions in a voting machine; they must relearn them each time.

Furthermore, there is likely to be a certain amount of cognitive interference from point-and-click interfaces they may be familiar with. On the iVotronic screen, there are no menus, icons, windows, or scrolling—just active areas that are not even surrounded by strong borders. It is not even visually apparent whether the voter is supposed to touch the candidate’s name on the screen or touch the box to the right of the candidate’s name.

The voter also has to visually “parse” the screen to find the races and candidates. What visual cues

OFFICIAL GENERAL ELECTION BALLOT

SARASOTA COUNTY, FLORIDA

NOVEMBER 7, 2006

CONGRESSIONAL

UNITED STATES SENATOR

(Vote for One)

Katherine Harris	REP	☐
Bill Nelson	DEM	☐
Floyd Ray Frazier	NPA	☐
Belinda Noah	NPA	☐
Brian Moore	NPA	☐
Roy Tanner	NPA	☐
Write-In		☐

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Public Count: 0

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FIGURE 2a First page of the Sarasota County CD13 ballot.

U.S. REPRESENTATIVE IN CONGRESS

13TH CONGRESSIONAL DISTRICT

(Vote for One)

Vern Buchanan	REP	☐
Christine Jennings	DEM	☐

STATE

GOVERNOR AND LIEUTENANT GOVERNOR

(Vote for One)

Charlie Crist	REP	☐
Jeff Kottkamp		
Jim Davis	DEM	☐
Daryl L. Jones		
Max Linn	REP	☐
Tom Macklin		
Richard Paul Dembinsky	NPA	☐
Dr. Joe Smith		
John Wayne Smith	NPA	☐
James J. Kearney		
Karl C.C. Behm	NPA	☐
Carol Castagnero		
Write-In		☐

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Public Count: 0

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FIGURE 2b Second page of the Sarasota County CD13 ballot.

indicate that one race has ended and another has begun? A page (screen) boundary? A big, background-colored heading? A thin horizontal line? Are races split over pages? After a few pages voters may begin to

intuit the answers through experience. But in the first few races, before the patterns have been established, some voters may make mistakes.

Based on the first two pages of the ballot shown in Figure 2, many observers argue that the congressional race on page two appears, at first glance, not as a separate race at all, but as a continuation of the U.S. Senate race on the previous page. The congressional race is sandwiched between two major statewide races, both of which are introduced by large, colored headings. But the congressional race does not have such a heading. With careful reading, the ballot is clear. But voters nervously trying to learn the interface, or voters who are more visually than textually oriented, might not take the time to process all of the text and, therefore, might miss voting in the congressional race.

How can we determine for certain whether the ballot layout hypothesis is the explanation for the undervote? Unfortunately, there is no direct, controlled way to test the hypothesis. One could try conducting a number of mock elections with the same races laid out on the ballot in different ways using test voters demographically similar to the ones in Sarasota County and then compare the undervote rates. But if the test voters were from Sarasota County, they would probably guess what was being tested, which would completely undermine the experiment. If one controlled for that factor and chose test voters who were unfamiliar with the Sarasota County candidates and the outcome of the real election, the degree of motivation among Sarasota voters to vote in the CD13 race as a result of being exposed to the heated campaigns would not be replicated.

Ballot layout now seems the most likely explanation for the undervote.

In the absence of experimental verification of the ballot layout hypothesis, we are left in an unsatisfying situation. Although ballot layout now seems to be the most likely explanation for the CD13 undervote, this conclusion is based more on arguments of plausibility and the elimination of other hypotheses than on direct evidence in its favor.

Conclusion: What Should Be Done?

Some of the serious technical problems in all-electronic voting systems are illustrated in the Florida CD13 election in Sarasota County. In the Sarasota County case, an enormous amount of time and technical expertise have been spent to determine that software errors were (probably) not responsible for the anomalous outcome. Clearly, an election system that requires this much work to resolve a disputed election is unsustainable. To avoid these problems in the future, voting systems must be *transparent*, and they must produce results that are *verifiable*, so that even in a close election, the results are indisputable and even the losers agree with their validity.

At least two technical conclusions can be drawn from the CD13 experience. First, much more attention must be paid to the human-computer interface of voting machines. Representatives of both parties had approved the ballot layout used in the CD13 election, and yet the problem occurred. As yet no systematic body of experience, conventions, or standards have been developed to ensure reliable human interaction with computerized voting machine interfaces. (This is also an especially serious problem with audio interfaces for the disabled.) This is an area ripe for research.

Second, and of deeper concern, is the intrinsic difficulty of building software that is verifiably correct, reliable, and secure for such profoundly important missions as public elections. We clearly need voting systems and procedures that can produce verifiably accurate election results *even in the presence of software errors or malicious code*.

One recent explication of this idea, the notion of “software independence,” is under consideration by the Technical Guidelines Development Committee, the panel that recommends technical standards for voting to the Election Assistance Commission. A voting system is software-independent “if an undetected change or error in its software cannot cause an undetectable change or error in an election outcome” (Rivest and Wack, 2006).

A software-independent system would not, in and of itself, have resolved the mystery of the CD13 election, which centers on votes that were not recorded. But it could prevent or resolve disputes in elections in which votes are alleged to be incorrectly recorded or counted.

Even with voting systems designed on the principle of software independence, however, we cannot rely solely on software to determine the outcome of an election.

There must be an alternative, end-to-end data path, independent of software, such as a voter-verified paper audit trail, that can be used as a check on the validity of the electronic results.

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Our system of self-government works only if we believe it does.

Legal Issues, Policy Issues, and the Future of Democracy



Rush Holt is the U.S. Representative from the 12th District of New Jersey. This article is based on a presentation to the NAE Symposium, The Impact of Technology on Voting and Elections in the 21st Century.

Rush Holt

The presidential election of 2000 is still fresh in most of our minds, and—no matter whom we voted for—everyone agrees that the post-election spectacle and controversy left a black mark on democracy in the United States. Congress responded immediately, and in 2002, passed the Help America Vote Act (HAVA) shortly before the very next general election. HAVA was landmark legislation that authorized almost \$4 billion in funding to states to enable them to upgrade their voting systems and improve the administration of elections. Yet more controversy followed.

The presidential election in 2004 was subject to an official challenge in the House and Senate that hadn't been seen in more than 100 years.¹ When Congress reconvened in January 2005, one senator and one representative issued a joint challenge to the certificate of the electoral votes of the state of Ohio. A lengthy debate ensued before the matter was put to a vote and the certificate was approved.² Although the certificate was ultimately accepted, the first general election following the enactment of HAVA had delivered another blow to the integrity of the electoral system.

¹ Prior to the 2004 general election, the last time the certificate of all of the electoral votes of any state (and in that case, a number of states) was challenged in Congress was in 1877, in the Hayes-Tilden election of 1876. Congressional Research Service Report for Congress, *Electoral Vote Counts in Congress: Survey of Certain Congressional Practices*, December 13, 2000.

² See 151 Cong. Rec. 2 (2005), for the debate on January 6, 2005, concerning the challenge to the certificate of the electoral vote of the State of Ohio from the 2004 General Election.

In 2006, the first general election after HAVA had been fully implemented, at least one contest resulted in substantial, unresolved controversy. In Florida's 13th Congressional District, a winner was declared by a margin of 369 votes, but the votes of 18,000 voters for the congressional race were unaccounted for. The under-vote rate on the electronic voting machines in one of the five counties in that district—Sarasota County—was an astonishing 14.9 percent, as compared to a rate of 2.5 percent for absentee ballots in the same county and 2.2 percent to 2.5 percent in the surrounding four counties in the same congressional district.³ Therefore, when the 110th Congress convened, I rose when the new members were about to be sworn in, to enter a parliamentary inquiry into the record to ensure that the seating of the new member from Florida's 13th Congressional District would not prejudice the pending legal action to uncover the truth about those 18,000 votes and what those voters intended.⁴

Almost six months later, the mystery surrounding the missing electronic votes is no closer to being solved. In fact, it is impossible to solve it because there are no voter-verified paper ballots to enable us to check the accuracy of the electronic tally.

The Greatest Invention

I often visit schools, and when I'm with students who are interested in science and technology, I ask them what they consider the greatest invention in human history. Knowing that I am a physicist by background, they often come up with technological answers, such as the microchip, the iPod, or the wheel. But in fact, I think the greatest invention in human history is our system of self-government, which is constantly growing, subject to self-criticism, and allows for self-correction. Indeed, it is designed specifically to be self-correcting.

Free and fair elections are the very cornerstone of democracy, but democracy only works if we believe it does. Today, in the age of computer-assisted elections, if we have questions about the election results, the voting-system manufacturers simply assure us that the software counts votes accurately and we have nothing to worry about. But this leaves voters feeling that neither they nor their election officials are in control of the democratic process.

If a voter casts a vote on an electronic voting machine, no election official, computer scientist, or voting-system manufacturer can reconstruct what that voter intended. The voter votes in secret, so only the voter can verify that his or her intention has been recorded correctly. That is why an independent paper copy of each vote—verified by the voter and preserved for use in recounts and audits—must be required for every vote that is cast.

Votes are, in a sense, the “currency” of democracy—the mechanism by which we preserve and maintain the vibrant life of the greatest invention, our democracy. Thus votes are inherently valuable, and anything valuable must be independently auditable and regularly audited.

Our system of self-government is designed to be self-correcting.

Disappearing Evidence of Voter Intent

Probably the most memorable image of the 2000 general election is of election officials in Florida holding punch-card ballots up to the light and squinting in an effort to discern whether a so-called “hanging chad” (the punched spot on the card) was sufficiently detached from the punch card to count as the voter's intended vote. The image was replayed over and over on television screens across America, as if to burn into our collective consciousness the notion that ambiguous evidence of voter intent is the enemy of the democratic process.

As Congress took up the issue, a consensus was reached that punch-card machines were unreliable and should be replaced. Arguments were also made that paper-ballot-based voting systems were inaccessible to voters with disabilities. The result of this double-pronged argument against paper ballots was that HAVA funded the replacement of punch-card and other voting machines deemed to be obsolete and unreliable and explicitly recommended the use of “direct recording electronic” voting machines (DREs) to meet the disability-access requirements of the bill.⁵

³ Complaint at 2 and 7, *Jennings v. Elections Canvassing Commission of the State of Florida et al.*, No. 2006 CA 2973 (2nd Cir. Nov. 20, 2006).

⁴ 153 Cong. Rec. 1, H5 (2007).

⁵ Section 301(a)(3)(B) of HAVA (42 U.S.C. 15481(a)(3)(B)) provides that jurisdiction shall meet the accessibility requirements of the bill “through the use of at least one direct recording electronic voting system or other voting system equipped for individuals with disabilities at each polling place.”

On the one hand, this was simply not necessary. On the other hand, it created a substantial security and integrity risk to the electoral system. Although DREs may be accessible to voters with disabilities (if fully outfitted), they record all voting data internally where it cannot be inspected or independently verified by the voter. In contrast, ballot-marking devices, which may also be accessible, produce an external paper ballot that the voter can verify. Achieving accessibility did not require removing paper ballots from the voting process.

In the end, HAVA encouraged the purchase and use of voting systems that were not necessarily more accessible than ballot-marking devices and that had a fatal flaw—they left no direct, permanent evidence of voter intent verified by the voters. In other words, there was nothing that could be used to conduct a meaningful recount after an election.

Unless we require voter-verified paper ballots, we might as well outlaw recounts.

“Lack of Evidence” vs “Voter Intent”

Consider again the race in Florida’s 13th Congressional District in this context. How can the losing candidate prove that the reported result did not reflect the intent of the voters? (The losing party must be convinced of the results; the winner always accepts and believes them.) The votes that show on the screen surface evaporate the minute the voter hits the “Cast Vote” button, and there is left behind no tangible copy of anything verified by the voters. The electronic record could be erroneous, either by innocent error or malicious hacking. And no election official, computer scientist, or voting-system manufacturer can definitively reconstruct what the voters intended.

In Florida, “lack of evidence” is the winner and “intent of the voters” is the loser. Even though neither the loser nor the winner of an election has any evidence to prove the intent of those 18,000 voters, the “lack of evidence” tips the scale, by default, in favor of the declared winner. Thus the intent of the voters, because it cannot be proven to support one candidate or the other, is irrelevant to the end result.

The Future of Recounts

We simply cannot go forward into another general election without addressing this problem head on. Fifteen states do not use paper-ballot-based voting.⁶ That means that these 15 states are in the same position as Florida’s 13th Congressional District. Unless we require voter-verified paper ballots, we may as well outlaw recounts. The outcome of the 2008 presidential election may hang in the balance in one of those states.

Being a physicist, I consider myself a bit of a techie. Thus, I find it ironic, if not downright humorous, that some have attributed my call for voter-verified paper ballots to what they perceive as technophobia on my part. Nothing could be further from the truth. In fact, computer scientists from the most prestigious universities in America—the very people who understand computers and computer security better than anyone else—are the ones urging Congress to require voter-verified paper ballots as an independent auditing mechanism to ensure accurate tallies that voters can believe in.

Computer scientists have recognized that computer-generated recounts are more like reruns, repeats, or replays than actual recounts. A recount on an electronic voting system is simply a replay of the same answer the computer gave the first time. If the software translation of the voting data entered into the machine was wrong the first time, the “recount” will never reveal that.

Less Reliance on Technology Is More

Shortly after HAVA was enacted, and before most jurisdictions had an opportunity to spend any of their equipment replacement funds, I introduced legislation to address this crisis. That legislation, the Voter Confidence and Increased Accessibility Act (HR 811 in the current, 110th Congress) includes the following provisions:

- Requires a voter-verified, durable paper ballot for every vote cast to serve as the vote of record.
- Requires routine, random audits in a specified percentage of precincts in every federal election and a higher percentage of precincts when races are extremely close.
- Bans the use of wireless devices, undisclosed software, and Internet connections to machines upon which votes are cast.
- Preserves and enhances the accessibility requirements

⁶ <http://verifiedvoting.org> as updated April 6, 2007.

of HAVA and funds the development of new, accessible, ballot-marking and ballot-reading technologies.

- Authorizes hundreds of millions of dollars to defray the costs of implementing the paper ballot and accessible-verification requirements of the bill.

This legislation, which is likely to come to a vote in the House of Representatives as this article goes to press, will strike an appropriate balance between the accessibility and the auditability of voting in our electoral system, making a much-needed adjustment to HAVA.

Restoring Trust in Government

When I ran for Congress eight years ago, restoring the trust of the people in their government was one of my principal motivations. The rampant cynicism about government that seems to infuse political commentary almost daily concerned me greatly, although I did not focus my efforts on the specific mechanism of our democracy until the 2000 elections.

After the enactment of HAVA, public discussion increased about the dangers of the push towards using paperless electronic voting machines. It became apparent to me, perhaps because of my technical background, that we should not rely on the word of

software engineers working for private voting-system manufacturers to tell us who wins an election.

After my legislation was introduced and people became aware that the voting machines purchased under HAVA did not have to use or produce voter-verified paper ballots, groups demanding integrity in electronic voting sprang up in virtually every state in the nation to support the legislation. As far as these groups were concerned, HAVA may have made it easier for some Americans to vote, but it did virtually nothing to ensure that all of those votes would be counted as cast.

Restoring the trust of the public in the machinery by which they exercise their right to govern themselves was a critical objective in my running for Congress in the first place. Today, after a four-year-long effort, and thanks largely to the attention of the voting public to this issue and their fierce passion for making sure that all voters can be confident that their votes have been counted as they intended, the legislation is now perceived as a mainstream idea and is on the verge of passing. It may always seem odd that a physicist would be the staunch proponent of a low-technology solution. But as so many computer scientists have shown, simpler can sometimes be better.

For the good of the country, we need voting technologies produced and operated according to the best methods.

Voter Assurance



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Eugene H. Spafford

Voting with assurance seems to be an obvious, simple concept. A registered voter should be able to cast his or her ballot with the confidence that the vote will be counted as cast. Traditionally, paper ballots have seemed like a simple, comfortable voting solution. However, paper ballots in some forms can be easily manipulated, result in ambiguous interpretations (e.g., “hanging chads”), are sometimes error-prone, and do not provide a quick tally. In our technology-saturated society, we want results right away, and it would seem that technology could speed up vote counting and make it more accurate. Computers are being integrated into every aspect of our lives, so why can’t they work for voting, too? If we can use computers to control airplanes, factories, and ATM machines, we should certainly be able to use them in voting!

For a number of years, computerized voting machines have been used in various jurisdictions around the United States and around the world. As a result of the Help America Vote Act (HAVA), which was passed in 2002, thousands of new machines were purchased and deployed around the United States to replace paper-based and lever machines. The vendors of these machines repeatedly stated that they were accurate and secure, and election officials echoed their claims. Yet there have been repeated incidents of surprising vote totals, interface glitches, and unexplained behavior in some machines. As a result, voter confidence seems to be waning.

“Assurance” can be defined as a positive declaration intended to give confidence. In this context, it is a promise to voters that their votes will be counted accurately and fairly, and thus will figure in the overall outcome. Assurance means providing certainty about something, in this case, the certainty that each vote matters. This is essential to our republic, which depends on citizens voting to express collective choices.

We want people to vote. We want them to participate in our democracy and to voice their opinions. Thus we want them to have confidence in the honesty of the process, and we want them to have justified confidence that their votes will actually be counted.

A Lack of Confidence

A number of indicators show that some of the voting population does not have confidence, or is losing confidence, in the technologies that have been deployed as a result of HAVA. A study by the Pew Internet Trust found that groups of minority voters in the South do not trust the technology and believe it has been manipulated, or could be manipulated, so that their votes would not count. They expressed a significantly higher rate of distrust in computerized voting technology than the general voting population (Kohut, 2006).

A study by the University of Maryland Center for American Politics and Citizenship found that one of every 10 voters leaving the polling place did not have confidence in the technology they had just used—direct-recording electronic touch-screen voting machines (DREs) (UMd, 2002). Ten percent of voters, a significant number, were not certain their votes would be counted accurately. Add to this another large group that may not have bothered to vote because they also distrusted DREs.

Some have speculated that the significant increase in absentee balloting in recent years is at least partly attributable to voter distrust in electronic voting machines. For example, in California, 43 percent of the electorate cast their votes in the most recent election by absentee paper ballots, which may have reflected a lack of faith in electronic voting machines (Elias, 2007). These machines, which have been deployed throughout California, did have some problems, such as miscounts and lost votes, and public debate has arisen about whether certain machines were reliable and about problems with the systems.

Other states have also noticed an increase in the number of absentee ballots. Some computer scientists and voting advocates have stated publicly that voters

should use absentee ballots to ensure that their votes are counted if their local precincts use DRE machines without paper audit trails (note, that mail-in ballots may be even more susceptible to coercion and fraud). Coupled with voter unease, this may explain some of the increase in absentee balloting.

Many professionals working in the area of information security and reliability question some of the assumptions about voting technology. They have also expressed considerable doubts about pronouncements by a few people who claim to be experts in this area, particularly about how IT systems can be compromised, where failures can occur, and how such failures occur. Rather than reassuring real experts, these statements raise concerns because they are often simplistic or do not take into account known threat models.

Even some voting machine vendors admit that there is growing mistrust and, perhaps, for good reason. Dennis Medura, CEO of Accupoll, a now-bankrupt voting machine manufacturer, made the following statement about voting system software: “I do not feel that any of the vendors has a system that voters can trust” (Greene, 2006). He went on to say that vendors have misrepresented the robustness, stability, and security of their systems. This has long been suspected by many who have investigated these systems and, in some cases, had hands-on experience with the equipment. These experts can testify that the software and the hardware are not as well protected as vendors suggest.

*Our republic depends on
citizens voting to express
collective choices.*

Seeking Assurance

How do we go about instilling confidence that a system works the way it is supposed to? Absolute assurance, by its very nature, can never be achieved because we cannot meet every requirement of every individual. At the very least, some otherwise rational individuals are deeply suspicious, and meeting the conditions to satisfy them would be cost-prohibitive.

In addition, voters have many different requirements. Consider the requirements for ensuring access

for voters with visual and hearing disabilities, limited motor skills and cognitive impairments, and for people unable to travel to the polls. Each of these groups needs different system interfaces that have dramatically different security and reliability issues.

Even more challenging, complete assurance means more than providing security and eliminating flaws. It requires that voters be able to understand the security properties and failure modes of a system well enough to have “observed confidence” that their votes will be counted. But because voters have varied backgrounds, some may not be able to judge the overall security or reliability of a complex software system.

The stakes in an election matter at almost every level.

Sources of Trust

One way to convince ourselves that something works is to examine and test it. Before we buy something, we examine it (or an exemplar) or try it in actual operation, look at it carefully, and subject it to tests to assure ourselves it will perform as expected. However, most people do not have the expertise, time, or resources to perform exhaustive tests on all aspects of every purchase.

An alternative is to find a trusted source that can verify and vouch for the results of testing. For example, we trust the judgments of Underwriters Laboratories because they publish their standards and we are familiar with their long history of certifying items. We may also trust governmental entities because of their level of funding and their presumed sense of responsibility to the public good. When it comes to voting, some people prefer to put their trust in local authorities, such as county supervisors, but most people recognize that federal organizations have more resources than most local organizations. Thus the federal government has established organizations, including the Federal Elections Commission (FEC)¹ and the Elections Assistance Commission (EAC),² to ensure election integrity.

Not everyone trusts government entities, however. For some people, the involvement of government

actually increases their distrust. To add to the problem, government agencies—especially those involved with any form of security—tend to keep their methods and operations confidential, which can exacerbate mistrust. Experience has shown that the more transparent and careful an organization is—whether governmental or not—the more likely people are to have confidence in its results.

But who can reassure us that our trust in an external organization is well placed? We often trust organizations because they are bound by law, such as laws against fraud. Then who can we trust to enforce those laws? The law enforcement agencies and the courts. Why should we trust them? And so on.

Eventually we reach a point at which we must place our trust in some entity to provide a reasonable presumption of accuracy, assurance, transparency, and correctness and hope that those presumptions are well founded. This is approximately the same problem as putting our trust in a computing system. At some point we must trust components without formal assurances (Thompson, 1984).

Concurrently, we must balance assurances against risks. What are we likely to lose if our trust is misplaced? I am more willing to trust someone’s recommendation if it is for an item that has little consequence to me if it fails. If someone guarantees that I will get my money back or receive a replacement item if something goes wrong, I may be more likely to trust a product based on otherwise weak assurances.

In elections, however, the stakes are often extremely high, so I am less likely to extend my trust. There is no simple recourse for elections. We cannot “get an election back.” We do not get a “do over.” The potential loss is significant, although not everyone realizes the extent of the risks. The stakes in elections matter at almost every level.

Transparency to Individuals

Very few people know what to look for in assessing the security of a voting system or understand how to look for signs of covert tampering. Very, very few people understand how to examine source codes to determine if something has been embedded or has previously been embedded and has now deleted itself. We know from experience with computer viruses that software can do damage and then delete itself so it is no longer visible (Thompson, 1984). These viruses are extremely difficult to detect.

¹ <http://www.fec.gov/>.

² <http://www.eac.gov>.

Most vendors of voting machines do not expose their system implementation or designs to outside scrutiny. Instead, they hide them behind trade-secret protections and become belligerent if anyone tries to examine them. This makes it difficult, if not impossible, for an informed individual who understands the risks to gain self-assurance by looking at the code.

The procedures used in voting are often not fully transparent. They may be described, but they are not transparent in the sense that individual voters can verify every step. For example, in many jurisdictions voting machines are taken home overnight by poll workers and thus are not under continual observation by election judges. These machines may be sealed shut with tamper-evident tape, but tamper-evident tape is not completely tamper proof. Furthermore, systems that have screws or other common fasteners that can be removed are not tamper proof; nor are systems that have any method of altering the software. Thus in some jurisdictions the procedures are not fully transparent and cannot be audited by individual voters.

People's experience may also lead them to false conclusions. Human beings have a tendency to believe that if something has not happened yet or has not been observed, then it is less likely to occur in the future. For example, we may reason: "I have not died yet, so maybe I am never going to die." Clearly this is fallacious, but generalizing prior personal experience often leads to false conclusions. Not understanding how to balance risk against prior behavior often leads people to act in risky ways, such as smoking, gambling, or driving without wearing a seat belt.

False conclusions can lead to an intuitively appealing inertia with regard to voting systems. People may believe that, because no incidents of catastrophic failure or fraud have been discovered or publicized, they are less likely to occur in the future. That is not the case, however. Not only is failure, such as a type of event not based on prior experience, likely, but it is also possible that fraud may have occurred but was never noticed (or proven).

Can We Trust Vendors?

If we cannot depend on our own evaluations as individual voters, can we trust the vendors? Experience has shown that trusting vendors is not a good idea. They not only try to hide their processes and their code so that it cannot be independently checked, but also have a vested interest in portraying their systems as infallible.

We have no sound basis for trusting them to assure us about their products.

Local election authorities have placed great emphasis on third parties, such as independent laboratories. However, those laboratories have historically been funded by voting machine vendors and thus may have conflicts of interest. So we cannot be sure that they are truly independent.

In addition, testing labs that have been used by voting machine vendors do not publish their procedures, disclose their test sets, or otherwise inform the public about the rigor of their tests. Their prior results have not been published, so the public cannot know when they tested the machines, whether or not the machines passed, what the tests were, and what the results were. Those details are shared only with the voting machine vendors who pay for the testing of their equipment.

Based on what we know, tests by these labs appear to be woefully incomplete. For example, the underlying operating system is assumed to be correct and is not tested. Thus, machines that run voting code on a Windows operating system have a significant gap in system assessment where it is commonly known that vulnerabilities (discovered and yet to be discovered) exist.

We have no sound basis for trusting vendors' assurances about their products.

Many companies that manufacture voting machines hire questionable employees and use questionable practices (Drew, 2007), and faults have been found in certified systems (Wagner et al., 2006). In at least one case, a vendor hired a known felon to work on its products. Some vendors are also alleged to have hired individuals who are not U.S. citizens and may not be fully trustworthy or may be easily influenced.

The de facto certification framework for the software security industry is the Common Criteria,³ although its efficacy and value are open to debate. To my knowledge, none of the voting machine vendors has had any of their products certified under the Common Criteria,

³ Information available at <http://www.commoncriteriaportal.org/> and elsewhere on the Internet.

and certainly not to one of the higher assurance levels. Nor has any of them been certified under ISO standards for security practices or for any other good practices established for developing software. Thus any comprehensive test regime must start with basic examinations, because no standard of good practice can be assumed.

Verification of Voting Systems

To maximize voter assurance, we must consider several factors. First, we must carefully specify what the equipment should do and the procedures for its use. It is hard to believe that this is not done routinely, but it is not. In addition, we should use best methods in the development of voting systems. Many “best practices” have been established by industry, such as the Capability Maturity Model,⁴ the ISO standards #9000⁵ and 17799, and the previously mentioned Common Criteria, any of which could be used by voting machine vendors. We should also have open review of the code and testing of voting machines so that external reviewers can examine them for shortfalls and flaws.

*We should have open review
of the code and testing of
voting machines.*

Voter Verification

Voter verification is a simple, yet reasonably new concept. The familiar voting experience is to indicate and cast a ballot, then leave the polling place confident that the vote is counted. However, with new voting technology, such as electronic touch screens, we need voter-verified mechanisms that the majority of voters can use. By verifying that a machine has correctly recorded the vote as cast, we gain confidence in the overall results. Independent verification by the electorate, combined with other checks and safeguards already in place, would make everyone feel more confident that the system is working correctly.

It is not necessary that every single voter verify his or her vote. It is only necessary that a random sample

of voters verify their votes to ensure that the machines behave correctly and that errors or fraud are detected on a machine-by-machine basis. Having a simple enough verification mechanism in place that any voter can understand and use makes every voter an election judge and a tester of system assurance. It also helps ensure that the voters who verify their ballots have not been pre-selected. This is one way of randomizing verification.

One very simple voter-verification method is using an optical scanning machine. This scheme, known as a voter-verified paper audit trail (VVPAT), can be accomplished in several ways. For example, a computerized ballot-marking system can be used to create the initial ballot. This system presents the choices in a variety of user-accessible languages or formats, and the interface helps prevent errors, such as a voter failing to cast a vote in each race. It can also present alternate interfaces to accommodate users with disabilities.

Upon completion of voting, the system prints a ballot for optical scanning. Once the voter has verified that the scan matches the ballot, he or she inserts the marked ballot into a scanning machine at the precinct to record the vote. With this system, the user can verify his or her vote and still enjoy the convenience of computerized voting when marking the ballot and tallying all of the votes in the precinct.

To double check that the tally is correct, a random audit must be performed after the polls are closed. This involves performing a manual recount of paper ballots from a set of randomly selected machines or precincts. These counts are then compared against the electronic versions to ensure that there are no significant discrepancies. This type of audit should be done as a matter of course under the careful oversight of the EAC and state and local boards.

The paper and electronic combination can be used with different technologies that have different failure modes. Tampering with one form of ballot cannot easily be replicated in the other, especially with election judges present and random audits and voter self-verification. The paper component is easily understandable by almost every voter, and the system can be implemented with great transparency.

Software Security

We do not yet know how to solve the problem of producing secure, 100 percent correct software for use in voting machines. Figures collected by the US-CERT

⁴ <http://www.sei.cmu.edu/cmmi/>.

⁵ <http://www.iso.org/iso/en/iso9000-14000/index.html>.

show that more than 8,000 security vulnerabilities alone were reported in commonly used software in 2006, a time when vendors were trying diligently to keep from introducing new problems into their products. Flaws of any kind are a danger in voting. Votes that are lost or altered by an unexpected failure are as lost as votes corrupted by fraud, and flaws in general are more common than security-specific problems.

In the last few years, Microsoft alone has reportedly spent tens of millions of dollars to retrain its personnel and build new tools to try to eliminate flaws in its software. Despite these efforts, we continue to see reports of new, serious flaws in Microsoft products. Why should we expect voting machine software to be different? In fact, it is not. Unfortunately, it is not even produced with the same care as some software games and word processing software.

Moreover, there are theoretical limits to software assurance as a process. Many believe it is easy, or at least straightforward, to examine software systems to detect flaws. Quite the contrary! Those of us who work in security and software testing know that there is no way to guarantee that software does not have hidden flaws. And, as government agencies use more and more software produced outside the United States, this is becoming a major national security issue, not only related to voting equipment.

Despite many, many decades of effort and funding, our national agencies and research labs have not been able to develop systems that can detect whether or not there is hidden functionality in selected code. And despite decades of effort by industry and academia, we still do not know how to produce large, error-free software artifacts. Thus it seems likely that our shortcomings in assurance methodologies will continue to impose limits on how well we can assure software in voting systems.

Clearly, voting systems are far too important to operate on faulty software, or even on systems that are not designed for high assurance. Because of the necessarily distributed nature of election management, we must find a way to provide local election officials with credible information about voting system security before they purchase and operate new systems. Recent efforts by the EAC (and FEC before them) to implement testing and certification procedures for voting systems have been well intentioned, but so far ineffective. In the meantime, VVPAT voting methods would go a long way toward restoring voter confidence.

Conclusion

It is almost inevitable that some people will be unhappy and believe that an election went the wrong way. Usually these are supporters of the losers, but some results may also make winners feel uncomfortable. Missing votes, user complaints of disenfranchisement, and unexpectedly lopsided vote totals are inappropriate no matter which party or candidate benefits. Whether these

Votes that are lost by a software failure are as lost as votes corrupted by fraud.

anomalies are the results of tampering or unexpected errors, they add to voters' disillusionment. The voters in this country (and arguably, every country) deserve better. Moreover, our form of government demands better, because our ability to elect our representatives confidently is the foundation of our republic.

The changes triggered by the 2000 election and signaled by HAVA will not happen overnight, and even those changes will not completely solve all of the problems. However, voting system assurance is possible through the rigorous application of engineering practices in the development, certification, and operation of voting machines, coupled with the appropriate use of audits and operational care. We must remain involved and diligent. It is our voting system, and it will only be trustworthy if we demand that it is.

Acknowledgment

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We have never encountered a security problem with electronic voting machines.

Voting as an Engineering Problem



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Michael Ian Shamos

Electronic voting has been in the news almost constantly since 2000, when the punch-card debacle in Florida caused a rapid re-evaluation of elections in the United States and fomented a revolution in voting processes and technologies. In 2002, Congress passed the Help America Vote Act (HAVA), which allocated more than \$3 billion to replace punch-card equipment, and states, eager to spend this bounty, rushed off to purchase a wide variety of electronic replacements.

A learning curve is to be expected after the introduction of unfamiliar technology, and election jurisdictions experienced a wide variety of problems with their new systems, including machine failures, inadequately trained poll workers, poor ballot setup, and voter confusion. In some cases, votes validly cast were not counted and were lost forever. In 2004, in Carteret County, North Carolina, in a now-classic failure, a voting machine with a capacity of about 3,000 votes was used to record more than 7,000, resulting in the loss of about 4,500 votes. As a result, a new election had to be held. The causes of incidents of this kind are generally well understood and can be traced to canonical engineering failures. In Carteret County, for example, if the voting machine had been engineered not to accept ballots once its memory was full, the problem would not have occurred.

One problem that was not encountered, and has never been encountered, is a security incident involving an electronic voting machine. There is no

evidence that anyone in the 28-year history of direct-recording electronic voting machines (DREs) has ever breached security to alter the outcome of an election. Nevertheless, following the publication of a report suggesting that tampering might be possible (Kohno et al., 2004), public attention has focused almost exclusively on the issue of computer security. In recent months, unjustified fears caused the Maryland legislature to discard its statewide system, which cost the state more than \$100 million, in favor of a completely different, antiquated technology, believed (wrongly) by lawmakers to be more secure. The Florida legislature, reeling from embarrassment over yet another Florida voting incident in 2006, made the same decision, to outlaw DREs and replace them with optically scanned paper ballots. Neither legislature commissioned a scientific study comparing the old and new systems or received or evaluated relevant engineering data. In the end, the cries of activists not only trumped science, they pushed it off the table altogether.

Activists have pushed science aside in addressing problems with voting technologies.

History

Voting in the United States has always been subject to manipulation. A thorough but frightening treatment can be found in *Deliver the Vote* by Tracy Campbell (2005). Since the earliest days of paper ballots, a wide variety of techniques have been used to influence election results, including forging, altering, losing, substituting, and augmenting ballots, to say nothing of vote-buying and other coercive schemes. This very problem led to the invention in 1892 of the lever machine, which its creator, Jacob H. Myers, claimed could “protect mechanically the voter from rascaldom, and make the process of casting the ballot perfectly plain, simple and secret.”

As technology has advanced, mechanical machines have been replaced by computerized systems, including punch-card, optical scan, and DRE devices. The underlying reason for using new technologies is not only to streamline the voting process, but also to speed up the count so winners can be declared quickly.

During this technological development, the important distinction between document ballots (those marked by the voter on a physical medium) and non-document ballots (totals recorded on counters or ballot images stored electronically) was lost or ignored. A document ballot provides only one copy, namely, the one marked by the voter, and this copy must be handled to be tabulated. In the handling, a document ballot may be altered or substituted, and once a substitution is made, it is impossible to recover the original voter’s selections, which are gone forever. The movement from paper to lever machines to DREs was an effort to eliminate the inherent insecurity of document ballots.

By contrast, in a DRE system multiple copies of ballots are retained on different media in different physical locations. To affect the outcome of an election, redundant encrypted records would have to be altered. To date, no one has even suggested, let alone demonstrated, a way to do this.

Despite our lurid history of tampering with document ballots, repeated calls are being made to return to hand-counted paper ballots or optically scanned ballots, which are often used in other countries. However, most other countries use extremely simple ballots. In the more than 90 parliamentary and multiparty democracies in the world, voters typically select a party, rather than individual candidates. One race, one choice.

Despite their use in foreign countries, hand-counted paper ballots are completely impractical in the United States, because our ballots are far more complicated than any other country’s. For example, the 2006 (off-year) general ballot in Marin County, California, included 98 candidates in 30 races and 30 ballot propositions. The resulting mark-sense ballot was six pages long. Or consider the still-disputed 2006 U.S. House race in Sarasota County, Florida, which presented voters with 21 pages of electronic ballot followed by four pages of review screens. Perhaps we shouldn’t have been surprised that 15 percent of the voters were unable to cast votes for either congressional candidate in Sarasota.

The perception persists that we cannot control the security of isolated, non-networked machines that have no operating systems, but that problems with the production, storage, transportation, and counting of paper ballots were solved long ago. In fact, there are neither standards nor procedures nor any reference work on protecting, transporting, and storing document ballots in a secure way.

The Inevitability of Errors

The very notion that perfection is achievable in a voting system is a fantasy. All systems have error rates, which are easy to define but difficult to measure. In a given race, a system is “correct” if it records and tabulates votes for the people the voters intended to vote for. The error rate for that race is the percentage of recorded choices that do not match the voters’ intent.

In any real election, there are errors, not necessarily because of machine failures or incorrect counting logic, but because of human interface issues. A voter may, for whatever reason, not understand how to cast a vote or may overlook a race or make a mistake. The error rate cannot be easily measured because there is no effective way to determine voter intent other than through the voting system itself. (If there were such a method, it would be a perfectly good voting mechanism by itself!)

In one of the first experiments of its kind ever conducted, subjects were given a sheet of paper telling them how to vote in a mock election; this sheet became the voter’s intent. Each subject used a single voting machine, but several different types of machines were used in the study. In general, error rates were approximately 10 percent. That is, 10 percent of the ballots cast failed to conform in some way to the predetermined choices. When straight-party voting was allowed, the error rate went up to 20 percent.¹ And these rates were observed with fully functional equipment (Herrnson et al., 2006).

A 10-percent differential would have changed the outcome in 25 of the 45 presidential elections in which the popular vote was recorded.² However, even assuming that the error rate could be reduced to, say, 1 percent, elections inevitably will occur in which the margin of victory is below the error rate. Noise can exceed signal. In fact, this must happen because there is a lower bound on the error rate for a given system, but no lower bound on the winning margin.

Close elections occur frequently. The famous Bush-Gore margin in Florida in 2000 was 537 votes out of almost 6 million votes cast, a difference of less than

0.1 percent. How likely is such a close election? Assuming an equal distribution of Republicans and Democrats, if a sample of six million votes is taken from the population, the margin will be less than 537 votes about one-third of the time. The 2006 margin in Sarasota was 0.15 percent, far lower than the most optimistic estimate of system error rate for any voting method in existence.

The notion of perfection in a voting system is a fantasy.

An Engineering Formulation

Just because voting is fundamental to democracy does not remove it from the realm of science and engineering. A voting system must perform three functions:

- Present the correct set of possible choices to the voter.
- Capture and record the voter’s actual choices.
- Produce an accurate tally of the actual choices.

It must satisfy the following conditions:

- Privacy—an individual voter’s choice cannot be discoverable by any other person.
- Security—the system must not be susceptible to manipulation or corruption by a small set of individuals.³
- Auditability—independent, after-the-fact observers must be able to confirm that the correct person has been elected.
- “Receipt-freeness”—the voter must not be able to prove to any other person how he or she voted.
- Verifiability—the voter must be able to determine with confidence after the election that his or her vote was recorded and tabulated accurately, without violating the requirement of receipt-freeness.

Usability and reliability are relevant only to the extent that they affect the functions or conditions listed above. They are not separate requirements.

¹ “Straight-party voting” means that a virtual office, called the straight-party office, is on the ballot. Choosing a party for that office has the effect of casting a vote for all candidates of that party throughout the ballot. On multipage ballots this causes an unseen side effect because a voter cannot see the consequences of his or her choice without navigating the entire ballot.

² This does not take into account the electoral vote.

³ Freedom from corruption cannot be guaranteed if arbitrary subsets of persons are allowed to collude.

The design of a system that can achieve the required objectives is purely a matter of engineering. No one has proven that a system that satisfies the requirements either exists or cannot possibly exist. Arguments have been made that privacy, verifiability, and auditability are mutually inconsistent and that auditing and verification are impossible without being able to determine how a particular voter voted (or permitting that voter to prove how he or she voted). However, it has been demonstrated numerous times through the use of cryptography that the common intuition is incorrect (see, e.g., Acquisti, 2004; Neff, 2001).

Security deficiencies can be designed out of a system.

The issue of security requires careful attention. Several systems that have been deployed in the field have significant vulnerabilities that have been remediated through administrative procedures rather than through redesign of the system. The most serious of these vulnerabilities would allow an attacker who gained private physical access to a voting machine to replace its software/firmware with a Trojan horse. Whether such an attack could be mounted successfully and undetectably in a way that would affect more than a small number of machines is purely speculative. However, security deficiencies should be, and can be, designed out of a system.

A demonstration that an attacker, under unrealistic conditions, might corrupt a voting machine, although cause for concern, does not justify discarding an entire technology. The United States did not outlaw bridges after the Tacoma Narrows Bridge collapsed due to uncontrolled wind-induced oscillation. Instead, bridges of similar design were reconfigured, and the drawbacks of the original design informed future designs. When the gas tank of the Ford Pinto caught fire and caused repeated highway deaths, we did not abandon cars, or even the Pinto. The offending models were recalled, and their tanks were replaced. Yet when computer security experts merely pointed out the possibility of security intrusions in voting machines, Congress and state legislatures moved to ban DRE machines entirely, one of the most extreme overreactions in the history of engineering.

Reliability

Voting machines are among the least reliable devices on this planet. It has been reported anecdotally that approximately 10 percent of DRE machines fail in some respect during the average 13 hours they are in use on election day.⁴ In some cases, the percentage is much higher (Bishop et al., 2005). The percentage rises to 20 percent, for example, if the machines have paper-trail printers attached to them. If electric razors failed *en masse* within the first 13 hours, the Federal Trade Commission would institute action against the manufacturer. Why don't voting machines and their manufacturers face such consequences? The unfortunate answer is that these failure rates are permitted by applicable standards.

The development of voting standards is a cautionary tale too long to relate here, but the currently applicable standard is that a voting machine must exhibit a mean time between failure (MTBF) of 163 hours.⁵ Under the exponential failure model, one would expect 10 percent of machines with this MTBF to fail within 17 hours. Given that machines are typically used for several hours during pre-election testing and that the ones that fail are removed from service, the observed failures are consistent with the standard. An ordinary personal computer has an MTBF of about 30,000 hours, and many voting machines are constructed from simplified PCs. So how can we explain the difference in reliability?

In fact, the standards for voting machines, which were heavily influenced by the manufacturers, are grossly inadequate. One reason is that they were developed ad hoc rather than from a set of principles applicable to voting systems. In addition, some standards are imprudent, to say the least. For example, there is a prohibition against interpreted code, which excludes some excellent programming languages, such as Java. Other standards are irrelevant or poorly formulated. But most important, necessary standards, such as computer security requirements, are missing altogether.

With the passage of HAVA, the National Institute of Standards and Technology (NIST) became responsible for formulating guidelines for voting systems. NIST has focused significant effort in this direction, but for

⁴ In general, failures result in the loss of none, or possibly one, vote, namely, the vote that was in the process of being cast when the failure occurred. The problem is not loss of votes but the loss of voting capability, voter inconvenience, and the loss of voter confidence.

⁵ See the 2002 Federal Voluntary Voting System Guidelines, Sect. 4.3.5.

a guideline to be adopted, it must pass first through two bodies, the Technical Guidelines Development Committee and, ultimately, the Election Assistance Commission (EAC).

The EAC, which was created by HAVA, is inherently political. By law, it is composed of four members, two nominated by the majority party in Congress and two nominated by the minority party. EAC members, being presidential appointees, must then be confirmed by the Senate. This structure is supposedly designed to ensure that exacting technical standards are adopted.

Conclusion

It is no surprise that rampant reliability problems have led to widespread, largely justified mistrust of voting machines. The threshold question is whether we will implement and deploy reliable machines or turn to a technology with reliability properties that have not yet been studied. The first alternative is difficult because there is no accepted design for a reliable voting machine (e.g., 30,000-hour MTBF), and certainly none that satisfies the properties listed above.

If an election is not close (that is, there is a large difference in vote totals between the winner and the next-highest vote getter), it doesn't matter which voting system is used. Even a bad system can discriminate when the margin is large. The sad fact, which is not obvious, is that, if an election is very close, it also makes no difference which voting system is used, because even a good system cannot determine in a trustworthy way who wins when the margin is very close (say, less than 0.1 percent). This is because of the large number of operational components and human beings participating in an election and because there is no system that can provide a post-election audit that will satisfy the losing candidate and his supporters. The situation might be different if universally verifiable systems were available.

Under the present circumstances, there is a great risk that the development of truly verifiable systems may be delayed for decades. (Paper-trail and optical-scan systems provide only instantaneous verification, which is insufficient to settle a close election.) When a legislature outlaws DRE voting, an inventor has no incentive to design a verifiable electronic system, which would then be illegal. If Congress adopts the bill introduced by Congressman Rush Holt (currently HR 811), which requires verifiable paper trails, there would be no point in improving current systems, or engineering a new

one, because it could not be used in elections for federal office.

I am arguing for federal funding of an engineering project to develop an electronic voting system that can meet the requirements listed above. We know that government is capable of acting when it is properly motivated. After NASA's *Challenger* disaster of 1986, President Reagan created a select scientific panel, the Rogers Commission, to determine the cause of the accident and even to review the culture at NASA that may have contributed to it. The outcome was a striking success, and the space program continued. Nothing of the kind is in sight for electronic voting, however, and we appear destined to repeat the paper manipulations of the nineteenth century that led to the development of voting machines in the first place.

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NAE News and Notes

A Celebration of Outgoing President Wm. A. Wulf

Auf Wiedersehen



Wm. A. Wulf has been president of NAE since 1996.

It has been an incredible pleasure to serve as president of NAE for the last 11 years. In fact, it's a bit hard to believe it's been that long. Time really does fly when you're having fun! I'd be less than honest if I didn't admit that I also feel pretty good about leaving the academy in better shape than when I took up the reins—financially, programmatically, and as a full partner with NAS and IOM in advising the nation. I also think we've had an important impact in many areas, ranging from engineering education and diversity to counterterrorism and our future prosperity.

There are so many people I should thank that it's a bit dangerous to thank anyone, in case I inadvertently omit some. But I must mention my counterparts in NAS and IOM, Bruce Alberts, Ken Shine, Ralph Cicerone, and Harvey Fineberg; the NAE and NRC staff; the NAE officers and councillors who have served with me; and everyone who has taken the

time to set me straight when I was going astray. But none of this would have been possible without my wife, Anita Jones, who, with the best of humor, put up with a "weekend husband" for these 11 years.

As I traveled around the world and interacted with the leaders of other engineering academies, I developed a deep appreciation of the special role of the National Academies. Most scientific academies are purely honorific. A few write occasional reports and make recommendations to their governments, but they almost never provide the kind of independent, fact-based, tightly reasoned, peer-reviewed reports that we provide. And, of course, the scale of our reporting is much greater—the National Academies produces a report every working day, involving up to 10,000 pro bono volunteer experts a year.

I have the strong impression that in the last 11 years, in no small measure because of cooperation between NAE, NAS, and IOM, we have taken on more important and more controversial subjects—and thus are having an even greater positive impact than we had before. Our post-9/11 report, *Making the Nation Safer*, and last year's report, *Rising Above the Gathering Storm*, could not have been produced without close cooperation among the three academies. We are about to embark on a major energy study to collect all of the information necessary for

our government to make rational policy decisions. This report, too, will depend on the cooperation of scientists and engineers. I also consider the NAE/NRC joint report, *The Hydrogen Economy*, and the NAE/IOM joint report, *Building a Better Delivery System*, as publications with significant impact that would not have been possible without inter-academy cooperation.

In other cases, the NAE independent imprimatur is essential—for example, our prizes celebrating the impact and accomplishments of engineers and engineering (the Draper, Gordon, Russ, and Grainger prizes) and our work on engineering education, diversity, and technological literacy. With a significant gift from NAE member Harry Bovay, we recently established the Center for Engineering Ethics at NAE, one of my long-term goals. Most of the ethics cases involve the engineering profession itself, so it's important that NAE speak to that community and to those issues. No doubt, there will be other prizes and many more important projects in the future.

My philosophy in designing NAE programs has been to have the NAE Program Office do only those things for which the NAE imprimatur is essential and to work as part of the larger National Academies on everything else. In the last 10 years, our program budget has grown from just over \$1 million dollars in 1997 to a projected \$11 million for 2007.

We are in what economists call a “virtuous cycle”—the more we do, the more we are recognized and are asked to do, which leads to still more recognition, and so on. It has become routine for me to get phone calls asking NAE to take on projects as diverse as reviewing the National Nanotechnology Initiative, studying the need for more supercomputing capability, laying out a research agenda for counteracting improvised explosive devices (IEDs), and hosting a dinner for the former president of Iran.

The last 11 years has been an “interesting time” at the National Academies. One of the first things that happened after I arrived was that we lost a court case, and in the process, we lost the ability to operate outside the jurisdiction of the Federal Advisory Committee Act, better known as FACA. If that judgment had stood, we would have been out of business—we would not have been able to ensure our independence. Fortunately, enough people in Congress understood the value of the National Academies,

and a special new section was added to FACA that applies almost exclusively to us. We had to change the way we do some things, such as posting proposed committee rosters for public comment and publishing the names of reviewers in reports, but in the end, I believe these changes actually improved and strengthened our processes.

We also embarked on a joint capital campaign that helped us gather the resources we need to produce independent studies on timely, important issues that government hadn’t requested or funded—such as *Rising Above the Gathering Storm*. We built a new building, the Keck Building, that has made it significantly easier for the academies to collaborate. We also underwent a major reorganization that significantly improved our business practices. Yes, it’s definitely been an interesting time.

I’d like to take this opportunity to express my sincere appreciation to everyone who has supported the Wm. A. Wulf Campaign for Engineering Excellence. Over the years,

I have been overwhelmed by the generosity of members and friends, but this honor—a fund dedicated to supporting NAE programs in my name—has been especially gratifying and touching (and a little embarrassing!). Many, many thanks to everyone who has contributed. I am humbled by your support.

Oh, and in case you’re curious, I chose the title of this article, “Auf Wiedersehen,” for two reasons. First, I am a second-generation German immigrant (my father immigrated to the United States in the 1920s, fleeing the hyperinflation of the Weimar Republic). As a result, I am, perhaps, especially sensitive to the contributions of immigrants to this country, and I am disturbed by the current xenophobia of some to *all* immigrants, legal as well as illegal (see my testimony before Congress on our website). Second, a literal translation of *auf wiedersehen*, the German for “good bye,” is closer to “until I see you again.” I look forward to seeing all of you again sporting my best title, “member of NAE.”

A Reminiscence about Bill Wulf’s Presidency



Morris Tanenbaum, retired vice chair and chief financial officer, AT&T Corporation, and a member of NAE, made these remarks on October 13, 2006.

It is a pleasure and a privilege to take part in this celebration of Bill Wulf’s almost 12-year presidency of NAE. Paul Gray and I served on the NAE Council at the beginning of that period, and, in preparing for these remarks, he and I compared recollections. So I am speaking for the two of us. I became the spokesman because I was, perhaps, somewhat more personally involved than Paul.

During my professional career, I was lucky that I seldom found

myself in a challenging situation over which I had very little control. However, back in 1996, the NAE Council and membership voted to remove the recently elected president because he proved not to have the capabilities necessary for the job. As NAE vice president at the time, I was constitutionally expected to become the interim president for several months until a new election could be held. That would have been a great honor for me, but I had a number of corporate

commitments I could not easily change and that would have been considered a conflict of interest. There were also family issues that would have made it very difficult for me to move to Washington.

Therefore, the NAE Council began a search for an alternative interim president, and Bill Wulf's name appeared at the top of the list. At the time Bill was serving happily as a tenured professor at the University of Virginia, and leaving the campus was not an easy decision for him. In addition, he realized, of course, that he would be stepping into a somewhat messy situation. His predecessor had demoralized the NAE staff and antagonized many of our colleagues in the National Academies complex. In addition, the position was clearly an interim appointment with no future commitments by NAE. In preparation for a new election, the Council had decided to try to find and nominate at least two candidates for the presidency, but there was no guarantee that Bill would be one of them, even if he should decide he wanted to run.

Fortunately for us, after much consideration and lots of encouragement from the NAE Council, Bill agreed to serve. I was off the hook, but more important, even though we didn't know it at the time, NAE had found an outstanding leader for the next 11 years. Thank you, Bill!

Bill got to work immediately reinvigorating the staff and impressing the council. He reclaimed the respect of our colleagues in NAS, IOM, and NRC with his grasp of the job and his leadership. As you know, Bill was nominated as one of the two candidates in the next election, and he was chosen by the membership as the new president. The rest is history.

Bill has accomplished a great many things during his tenure. Paul and I have been especially impressed by the improvement in the relationship between NAE and our colleagues in NAS, IOM, and NRC. One of the most visible changes reflecting NAE's new status was the adoption of a new name, the National Academies, as the umbrella for all four components.

Another is a successful joint capital campaign that has strengthened all of us.

I'm sure there are many other aspects of change that are also important, and I suspect there is room for further improvement. But we are much closer today to a full partnership than we have ever been. There was a time, a few years after NAE was founded in 1964, when serious consideration was given to seeking a separate Congressional Charter for NAE and a complete separation from NAS. That would have been an unfortunate move for both academies and for the nation. Today, I sense that that consideration is no longer on anybody's radar screen.

Now, Bill, the University of Virginia will again have the benefit of your talents. They are very lucky! And you and Anita may see a good deal more of each other. You are very lucky! I know I speak for Paul, and I believe I speak for the NAE Council and members, when I wish you the very best of success and satisfaction in your future career. You have earned it!

Bill Wulf's Remarkable Presidency



George Bugliarello is President Emeritus and University Professor, Polytechnic University, and NAE foreign secretary.

During Bill Wulf's presidency of NAE, I have had the privilege of serving as interim editor-in-chief of *The Bridge* for 10 years and NAE foreign secretary for four years. Before that, I had been involved in two other major policy interests of his presidency—technological literacy and cities.

My purpose is not to write a hagiography of Bill Wulf or to recount his many accomplishments that have moved NAE forward from the disarray just before he

assumed the presidency. My purpose is to provide a glimpse, based on my personal experience, of the qualities of leadership, humanity, diplomacy, and "down-to-earthness" that have made him such a successful and admired president of our academy.

To my mind, those qualities never shone more brilliantly than when, at the first Indian-American Frontiers of Engineering Symposium in Agra last year, Bill addressed an acute irritant to our Indian

colleagues created by the decision of an immature State Department functionary to deny a visa to a leading Indian scientist—the result of recent U.S. visa policies that Bill has encountered many times in many places in his travels around the world. With complete frankness, Bill conveyed his personal consternation, and the concerns of NAE, about that decision in a way that was so patently heartfelt that the feelings of our Indian colleagues must have been assuaged. Bill showed them the genuine, honest, and friendly face of America.

As spokesperson for the academy worldwide, Bill has had an enormous impact, from his actions as president of the International Council of Academies of Engineering and Technological Sciences (CAETS) and his participation in the Frontiers of Engineering programs (which he instituted and to which he always brings a keen interest and natural warmth) in the United States and with Germany, Japan, and now India, to his trip to China to sign an agreement of collaboration with the Chinese Academy of Engineering, his energizing presence at the Russian-American Academies joint committee meetings on science and

technology to address terrorism, and his encouragement of a dialogue between the National Academies and Iranian scientists and engineers. Bill has become, in effect, a respected, trusted, and sought-after spokesperson for American engineering around the world.

Bill's sense of mission as NAE president was also expressed when he and the presidents of NAS and IOM joined forces to address the growing concerns of the scientific and engineering community, as well as many in the general public, about "the gathering storm," the disquieting trends that may presage a dangerous weakening of our scientific and technological capabilities and that urgently demand a national response. Bill has been indefatigable in speaking out on this and related issues before Congress, at national meetings, and at regional meetings of NAE members, another innovation of his presidency.

The joint project of the three academies addressing the issues raised by the gathering storm owed much to the rapprochement between NAE and its partner academies, for which Bill set the tone and which his personal qualities made so effective. With that rapprochement, the three academies began to see themselves

as a single entity—the National Academies—and they subsequently joined forces to launch a combined fundraising campaign.

When Bill appointed me interim editor of *The Bridge*, a magazine that had an excellent editor but was buffeted by conflicting, often unrealistic demands as to what it should do and publish, I feared the worst. But I have been enormously gratified by Bill's thoughtfulness in giving *The Bridge* the freedom to adhere to our mutually agreed upon editorial program.

Despite the heavy burden of the many tasks Bill has assigned himself, I never saw him lose his temper or change his friendly and welcoming manner, no matter how thorny the issue confronting him. Perhaps the key to understanding his superb human qualities is revealed in his and Anita's sylvan home in Virginia, with its atmosphere of order, peace, and communication with nature—and Bill's driving his tractor and helping nature out.

I join with everyone who has had the privilege of knowing and working with Bill in thanking him for what he has done for our academy and thanking him for his friendship and his lesson in humanity and enlightened leadership.

Recent Events

Charles M. Vest Elected Next NAE President



Charles M. Vest

"The nation's well-being and our place in the world community depend in large measure on our leading and implementing the new, cutting-edge innovations that come from both basic research and sophisticated development." These are the words of **Charles M. Vest**, president emeritus of the Massachusetts Institute of Technology (MIT) and president-elect of NAE. Dr. Vest will succeed **Wm. A. Wulf**, whose second term as NAE president ends on June 30, 2007.

Dr. Vest, now 65 and a mechanical engineer by training, has led a distinguished career that has included service on many academic and government advisory bodies. Dr. Vest was president of MIT from 1990 through 2004, during which time he reinforced federal-university-industry

relations and undertook a number of initiatives to increase public awareness of educational and research issues. He placed special emphasis on improving science and engineering in undergraduate education, arguing for more racial and cultural diversity among faculty and students at MIT, and focusing on the international dimension in university programs.

A member of the bipartisan Commission on the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction, Dr. Vest brought a strong science and engineering background to the committee's deliberations. He also headed a U.S. Department of Energy task force on the future of science programs in 2002–2003 and chaired a presidential advisory commission on the redesign of the International Space Station in 1992–1994. He was vice chair of the Council on Competitiveness for eight years, is a former chair of the Association of American Universities, and is a member of the U.S. Secretary of Education's Commission on the Future of Higher Education.

Dr. Vest was elected a member of NAE in 1993 "for technical and educational contributions to holographic interferometry and for

leadership as an educator," and he served on the NAE Council from 2005 to 2007. Among his many honors is the 2000 NAE Arthur M. Bueche Award, which he received for "outstanding university leadership, commitment, and effectiveness in helping mold government policy in support of research, and forging linkages between academia and industry." He has also served on committees for numerous National Academies studies, most recently on the committee that wrote the highly influential report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, which highlights the importance of science and engineering in U.S. economic growth and competitiveness.

Dr. Vest earned a B.S. degree in mechanical engineering from West Virginia University in 1963. He received his M.S. and Ph.D. degrees from the University of Michigan in 1964 and 1967, respectively, and later held the positions of dean of engineering, provost, and vice president for academic affairs at Michigan. He has also been awarded 10 honorary doctoral degrees.

NAE Elects Foreign Secretary and Councillors

In the spring 2007 election of NAE officers and councillors, the academy not only elected a new president, but also re-elected the incumbent foreign secretary and an incumbent councillor and elected three new councillors. All terms begin July 1, 2007.

George Bugliarello, president emeritus of Polytechnic University, was re-elected to a four-year term as NAE foreign secretary.

Lawrence T. Papay, retired sector vice president of Science Applications International Corporation, was re-elected to a second three-year term as councillor. **Linda M. Abriola**, dean of the Tufts University School of Engineering, **Ruth A. David**, president and chief executive officer of ANSER (Analytic Services Inc.), and **Charles Elachi**, director of the Jet Propulsion Laboratory and vice president of California Institute of Technology, were newly elected to three-year terms as councillors. An additional councillor was subsequently elected by the NAE Council for a one-year term to fill the seat vacated by Charles Vest.

William F. Ballhaus Jr., president and CEO of the Aerospace Corporation, **R. Ray Beebe**, retired senior vice president of Homestake Mining Company, and **M. Elisabeth Paté-Cornell**, Burton J. & Anne M. McMurty Professor and chair of the Department of Management Science and Engineering at Stanford University, completed six continuous years of service as councillors, the maximum allowed under the academy's bylaws. Dr. Wulf, Dr. Ballhaus, Mr. Beebe, and Dr. Paté-Cornell were recognized for their distinguished service and other contributions during a dinner in May attended by NAE Council members and staff.



George Bugliarello



Lawrence T. Papay



Linda M. Abriola



Ruth A. David



Charles Elachi



William F. Ballhaus Jr.



R. Ray Beebe



M. Elisabeth Paté-Cornell

Tenth Annual German-American Frontiers of Engineering Symposium



NAE President Bill Wulf, Dr. Myrjam Winning of the Max-Planck Institute for Metallurgy, and Ram Devanathan of Pacific Northwest National Laboratory during a GAFOE poster session.

On April 25–28, the tenth annual German-American Frontiers of Engineering (GAFOE) Symposium was held at the Crowne Plaza Hotel in Hamburg, Germany. Located near Lake Aussenalster and within walking distance of the city center, the hotel provided a wonderful setting for the interaction and exchange of ideas that are the hallmarks of FOE meetings.

Modeled on the U.S. Frontiers of Engineering Symposium, this bilateral meeting brought together approximately 60 engineers, ages 30 to 45, from German and U.S. companies, universities, and government laboratories. Like the U.S. symposium, the goal of the meeting was to bring together emerging engineering leaders to learn about leading-edge developments in a range of engineering fields and facilitate an interdisciplinary transfer of knowledge and methodologies. The GAFOE Symposium and other bilateral FOE meetings also encourage cooperative networks across national boundaries.

NAE works with the Alexander von Humboldt Foundation to organize GAFOE symposia.

NAE member **Tresa Pollock**, L.H. and E.E. Van Vlack Professor in the Department of Materials Science and Engineering at the University of Michigan, and Thomas Bock, professor of automation and robotics in construction at the Technical University in Munich, co-chaired the organizing committee and the symposium. The four topics covered at the meeting this year were: space technologies; robotics: from theory to systems; smart materials and structures; and brain research technologies. Presentations by two Germans and two Americans in each of the four areas covered the European space mission to Mercury, robot-assisted surgery, new developments in smart materials with sensor and actuator abilities and their applications, MEMS technologies for neuroengineering applications, and many other areas of cutting-edge research. The participants engaged

in spirited discussions, both during formal sessions and during breaks, receptions, and dinners. Poster sessions on the first afternoon gave all of the participants an opportunity to talk about their research or technical work.

On the second afternoon, there was a bus tour of Hamburg, Europe's second largest port city, followed by a stop at the port. The dinner took place aboard a nineteenth-century sailing ship, the *SS Rickmer Rickmers*.

Five Indian and four U.S. members of the organizing committee for the second annual Indo-American Frontiers of Engineering (IAFOE) symposium also attended the GAFOE meeting. They held a planning meeting after the symposium ended. The U.S. co-chair for IAFOE, scheduled for February 2008, is NAE member **Athanassios Panagiotopoulos**, professor in the Department of Chemical Engineering at Princeton University.

Funding for the GAFOE Symposium was provided by the Alexander von Humboldt Foundation, NAEF, and the National Science Foundation. Tresa Pollock will continue to serve as U.S. co-chair, and Kai Sundmacher, director and scientific member of the Max Planck Institute in Magdeburg, will serve as German co-chair for the eleventh GAFOE meeting, to be held April 25–27, 2008, at the Beckman Center in Irvine, California.

For more information about FOE activities, contact Janet Hunziker in the NAE Program Office at 202/334-1571 or by e-mail at jhunziker@nae.edu.

Rachelle Hollander Joins Program Office



Rachelle Hollander

Dr. Rachelle Hollander, a senior research scholar at the Institute for Philosophy and Public Policy at the University of Maryland, College Park, is the new director of the NAE Engineering Ethics Center.

In 2006, Dr. Hollander received the Olmsted Award “for innovative contributions to the liberal arts within engineering education” from the ASEE Liberal Education Division. She also received special acknowledgment at the Association for Practical and Professional Ethics (APPE) Annual Meeting and the American Association for the

Advancement of Science (AAAS) Annual Meeting for her professional contributions on the occasion of her retirement from the National Science Foundation (NSF). She is also a fellow of the AAAS.

When Dr. Hollander retired from NSF, she was senior advisor in the Directorate for Social, Behavioral, and Economic Sciences (SBE). Her assignments included oversight of the NSF-wide program on human and social dynamics and SBE involvement in the Nanoscale Science and Engineering Program, for which she managed the 2005 competition for the Nanotechnology in Society Centers. That same year, NSF held its first competition by the Ethics Education in Science and Engineering (EESE) Program. Dr. Hollander worked with colleagues in a number of other NSF directorates to initiate this program.

Engineers know Dr. Hollander best for her role in founding and directing science and engineering ethics activities at NSF, such as

Ethics and Values Studies (EVS), which is now part of the Science and Society (S&S) Program, and the ethics components in the Research Experiences for Undergraduates (REU) Program.

In the course of her career, Dr. Hollander has been instrumental in the development of the fields of research ethics and professional responsibility, engineering ethics, and ethics and risk management. She has written articles on applied ethics in numerous fields and on science policy and citizen participation.

Dr. Hollander received her doctorate in philosophy in 1979 from the University of Maryland, College Park. She was a visiting professor in the Science and Technology Studies Department at Rensselaer Polytechnic Institute in 1989–1990 and a visiting scholar in the Department of History of Science, Medicine, and Technology at Johns Hopkins University in 2001–2002.

NAE Newsmakers

Rodney C. Adkins, vice president of development, International Business Machines Corporation, IBM Systems and Technology Group, has been named **2007 Black Engineer of the Year** by *U.S. Black Engineer and Information Technology Magazine*.

Frances E. Allen, IBM Fellow Emerita, received the **2006 Turing Award** from the Association for Computing Machinery. Ms. Allen was cited for “pioneering

contributions to the theory and practice of optimizing compiler techniques that laid the foundation for modern optimizing compilers and automatic parallel execution.” She is the first woman to be awarded the prestigious Turing Award.

Robert K. Brayton, professor of electrical engineering and computer science, University of California, Berkeley, received the **2006 Paris Kanellakis Theory and Practice**

Award presented by the Association for Computing Machinery. Dr. Brayton was honored for “leading the development and practical realization of algorithms for logic synthesis and for electronic system simulation, thereby helping to create key enabling technologies for the Electronic Design Automation industry.”

Stuart K. Card, senior research fellow, Palo Alto Research Center

Inc., was awarded the Franklin Institute **2007 Bower Award and Prize for Achievement in Science** for “fundamental contributions to the fields of human-computer interaction and information visualization.”

Earl H. Dowell, William Holland Hall Professor and Dean Emeritus, Edmund T. Pratt Jr. School of Engineering, Duke University, received the **2007 Walter J. and Angeline H. Crichlow Trust Prize** presented by the American Institute of Aeronautics and Astronautics. Dr. Dowell was honored for “pioneering contributions to aeroelasticity, structural dynamics and unsteady aerodynamics, which had an enormous influence on aerospace technology, and for contributions to education and public service in aerospace engineering.”

The Geological Society of America (GSA) has established the **Farouk El-Baz Student Award** to encourage and promote desert research throughout the world. The award is named in honor of NAE member, **Farouk El-Baz**, research professor and director, Center for Remote Sensing, Boston University. The award, funded by the Qatar Foundation for Education, Science and Community Development as an endowment, will be based on a student’s proposal for arid-land research and a recommendation by an advisor. This is the second award established by GSA in Dr. El-Baz’ name.

Douglas W. Fuerstenau, P. Malozemoff Professor Emeritus of Mineral Engineering, Department of Materials Science and Engineering, University of California, Berkeley, was awarded the **2006 Particle Technology Forum Award** of the American Institute of Chemical Engineers at their recent

annual meeting, held in San Francisco. Dr. Fuerstenau was honored “in recognition of his distinguished career, contributions to particle technology research and scholarship, and for outstanding leadership to the particle technology community worldwide.”

Nicholas J. Garber, Henry L. Kinnier Professor, Civil Engineering Department, University of Virginia, was honored by the American Road and Transportation Builders Association with the **S.S. Steinberg Award**. Dr. Garber was recognized “for his contributions to transportation education.”

Susan L. Graham, Pehong Chen Distinguished Professor, Computer Science Division—EECS, University of California, Berkeley, has been selected to receive the **2006 Distinguished Service Award** from the Association for Computing Machinery “for service to the computing community, especially for service on national committees.”

Shirley Ann Jackson, president, Rensselaer Polytechnic Institute, was awarded the National Science Foundation **Vannevar Bush Award** “for a lifetime of achievements in scientific research, education and senior statesman-like contributions to public policy.” Dr. Jackson is the first African-American woman to receive the Bush Award in its 27-year history.

Lawrence L. Kazmerski, director, National Center for Photovoltaics, National Renewable Energy Laboratory (NREL), received the **2007 Karl Boer Solar Energy Medal of Merit**. To support human-resource development in the field of solar technology, Dr. Kazmerski has indicated that the \$40,000 cash award will be donated to a program enabling students from the

University of Delaware and other universities to conduct research at NREL.

Yoram Koren, Paul G. Goebel Professor of Engineering and director, NSF Engineering Research Center for Reconfigurable Manufacturing Systems, University of Michigan, received the Society of Manufacturing Engineer’s **Gold Medal** “for his outstanding service to the manufacturing engineering profession in technical communications through published literature, innovations, technical writing, and lectures.”

Nancy A. Lynch, NEC Professor of Software Science and Engineering, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, will receive the Association for Computing Machinery **2007 Knuth Prize**. Dr. Lynch is the first woman to receive this award, which was first awarded in 1996. She was cited for her “seminal impact on the reliability of distributed computing systems, which are used to power traditional wired networks, modern mobile communications systems, and systems with embedded computers, including factory machinery, vehicles, robots, and other real-world devices.”

Perry L. McCarty, Silas H. Palmer Professor Emeritus, Department of Civil and Environmental Engineering, Stanford University, is the **2007 Stockholm Water Prize Laureate**. The citation for Dr. McCarty reads: “For pioneering work in developing the scientific approach for the design and operation of water and wastewater systems. He has established the role of fundamental microbiology and chemistry in the design of bioreactors. Professor McCarty has defined the field

of environmental biotechnology that is the basis for small-scale and large-scale pollution control and safe drinking water systems."

Several NAE members received awards from the Institute of Electrical and Electronics Engineers (IEEE) at its annual honors ceremony on June 16, 2007, in Philadelphia, Pennsylvania.

The **IEEE Medal of Honor** was presented to **Thomas Kailath**, Hitachi America Professor of Engineering, Emeritus, Stanford University, for "exceptional development of powerful algorithms in the fields of communications, computing, control and signal processing."

The **IEEE Edison Medal** was presented to **Russell D. Dupuis**, professor of electrical and computer engineering and Steve W. Chaddick Endowed Chair in Electro-Optics, School of Electrical and Computer Engineering, Georgia Institute of Technology, for "pioneering contributions to metalorganic chemical vapor deposition technology and continuous-wave room-temperature quantum-well lasers."

The **IEEE Founders Medal** was presented to **Anita K. Jones**, Lawrence R. Quarles Professor of Engineering and Applied Science, School of Engineering and Applied Science, University of Virginia, for "outstanding leadership in academic research and in directing computer science and engineering research in the Department of Defense."

The **IEEE Jack S. Kilby Signal Processing Medal** was presented to **Alan V. Oppenheim**, Ford Professor of Engineering, Massachusetts Institute

of Technology, for "visionary leadership and exceptional contributions to the field of digital signal processing."

The **IEEE/RSE Wolfson James Clark Maxwell Award** was presented to **Irwin M. Jacobs**, chairman, QUALCOMM, Inc., and **Andrew J. Viterbi**, president, Viterbi Group LLC, for "fundamental contributions, innovation, and leadership that enabled the growth of wireless telecommunications."

The **IEEE Simon Ramo Medal** was presented to **Victor B. Lawrence**, Batchelor Chair Professor of Electrical Engineering and associate dean for special programs, Charles V. Schaefer Jr. School of Engineering, Stevens Institute of Technology, for "technical innovation and leadership in the systems engineering of worldwide data communications networks."

The **IEEE John von Neumann Medal** was presented to **Charles Thacker**, technical fellow, Microsoft Corporation, for "a central role in the creation of the personal computer and the development of networked computer systems."

The **IEEE Control Systems Award** was presented to **Lennart Ljung**, Division of Automatic Control, Department of Electrical Engineering, Linköping University, for "seminal contributions to system identification and its impact on industrial practice."

The **IEEE Andrew S. Grove Award** was presented to **James D. Plummer**, dean of engineering, Stanford University, for "seminal contributions to the modeling, simulation and physics of silicon devices."

The **IEEE Daniel E. Noble Award** was presented to **Ching Tang**, professor of chemical engineering and chemistry, University of Rochester, for "pioneering contributions to the development of organic light emitting diodes (OLEDs)."

The Consumer Electronics (CE) Hall of Fame honors leaders who have contributed to the consumer electronics industry and improved the lives of consumers. On October 17, 2006, six NAE members were among 12 individuals **inducted into the CE Hall of Fame**.

Robert W. Galvin, Chairman Emeritus, Motorola Inc., was recognized for expanding the company his father founded into a global semiconductor and cell phone company.

George H. Heilmeier, Chairman Emeritus, Telcordia Technologies Inc., was honored for leading the team that developed the LCD (liquid crystal display), earning 15 patents along the way.

Nick Holonyak Jr., John Bardeen Chair Professor of Electrical and Computer Engineering and Physics, University of Illinois, was honored for inventing the LED (light-emitting diode) and earning 34 patents.

Andrew S. Grove, senior advisor to Executive Management, and **Gordon Moore**, Chairman Emeritus, were honored as co-founders of Intel Corporation.

Donald L. Blitzer, Distinguished University Research Professor, North Carolina State University, was inducted, along with Gene Slottow and Robert Willson, as co-inventor of the plasma display.

2007 NAE Awards

NAE Honors 2007 Awards Recipients

The 2007 NAE award winners were honored at a gala dinner on February 20 at historic Union Station in Washington, D.C. The awards are given to outstanding individuals who have made significant contributions in innovation, leadership, and bioengineering. The

winners of the 2007 Charles Stark Draper Prize, Fritz J. and Dolores H. Russ Prize, and Bernard M. Gordon Prize received their awards at a ceremony emceed by NAE President **Wm. A. Wulf** before an audience of more than 400 guests. The winners of the Grainger Challenge Prize for

Sustainability were also honored at the dinner. The Grainger Prize is an inducement award, funded by The Grainger Foundation, that recognizes individuals for the development, in-field verification, and dissemination of effective techniques for reducing arsenic levels in water.

Charles Stark Draper Prize



Timothy J. Berners-Lee

Timothy J. Berners-Lee was awarded the 2007 Charles Stark Draper Prize for developing the World Wide Web. The Draper Prize, one of the most prestigious honors in engineering, is a \$500,000 award given annually to an individual(s) who has contributed to an achievement or body of work that has enhanced the well-being and freedom of humanity. This year's award was presented by James D. Shields of the Charles Stark Draper Laboratory.

The impact of the World Wide Web rivals that of electricity, the automobile, radio, television, and the computer. In less than 20 years, the Web has come to dominate much of modern life, dramatically speeding the transfer of information and changing the way we learn, shop, and get our news. From his initial vision of the Web as "a place where the whim of a human being and the reasoning of a machine coexist in an ideal, powerful mixture," through his critical innovations of the Universal Record Locator (URL), Hypertext Transfer Protocol (HTTP), and Hypertext Markup Language (HTML), Berners-Lee has made it possible for us to access stored information anywhere in the world from a single location. When we speak of the Internet, we usually mean the power and capability of the World Wide Web.

Berners-Lee, a graduate of Oxford University, holds the 3Com Founders Chair and is a senior research scientist at the Laboratory for Computer Science and Artificial Intelligence (CSAIL) at the Massachusetts

Institute of Technology; he is also director of the World Wide Web Consortium, founded in 1994. In 1989, he invented the World Wide Web for global information sharing while working at CERN, the European Particle Physics Laboratory. Berners-Lee specifications of URLs, HTTP, and HTML were refined as Web technology spread.

In 2001, Berners-Lee became a fellow of the Royal Society. He has been the recipient of several international awards, including the Japan Prize, the Prince of Asturias Foundation Prize, the Millennium Technology Prize, and, most recently, Germany's Die Quadriga Award. In 2004, he was knighted by H.M. Queen Elizabeth. In February 2007, he was elected a member of NAE.

The Draper Prize, established in 1988, was endowed by the Charles Stark Draper Laboratory Inc., Cambridge, Massachusetts, to honor the memory of "Doc" Draper, the "father of inertial navigation," and to increase public awareness of the contributions of engineering and technology to our quality of life.

**Acceptance Remarks by
Timothy Berners-Lee**

Ladies and gentlemen, it is a tremendous honor to be the recipient of this prize. Actually, it's a tremendous honor to be honored as an engineer. I think a lot of people don't understand about this engineering thing—that it's about building things. Even in computer science, although it is called computer science, in fact, the most interesting thing about it is that it's really engineering—building things.

In the days before the U.K. was involved in the European Union, a passport form used to have a space for occupation. I used to put down “engineer” because, when I was actually forced to contemplate what I did, for the purposes of filling in a passport form, I felt the most important part was that we build things. We make things. Often those things don't work, of course, but sometimes they do. And when they do, it's always good to celebrate them. So in that spirit, I'm very happy to accept this prize. I am very grateful to everybody at the Draper Lab and in the Draper family, not to mention all the folks on the selection committee, who helped make it happen. So, let us celebrate. And what a wonderful party this is for celebrating.

Was it all engineering, the task of starting the World Wide Web? Yes, it involved designing a program, but it also involved setting some standards, which doesn't just mean writing them, but also traveling all over the place and meeting with people and getting them to use the same standards. There is an essential difference between an Internet application and a mouse

trap. When you invent a better mouse trap, you can make more like it and go out and sell them. When you invent a better Internet application, for it to produce a completely new market you have to persuade everybody else to use the same standards.

That involves talking to people, another set of skills, and a lot of travel, a lot of being away from home and all kinds of obnoxious behavior, such as participating in teleconferences at all hours. We try to use the technology, to “eat our own dog food” as we say, and to do everything over the Internet, but in the end we always find that face-to-face meetings are necessary. I'd like to thank my family, including my wife and son who are here tonight, for putting up with all of that over many, many years.

So “thank you” is one thing I want to say. The other thing is that, even though we might celebrate this evening, the work is not yet done. Every now and again, people ask what I'm going to do next, as though the Web were finished. The Web is not done. We have a Web of documents, but we don't have a Web of data. We have a Web where you can read things, but very few people currently use it as a place to leave their thoughts or work out plans with colleagues.

The Web should be a two-way street. The shared space of information needs contributions from everybody, so we need to make the Web into a two-way Web. We need it to be a Web of data, scientific data, all kinds of data, as well as documents. There is a long list of things we would like the Web to be. If you go to the Web Consortium website

(www.w3.org), or to my website, you will find a list of things we've still got to do.

So, while it's good to celebrate and while I'm very grateful for the award, I want to be careful we don't end up falling into the trap of thinking that everything is done. There's a whole lot more to do, including making standards. So if people working for you keep flying off to strange places and meeting with strange people and end up producing standards documents instead of publications, when they get back, ask them all about it, respect them, and promote them. When it comes to the Internet, engineering cannot be done by one person alone in a lab. It requires international collaboration on common protocols that will work in the real world of people connected by the network.

So my final thank you is to the people who have done that. The idea of the Web was just an idea that was thrown out like a rose petal onto the Ganges. And, in fact, this idea was picked up by all kinds of people all over the world. Then ideas started coming back across the Internet. So the Web has, of course, been built by millions of people. You probably know many people who have put lots of creative activity into building the Web. It's been fantastic.

The most important and most exciting thing about the Web has not been the technology, or even the engineering, for all the fun that's been. It's been the collaborative spirit of people across the planet. So really, the greatest thank you goes to all of them.

Fritz J. and Dolores H. Russ Prize



Roderick McDavis, Bert Fung, and Wm. A. Wulf.

The Russ Prize, a \$500,000 award presented annually to an engineer whose work has significantly impacted society and contributed to the advancement of the human condition, was awarded to **Yuan-Cheng B. Fung** for innovations in the characterization and modeling of human-tissue dynamics leading to the prevention and mitigation of trauma. The award was presented by Roderick J. McDavis, president of Ohio University.

Few disciplines have had as great an impact as the emerging fields of biomechanics and tissue engineering. Biomechanical scientists and engineers are developing analytical tools to study the structure and function of living tissues, and advances in bioengineering have led to the design and manufacture of implants that have already saved

many lives and have the potential of improving the health of millions of people. It is no exaggeration to say that Dr. Fung created both fields—biomechanics in the 1960s and tissue engineering in the 1980s. He can fairly be considered the most outstanding bioengineering scientist in the twentieth century.

Dr. Fung, “Bert” as he is known, continues to make significant contributions through his own research, the research of his many students and their students, and his exemplary leadership. Professor Emeritus and research engineer at the University of California, San Diego, Bert has received numerous awards and honors, including the NAE Founders Award in 1998 and the National Medal of Science in 2000. He is also one of the very few who is a member of all three national academies,

the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine.

Acceptance Remarks by Yuan-Cheng B. Fung

I feel truly honored to be receiving the Fritz J. and Dolores H. Russ Prize. Fritz graduated from Ohio University in 1942 with a bachelor of science degree in electrical engineering and immediately went to work for the Naval Research Laboratory in Washington, D.C., and made many, many accomplishments. His work was so distinguished that Ohio University honored him with an honorary doctorate. Fritz certainly enjoyed universal honors from all engineers.

I was born and educated in China, came to the States in 1945, and received my Ph.D. in aeronautics in 1948 from the California Institute of Technology in Pasadena. From 1948 to 1965, I was interested only in aeronautical engineering, with my research concentrated on the survival of airplanes and rockets in rough weather, turbulent clouds, or terrible terrains for landing. The science of the art of survival of aircraft in rough conditions is called the theory of aeroelasticity. I worked on aeroelasticity for 20 years.

Then I turned to bioengineering, with focus on people, because I felt that although we know so much about airplanes, we don’t know much about ourselves. So, finally, beginning in 1965, I decided to change my career to bioengineering. I resigned from Caltech and came to the University of California at San Diego (UCSD) in La Jolla, California, and began to work

on a subject of my heart's desire. I really love that subject.

Nationwide, the bioengineering field is blossoming in many directions. Many other leaders are doing much more important work

with more important applications than myself. Dr. Wei Huang and I at UCSD are focusing our work on blood vessels. We welcome you, Dolores [Mrs. Russ], to visit us in La Jolla. We will show you our lab

and discuss our work with you. We want you to meet our people and experience the beautiful beaches of the Pacific Ocean protected by a warm current.

Bernard M. Gordon Prize



Arthur Winston, Wm. A. Wulf, Bernard Gordon, Jerome Levy, and Harold Goldberg.

The Bernard M. Gordon Prize for Innovation in Engineering and Technology Education was awarded to Arthur W. Winston, Jerome E. Levy, and Harold S. Goldberg for the development of a multidisciplinary graduate program to educate engineering professionals to be leaders capable of applying technological solutions to societal and environmental problems. The Gordon Prize carries a stipend of \$500,000, half divided equally among the recipients and half given to the recipients' institution. The award was presented by **Bernard M. Gordon**, founder of NeuroLogica Inc.

The Tufts University School of Engineering Master of Science in Engineering Management (MSEM) Program emphasizes managerial and

leaderships skills, product innovation and development, and communication and teamwork skills. The two-year program combines a modular classroom curriculum and real-world projects to give students, who are all engineering professionals, experience in conceptualizing and analyzing problems and implementing real-world solutions to challenges that arise in the business environment. Today, MSEM graduates hold leadership positions in technology-driven companies in a wide range of industry sectors.

Arthur W. Winston is director of the Gordon Institute and Research Professor of Electrical Engineering at Tufts University. Former president of the Institute of Electrical and Electronics Engineers (IEEE) and an

IEEE (UK) Fellow, he is an expert in the fields of instrumentation and measurement. As one of the creators of the Gordon Institute, Dr. Winston oversees many curricula, including the Engineering Management Master's Degree and Entrepreneurial Leadership programs. He has published more than 100 papers and holds three patents.

Jerome E. Levy, a consultant with Northeastern University, and his colleagues led the development of the innovative curriculum of a 52-week course for the Gordon Institute. He was also involved in the recruitment of faculty and assisted in defining the mission and policies of the institute in preparation for accreditation. He was the first associate director of the institute and subsequently became dean.

After a successful career in industry, Harold S. Goldberg became associate dean and professor at the Gordon Institute, where he has taught the course on Engineering Project Methodology for the past 10 years. He believes that the concepts taught in the MSEM Program will be essential to the future of the electronics industry and other industries in the United States.

The **Bernard M. Gordon Prize**, named in honor of Bernard M. Gordon, chairman of NeuroLogica Inc., is endowed by the Gordon

Foundation. The award is given annually in recognition of significant advances in education, such as innovations in curriculum design, teaching methods, and technology-enabled learning, that lead to the development of engineering leaders.

Acceptance Remarks by Harold S. Goldberg

Let me first tell you how to start a college. The process takes many months, starting with the application, the written proposal, and discussions. Then comes a peer visitation to inspect facilities, faculty, and curriculum concepts. This is followed by open meetings, closed meetings, public meetings, private meetings, conferences with everyone, including the governor, presentations to the Board of Regents, meetings with the Board of Regents and, a vote by the Board of Regents and—finally, the Gordon Institute is born.

But the more important question is why. Why start a college in the early 1980s? Weren't there enough schools? To answer that question, we have to look back to the engineering profession in the mid-1970s and early 1980s. Corporate engineering departments, worldwide, were failing in cost, time, and specification control, and engineers were being called "poor managers" who were unable to lead.

Meanwhile, Bernie Gordon and his engineering teams at EPSCO, Gordon Engineering, and Analogic were developing product after

product, from the first air traffic controller equipment for the FAA to the star-tracking computer for the first Polaris missile submarine, the instrumentation package for NASA's Goddard Space Lab, digital x-ray, and many, many more, on time, on budget, within product cost limits, and within specifications. These products are in addition to his most famous products, high-speed A/D converters and, of course, CT scanners. It was obvious that Gordon's teams had a lock on a technical-project methodology that was, indeed, successful and unique.

We had to find a way to train our own engineering leaders, but at the time no one was teaching engineering students anything but technology and science. Students never learned the business of engineering, project engineering, or technical-leadership skills. Gordon made presentations and wrote articles to alert academia to these shortcomings, but academia wasn't impressed. Even endowing university chairs to teach engineering for industry failed to bring results.

And so, Bernie proposed that we set up our own technical-leadership school to teach what he had taught us. There were attitudes to change, methodologies to apply, financial information to garner, personal-interface concepts to master, and speaking and writing techniques to learn.

I took on the responsibility of getting a charter. Jerry Levy spearheaded the group writing the curriculum. We required each student

to prepare an original development project to practice the methodology, to analyze selected literature to learn how others handled leadership problems, and to learn corporate finance to understand the business of engineering. Both Jerry and I taught classes. Bernie supplied the building, the financing, and lots of support. He also gave guest lectures.

Art Winston joined us as a faculty member when classes started and set out to help us get accredited. And we succeeded. When it came time to join with Tufts University, we were a fully accredited college. Arthur modified the curriculum to conform to Tufts academic environment, introducing the "Practicum," a summer program of consulting projects for outside entities.

Our graduates returned to their companies excited about what they had learned. And they, in turn, set out to teach their own people. Our alumni rang up leadership achievements in their careers, and our school is now consistently oversubscribed. It's also gratifying to see how many colleges have since introduced technical-leadership courses and curricula. That's what we wanted in the first place. Our goal now is to keep the program exciting, meaningful, and successful, a paragon for others to follow.

We thank NAE and its selection committee for recognizing our program, and we especially thank Bernie Gordon for his vision and his confidence in us.

Grainger Challenge Prize



Rear Admiral William Hayden, Abul Hussam, winner of the Grainger Prize Gold Award, and Wm. A. Wulf.

The Grainger Challenge Prize for Sustainability was established by The Grainger Foundation for the purpose of stimulating innovation for the betterment of mankind, and by NAE, to promote the technological welfare of the nation and the application of innovative technologies to global problems. The specific challenge for the 2007 Grainger Challenge Prize was the design of water-treatment systems for arsenic-contaminated groundwater. NAE, with the generous support of The Grainger Foundation, awarded gold, silver, and bronze awards of \$1,000,000, \$200,000, and \$100,000, respectively, for the winning systems. The awards were presented by William B. Hayden of The Grainger Foundation.

Abul Hussam, an associate professor in the Department of Chem-

istry and Biochemistry at George Mason University, Fairfax, Virginia, received the Gold Award of \$1 million for his SONO filter, a point-of-use household water-treatment system that removes arsenic from drinking water. A top bucket is filled with locally available coarse river sand and a composite iron matrix (CIM). The sand filters coarse particles and imparts mechanical stability, while the CIM removes inorganic arsenic. The water then flows into a second bucket where it is again filtered through coarse river sand, then wood charcoal to remove organic contaminants. Finally, the water flows through fine river sand and wet brick chips to remove fine particles and stabilize water flow. The SONO filter is manufactured in Bangladesh.

The Grainger Challenge Silver Award of \$200,000 was awarded to Arup K. SenGupta, John E. Greenleaf, Lee M. Blaney, Owen E. Boyd, Arun K. Deb, and the nonprofit organization, Water For People, for their community water-treatment system. Each arsenic removal unit, which is installed at a community wellhead, serves about 300 households. Water is hand pumped into a fixed-bed column, where it passes through activated alumina or a hybrid anion exchanger (HAIX) to remove the arsenic. After passing through a chamber of graded gravel to remove particulates, the water is ready to drink. This system has been used in 160 locations in West Bengal, India.

The Bronze Award of \$100,000 was awarded to the Children's Safe Drinking Water Program at Procter & Gamble Co. (P&G), Cincinnati, Ohio, for the PUR™ Purifier of Water, a coagulation and flocculation water-treatment system. Dr. Greg Allgood is director of the program, which consists of emergency relief work and the establishment of not-for-profit markets to provide P&G's safe drinking-water technology to children and their families in the developing world.

The PUR™ technology combines chemicals for disinfection, coagulation, and flocculation in a sachet that can treat small batches of water in the home. The system is simple, portable, and can treat water from any source. First, the sachet contents are stirred into a 10-liter bucket of water for five minutes. As the water rests for another five minutes, arsenic and other contaminants separate out. The water is then poured through a



Presentation of the Grainger Prize Silver Award: Rear Admiral William Hayden, Lee Blaney, Arun Deb, Patrick McCann, Owen Boyd, John Greenleaf, Arup SenGupta, and Wm. A. Wulf.

clean cloth to filter out the contaminants. After another 20 minutes to complete the disinfection process, the water is safe to drink. As part of P&G's focal philanthropy program, the Children's Safe Water Drinking Program has worked with partners to provide 57 million sachets in more than 30 countries over the past three years, enough to purify more than 570 million liters of drinking water. In Bangladesh each sachet costs about the same as one egg.

Acceptance Remarks by Abul Hussam

First, I would like to thank The Grainger Foundation and the National Academy of Engineering for initiating this challenge of global significance and for honoring me with this prize. Ladies and gentlemen, today is a special day in my life. I want to dedicate this achievement to my late mother, Mrs. Nurun Nahar, and late father, Dr. M.A. Quasem, who taught us

that "hard work with full commitment aimed at human good is the essence of life" and that "objective truth-seeking is an uncompromising process."

We have been working on measurement and mitigation of arsenic—the two interlinked processes—for about the last 10 years. Accomplishment of this daunting



Rear Admiral William Hayden, Carolyn Brehm (accepting the Grainger Prize Bronze Award for Procter & Gamble's Children's Safe Drinking Water Program), and Wm. A. Wulf.

task could not have been possible without the thought-provoking intellectual support and unstinting cooperation of many—both in Bangladesh and in the United States. I owe them all.

I am especially indebted to my prime coworker, Dr. A.K.M. Munir, my brother, who was instrumental in the production, distribution, and dissemination of the SONO filter in Bangladesh. I am also indebted to Professor A.H. Khan, my mentor in analytical chemistry; Prof. M. Alauddin, a consistent collaborator; Dr. S.S. Newaz, a friend and a believer in the technology; and Professor Abul Barkat, another brother, who taught us the social and human developmental significance of this innovation. I also wish to thank my colleagues at George Mason University and the university administration for helping me in this endeavor. Finally, I would like to thank my wife, Meherun Nahar, and my children, Shaheer, Tasneem, Reshmaan, and Shareef, for their unwavering support throughout the process. Therefore, I

am accepting this prize on behalf of many, including those people who are at risk of arsenicosis for whom this innovation was created.

Our work started with a simple premise and a focused goal—to develop a filter to purify tube-well water of arsenic in a short time. After intensive trials, we found the active material called the composite iron matrix—which remains active for many years and produces quality potable water.

Ensuring the quality of the human condition is impossible without a sustained supply of safe and clean drinking water. In most underdeveloped and developing countries, many of the health hazards and ill-being arise from contaminated drinking water. In Bangladesh, arsenicosis has been proved as a disease of poverty, that is, the poor are disproportionately affected. Now that we have the technology to remove arsenic from groundwater, it is another challenge to urgently provide the technology to the people who need it most.

The Grainger Challenge for Sustainability and the solution to this problem have lifted the hopes and aspirations of millions of people in Bangladesh, India, and Nepal. It has generated genuine scientific and practical interest among the relevant people worldwide. While I am immensely honored to receive this recognition, there is no room for complacency. This is because, in South Asia alone, at least 500 million people are at risk of arsenicosis. More so, we still are not sure about the intergenerational impact of drinking arsenic-contaminated water.

Therefore, I humbly urge all relevant national governments and the international development partners—private, nongovernment, bilateral, and multilateral agencies—to support innovations appropriate for the local people as a means to achieve the UN Millennium Development Goals, particularly those of “eradication of poverty and hunger,” and “environmental sustainability.”

NAE Regional Meetings

Design: Engineering and Innovation

At an NAE regional meeting at Northwestern University on April 19, eight speakers explored relationships between engineering design, “design thinking,” and business innovation. The conference, “Design: Innovation and Engineering,” which featured speakers from Boeing, Microsoft, Motorola, IDEO, and Thornton Tomasetti, was co-sponsored by the Robert R. McCormick School of Engineering and Applied Science and the

Kellogg School of Management. The speakers covered a wide range of topics, from sinus surgery to the Boeing 787, as well as a variety of design methods, from software development to building-information modeling. Two of the speakers were **Julio M. Ottino**, dean of the McCormick School of Engineering and organizer of the meeting, and J. Edward Colgate, Pentair-Nugent Professor in the Department of Mechanical Engineering

and co-director of the Institute for Design Engineering and Applications (IDEA) and the Segal Design Institute at Northwestern.

Two main themes emerged from the meeting. First, design can be a powerful driver of technological innovation. Second, companies can gain competitive advantage by embracing users’ needs. These ideas are hardly new, but they have greater urgency and importance today than ever before.

In *Pasteur's Quadrant*, Donald Stokes' 1997 book, he attempted to identify the drivers of technological innovation. Stokes challenged the notion that basic research, performed *without consideration for use*, is the ultimate driver. To back his argument, he cited Louis Pasteur, whose research was inspired by specific, practical problems but often led to breakthroughs in fundamental understanding. Stokes identified Thomas Edison as the archetypal researcher whose goal was not *fundamental knowledge* and whose work led to technological innovations that are ubiquitous in our lives.

Although fundamental understanding is empowering, innovation cannot always wait for science. The Romans built aqueducts long before the laws of statics had been discovered, Edison developed practical electric lighting although he had little understanding of the electric behavior of materials, and the Wright brothers built an airplane with a limited understanding of aerodynamics. Innovators must be prepared to go where scientific understanding has not reached.

Of course, the world of today is not the world of the Romans or even of a nineteenth-century innovator like Edison. Fundamental understanding today runs vastly deeper and is expanding at a breakneck pace. Scientific and technological breakthroughs have led to myriad innovations—radar, lasers, GPS, MRI, and so on. Nevertheless, it seems

logical that many of the technological challenges confronting any age are necessarily beyond the limits of fundamental understanding.

Many of the issues discussed at the meeting arose from our inability to predict how people and technology will interact. **Phil Condit**, former CEO of Boeing, gave the example of noise levels in an aircraft cabin. He explained that engineers have traditionally monitored noise levels by measuring the average sound intensity at typical head level. In reality, however, passengers pay much less attention to ambient noise than to *unexpected* bumps, squeaks, and groans. Taking this into consideration, Boeing designed the 777 to deaden sounds from intermittent noise makers, such as hydraulic pumps, landing gears, and even toilet seats.

Lessening the sound of a falling toilet seat was one of many—often amusing—examples of *user-centered design* presented at the conference. Andrew Burroughs of IDEO Product Development described how his firm managed to engage surgeons in the design of a breakthrough instrument for sinus surgery. Jim Wicks of Motorola discussed the extensive worldwide testing required to understand perceived quality of cell phones. Todd Warren of Microsoft explained how the company uses personas and user testing to develop software for mobile platforms. And Stuart Harshbarger of the Applied Physics Lab at Johns Hopkins

University described the iterative development of a 22-degree-of-freedom prosthetic arm.

A common thread throughout these presentations was that not only were user needs considered, but also that “enlightened trial and error” was necessary to elucidate, and ultimately meet, those needs. Just as Edison used trial and error to overcome his lack of understanding of physics, designers today have used trial and error to overcome their lack of understanding of human perception and psychology.

One presentation that did not focus on user-centered design was a useful reminder of how fundamental understanding has empowered designers. Joseph Burns of Thornton Tomasetti described how “building-information models” have enabled architects like Frank Gehry to create remarkable new structures with predictable results. However, not even Burns, or building-information models, could predict the critics' reactions to these structures!

Everyone left the meeting with a renewed appreciation for the duality of technological innovation. Just as Newton could see farther by standing on the shoulders of giants (allusions to Hooke notwithstanding), good designers can accomplish more by understanding the state of the art in science and engineering. But designers must ultimately be able—by superior trial and error—to overcome partial or inadequate understanding.

Advancing the Future of Healthcare Delivery

The NAE Regional Meeting at Purdue University on April 23–24, 2007, was held in conjunction with Purdue's Discovery Lecture Series

and the annual conference of the Regenstrief Center for Healthcare Engineering. The overall theme was “Advancing the Future of

Healthcare Delivery: Access, Quality and Responsibility.” The lecture series and conference featured speakers who embodied the spirit of

innovation, boldness, and interdisciplinary endeavor that characterizes Discovery Park, Purdue's hub for interdisciplinary research.

The Regenstrief Center for Healthcare Engineering was founded in January 2005 to apply the principles of engineering, management, and science to transform the health care delivery system, as was recently advocated in a report by NAE and the Institute of Medicine, *Building a Better Delivery System: A New Engineering/Health Care Partnership*. In the last two-and-a-half years, projects have demonstrated how systems-engineering methodologies could vastly improve the efficiency, effectiveness, safety, and quality of health care delivery in the United States. By bringing together people with engineering expertise and representatives of national health care industries, the Regenstrief Center is ideally situated to effect changes in health care delivery.

Two national leaders in health

care delivered keynote addresses. The talk by Stephen Shortell, dean of the School of Public Health at the University of California at Berkeley, was called "Marriage of Medicine and Management: Sustaining Improvements in Delivery, Quality, Cost, and Outcomes." An expert on organizing health care delivery systems, Dr. Shortell has received the Baxter-Allegiance Prize, an extremely prestigious award, for his research on institutional incentives for improving the quality of care, particularly for patients with chronic illnesses.

Karen Davis, president of the Commonwealth Fund, then spoke on "Achieving the Best: The Road to Improving National Performance of Healthcare Delivery." Dr. Davis is a nationally recognized economist with a distinguished career in public policy and research. The first woman to head a U.S. public health service agency, she served as deputy assistant secretary for

health policy in the Department of Health and Human Services from 1997 to 1980.

The second day of the conference was based on a CEO-level summit held last year at Purdue, at which health care executives representing a cross section of the health care supply chain were challenged to design the U.S. health care delivery system for the next generation. The conference sessions this year addressed equitable access, consumer-driven health care, wellness and prevention, and alternative models for providing care. Speakers and attendees represented many key stakeholders in health care delivery—Ascension Health, WellPoint, Indiana Hospital & Health Association, Indiana State Department of Health, Veterans Administration, and the Indiana University School of Medicine. Additional information about the Regenstrief Center for Healthcare Engineering is available at www.purdue.edu/rche.

Calendar of Meetings and Events

May 10–11	NAE Council Meeting Darby, Montana	July 31	NAE Council Orientation	October 8	CASEE Advisory Committee Meeting Milwaukee, Wisconsin
June 6	NAE Finance and Budget Conference Call	August 1–2	NAE Council Meeting Woods Hole, Massachusetts	October 9–10	Dane and Mary Louise Miller Symposium and CASEE Annual Meeting Milwaukee, Wisconsin
June 14	NRC Governing Board Executive Committee Meeting	September 12	NRC Governing Board Executive Committee Meeting	All meetings are held in the Academies buildings, Washington, D.C., unless otherwise noted.	
June 20	NAE/NAEF Audit Committee Meeting	September 24–26	U.S. Frontiers of Engineering Symposium Redmond, Washington		
July 11	NRC Governing Board Executive Committee Meeting	September 30– October 1	NAE Annual Meeting		

In Memoriam

ROBERT ADLER, 93, retired technical consultant, Zenith Electronics Corporation, and technical consultant, died on February 15, 2007. Dr. Adler was elected to NAE in 1967 for "the development of microwave tubes."

JOHN BACKUS, 82, retired fellow, IBM Almaden Research Center, died on March 17, 2007. Dr. Backus was elected to NAE in 1997 for "the development of programming languages, especially FORTRAN, for use in scientific and engineering computation."

ROBERT R. BERG, 82, professor of geology and Michel T. Halbouty Chair, Emeritus, Department of Geology, Texas A&M University, died on June 13, 2006. Dr. Berg was elected to NAE in 1988 for "outstanding contributions concerning the migration, accumulation, and production of oil through the development of concepts to quantify reservoir depositional systems."

ROBERT H. CURTIN, 90, retired vice president, Ralph M. Parsons Company, died on March 12, 2007. Dr. Curtin was elected to NAE in 1986 for "outstanding leadership in the engineering design and construction of large, complex ground support structures for aeronautical and space activities."

SHELDON K. FRIEDLANDER, 79, Parsons Professor of Chemical Engineering and director, Nanoparticle Technology/Air Quality, Engineering Lab, University of California, Los Angeles, died on February 9, 2007. Dr. Friedlander was elected to NAE in 1975 for "contributions to the understanding of the origin and control of pollution by particulate matter."

JAMES HILLIER, 91, retired executive vice president and senior scientist, RCA Corporation, died on January 15, 2007. Dr. Hillier was elected to NAE in 1967 for "the development of electron microscopy."

ALAN G. MACDIARMID, 79, James Von Ehr Distinguished Chair in Science and Technology and professor of chemistry and physics, University of Texas, died on February 7, 2007. Dr. MacDiarmid was elected to NAE in 2002 for the "co-discovery and development of conductive polymers."

DUANE T. MCRUER, 81, retired chairman, Systems Technology Inc., died on January 24, 2007. Mr. McRuer was elected to NAE in 1988 for the "pioneering application of guidance and control theory and to experimental man-machine interactions."

JAMES Y. OLDSHUE, 81, president, Oldshue Technologies International, died on January 16, 2007. Dr. Oldshue was elected to NAE in 1980

for "pioneering work in establishing the fluid mechanics of mixing and its practical application to industrial and municipal processing."

BRIAN H. ROWE, 75, Chairman Emeritus, GE Aircraft Engines, died on February 22, 2007. Mr. Rowe was elected to NAE in 1983 for "extraordinary contributions to the conception, design, development, and application of advanced high performance aircraft gas turbine engines."

CHAUNCEY STARR, 95, President Emeritus, Electric Power Research Institute Inc., died on April 17, 2007. Dr. Starr was elected to NAE in 1965 for his "pioneering work in the development of atomic power."

JOHN G. TRUXAL, 82, Distinguished Teaching Professor, Emeritus, College of Engineering and Applied Science, State University of New York, died on February 16, 2007. Dr. Truxal was elected to NAE in 1965 for his "work as a control systems engineer."

HENNING E. VON GIERKE, 89, clinical professor, Wright State University School of Medicine, died on March 10, 2007. Dr. von Gierke was elected to NAE in 1976 for his "pioneering work on the effects of noise, sonic boom, and vibration on humans; leadership in bionics; and the invention of acoustic devices."

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 (888) 624-8373. (Note: Prices quoted are subject to change without notice. Online orders receive a 10 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.)

Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. In a world in which advanced knowledge is widespread and low-cost labor is readily available, U.S. advantages in the marketplace and in science and technology (S&T) are being eroded. A comprehensive, coordinated federal effort is urgently needed to bolster U.S. competitiveness and ensure that the country remains preeminent in S&T and take advantage of the opportunities offered by rapid globalization. This congressionally requested report by a 20-member committee that included university presidents, CEOs, Nobel Prize winners, and former presidential appointees offers four recommendations and details 20 "implementation actions" for federal policy makers, including

steps for creating high-quality jobs in the United States and focusing new S&T projects on the development of clean, affordable, reliable energy.

NAE member **Norman R. Augustine**, retired chairman and CEO, Lockheed Martin Corporation, chaired the study committee. Other NAE members on the study committee were **Craig R. Barrett**, chairman of the board, Intel Corporation; **Charles O. Holliday Jr.**, chairman and CEO, Dupont; **Shirley Ann Jackson**, president, Rensselaer Polytechnic Institute; **Anita K. Jones**, Lawrence R. Quarles Professor of Engineering and Applied Science, University of Virginia; **C. Dan Mote Jr.**, president and Glenn Martin Institute Professor of Engineering, University of Maryland; **Cherry A. Murray**, deputy director for science and technology, Lawrence Livermore National Laboratory; **Lee R. Raymond**, chairman and CEO, Exxon Mobil Corporation; **Charles M. Vest**, President Emeritus, Massachusetts Institute of Technology; and **George M. Whitesides**, Woodford L. and Ann A. Flowers University Professor, Harvard University. Hardback, \$59.95.

Innovation Inducement Prizes at the National Science Foundation. Following a congressional directive in the FY 2006 Appropriations Act, the National Science Foundation (NSF) asked the National Research Council Board on Science, Technology, and Economic Policy (STEP) to "propose a plan for administering prizes to individuals or teams that achieve novel solutions to specified

social or research needs or capitalize on recognized research opportunities." Under the auspices of STEP, a committee of experts conducted this study and concluded that an ambitious program of innovation-inducement prize contests would be a sound investment in the infrastructure for U.S. innovation and that NSF, although inexperienced in this area, is well suited to designing an experimental program to help establish goals for such contests, analyze the motivations of participants and sponsors, and develop rules and conditions for contests. The committee recommends that NSF begin with small-scale prizes (\$200,000 to \$2 million) in various areas, and, at the same time, plan for much more ambitious contests (\$3 million to \$30 million) that would address significant economic or social challenges and be administered over a period of several years. The report addresses many generic aspects of administering innovation prize contests (e.g., types of contests, eligibility criteria, intellectual property rights, and decisions regarding awards) and identifies seven research and technology fields that might be appropriate for contests.

NAE members on the study committee were **Erich Bloch**, principal, Washington Advisory Group, and **Merton C. Flemings**, director, Lemelson-MIT Program, and Toyota Professor Emeritus, Massachusetts Institute of Technology. Paper, \$18.00.

Letter Report: Review and Assessment of Industrial Hygiene Standards

and Practices at Tooele Chemical Agent Disposal Facility.

As part of continuing efforts to destroy the nation's stockpile of chemical weapons, the U.S. Army Materiel Command conducted a Surety Management Review (SMR) to evaluate the industrial hygiene (IH) program at the Tooele Chemical Agent Disposal Facility (TOCDF). After the SMR, the IH program at TOCDF was rated "Mission Capable with Limitations." To ensure that the assessment was authoritative and independent, the Chemical Materials Agency requested that the National Research Council also review and assess the IH standards and practices at TOCDF as related to the SMR. This letter report presents an analysis of the SRM findings; an overview of the TOCDF IH program; a comparison of performance at TOCDF and specification standards; and recommendations for improving both the IH program and the review.

NAE member **Richard A. Conway**, retired senior corporate fellow, Union Carbide Corporation, was a member of the study committee. Free PDF.

Assessment of the Continuing Operability of Chemical Agent Disposal Facilities and Equipment.

The U.S. Army's Chemical Materials Agency (CMA) currently oversees contracts for the operation of facilities for incinerating stockpiled chemical agents at four disposal sites. Because the time required to dispose of these chemical agents has been extended beyond the original schedule, the Army is becoming concerned that operational problems may arise as the processing equipment ages. To help address these concerns, the CMA requested that the National Research

Council assess whether current policies and practices are adequate for anticipating and addressing facility obsolescence. This report presents: (1) a review of potential weaknesses in infrastructure and equipment as facilities are operated well beyond their original design lifetime; (2) an assessment of the Army's current and evolving obsolescence-management programs; and (3) recommendations for improving these programs to ensure the safe and expeditious completion of agent stockpile destruction operations and facility closures.

NAE member **Elisabeth M. Drake**, retired associate director for new energy technology, Energy Laboratory, Massachusetts Institute of Technology, chaired the study committee. Paper, \$18.00.

Enhancing Productivity Growth in the Information Age: Measuring and Sustaining the New Economy.

In the mid-1990s, there was an unprecedented upsurge in the U.S. economy, and rapid technological changes in communications, computing, and information management continue to promise gains in productivity, a phenomenon often referred to as the "new economy." The National Academies Board on Science, Technology, and Economic Policy initiated a project to measure the contributions of different elements of the "new economy" (semiconductors, computers, software, and telecommunications) and develop policies to meet the needs of these industries. Accompanied by four workshop reports, this summary volume describes the steps that should be taken to measure and sustain the benefits of the new economy in these sectors.

NAE member **William J. Spencer**, Chairman Emeritus, SEMATECH,

was vice chair of the study committee. Paper, \$35.50.

Interim Report on Methodological Improvements in the Department of Homeland Security's Biological Agent Risk Analysis.

In 2004, the president issued a homeland security directive on defending against biological weapons. This directive, along with the National Strategy for Homeland Security published in 2002, mandated that the U.S. Department of Homeland Security (DHS) conduct assessments of the biological-weapons threat to the nation. To assist in this project, DHS asked the National Research Council to conduct a study of the methodology used by the agency to prepare the first bioterrorism risk assessment. This interim report provides a preliminary examination of the methodology, near-term guidance, and recommendations for further development of DHS' risk analysis models. A final report will address long-term issues in DHS' development of risk assessment capabilities.

NAE member **Stephen M. Pollock**, Herrick Emeritus Professor of Manufacturing, University of Michigan, was a member of the study committee. Free PDF.

SBIR and the Phase III Challenge of Commercialization: Report of a Symposium.

The commercialization of products and processes funded by Small Business Innovation Research (SBIR) awards is essential to the program's mission of contributing to government missions. To identify challenges inherent in converting promising research to useful products and processes, the National Research Council convened a conference focused on the commercialization of SBIR-funded innovations

at the U.S. Department of Defense (DOD) and National Aeronautics and Space Administration (NASA). The conference brought together, for the first time, program managers, small business leaders, and prime contractor personnel involved in commercializing the results of SBIR awards through procurement by DOD and NASA. The participants not only identified challenges, but also defined best practices used in successful cases of commercialization, the third phase of the SBIR program. The conference proceedings, captured in this report, identify obstacles and opportunities in this phase of the SBIR program and will be helpful in the development of legislation to address these challenges.

NAE member **Jacques S. Gansler**, vice president for research, professor, and Roger C. Lipitz Chair in Public Policy and Private Enterprise, School of Public Policy, University of Maryland, chaired the study committee. Other NAE members on the committee were **Trevor O. Jones**, chairman and founder, BIOMECH Inc.; **Duncan T. Moore**, professor, Institute of Optics, University of Rochester; and **Charles R. Trimble**, chairman, U.S. Global Positioning System Industry Council. Paper, \$41.50.

Sustainable Management of Groundwater in Mexico: Proceedings of a Workshop. This report includes papers presented at a workshop in Merida, Mexico, Strengthening Science-Based Decision Making: Sustainable Management of Groundwater in Mexico. The cross-cutting themes of the workshop were (1) the elements or principles of science-based decision making and (2) how the scientific community can ensure that science is an integral part of

the decision making process. Papers included in this volume describe the groundwater resources of Mexico's Yucatan Peninsula, approaches to managing groundwater in Mexico, and governmental and scientific institutions concerned with water resources. Other papers describe U.S. approaches to managing scarce water resources. Participants in the workshop included representatives of leading scientific and academic institutions; federal, state, and local governments; nongovernmental organizations; and businesses.

NAE member **Perry L. McCarty**, Silas H. Palmer Professor Emeritus, Stanford University, was a member of the workshop steering committee. Paper, \$29.00.

Scientific Opportunities with a Rare-Isotope Facility in the United States.

More than 10 years ago, U.S. nuclear scientists proposed that a new rare-isotope accelerator be constructed in the United States that could house experiments on important questions in nuclear physics. To help assess this proposal, the U.S. Department of Energy (DOE) and National Science Foundation asked the National Research Council to define a science agenda for a next-generation U.S. facility for rare-isotope beams (FRIB). As the study began, however, DOE announced a substantial reduction in the scope of the facility and that the initial operation date would be pushed back by several years. As a result, the study is focused on an evaluation of science experiments for a smaller, less-capable facility. The report includes a discussion of the key science drivers for an FRIB, an assessment of existing domestic and international rare-isotope beams, an assessment of the current U.S. position related to

an FRIB, and findings and conclusions about the scientific and policy context for an FRIB.

NAE member **John F. Ahearne**, director, Ethics Program, Sigma Xi, The Scientific Research Society, was co-chair of the study committee. Paper, \$18.00

NOAA's Role in Space-Based Global Precipitation Estimation and Application.

The National Oceanic and Atmospheric Administration (NOAA) uses precipitation data in many applications, including hurricane forecasting. Currently, these data are collected from the Tropical Rainfall Measuring Mission (TRMM) satellite, which was launched in 1997 by the National Aeronautics and Space Administration (NASA) in cooperation with the Japan Aerospace Exploration Agency. NASA is planning to launch the Global Precipitation Measurement (GPM) Mission in 2013 to succeed TRMM, which was originally intended to last three to five years but has enough fuel to remain in orbit until 2012. The GPM Mission will consist of a "core" research satellite and "constellation" satellites that provide global precipitation data at three-hour intervals. This report, the second of two from the National Research Council on the future of rainfall-measuring missions, recommends that NOAA begin preparations for the GPM Mission as soon as possible and develop a strategic plan for the mission based on experience with TRMM. The first report in the series, *Assessment of the Benefits of Extending the Tropical Rainfall Measuring Mission* (2004), determined that TRMM provides high-quality, unique, extremely useful data and recommended that its mission be extended as long

as possible. NASA has officially extended TRMM to 2009.

NAE member **Eugene M. Rasmusson**, Research Professor Emeritus, University of Maryland, chaired the study committee, and NAE member **Kristina B. Katsaros**, retired director, Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, was a member of the study committee.

Science and Technology in Kazakhstan: Current Status and Future Prospects.

Kazakhstan has an ambitious five-year program to improve its technological competitiveness in the global marketplace, but achieving that goal will depend in large measure on upgrading the country's science and technology (S&T) capabilities. This report identifies opportunities and limitations in the educational system, research and development institutions, production companies, and service organizations. The report is intended to help governmental organizations in Kazakhstan with strong interests in S&T chart a course for their country.

NAE member **Alvin W. Trivelpiece**, retired director, Oak Ridge National Laboratory, and retired president, Lockheed Martin Energy, chaired the study committee. Paper, \$35.75.

Scientific Review of the Proposed Risk Assessment Bulletin from the Office of Management and Budget. Risk assessments are often used by the federal government to estimate risks to the public from exposure to chemicals

or the potential failure of engineered structures. These risk assessments are often used to develop or modify government regulations. In January 2006, the White House Office of Management and Budget (OMB) issued a draft bulletin for all federal agencies that included a new definition of risk assessment and proposed standards for improving federal risk assessments. This National Research Council report, written at the request of OMB, supports the overall goals of improving the quality of risk assessments, but concludes that the draft bulletin is "fundamentally flawed" from a scientific and technical standpoint and should be withdrawn. Problems include (1) an overly broad definition of risk assessment that conflicts with long-established concepts and practices and (2) an overly narrow definition of adverse health effects that defines only clinically apparent effects as adverse and ignores other biological changes that could lead to health effects. The report also criticizes the draft bulletin for focusing mainly on risk assessments of human health and neglecting assessments of technology and engineered structures.

NAE member **John F. Ahearne**, director, Ethics Program, Sigma, Xi, The Scientific Research Society, chaired the study committee. Other NAE members on the study committee were **Gregory B. Baecher**, professor, Department of Civil and Environmental Engineering, University of Maryland; **William E. Kastenber**, Daniel M. Tellep Distinguished Professor in Engineering,

University of California, Berkeley; and **Danny D. Reible**, Bettie Margaret Smith Chair of Environmental Health Engineering, University of Texas, and co-director, Hazardous Substance Research Centers/South and Southwest, U.S. Environmental Protection Agency. Paper, \$62.75.

Science and Technology to Counter Terrorism: Proceedings of an Indo-U.S. Workshop. This volume includes the papers and summarizes the discussions of a workshop held in Goa, India, in January 2004. The workshop was organized by the Indian National Institute of Advanced Science (NIAS) and the U.S. Committee on International Security and Arms Control (CISAC). During the workshop, Indian and U.S. experts examined terrorist threats facing their countries and explored opportunities for the United States and India to work together to counter those threats. The workshop brought together scientists and experts with common scientific and technical backgrounds from different cultures to explore ways of preventing or mitigating future terrorist attacks.

NAE member **C. Kumar N. Patel**, chairman, Pranalytica Inc., chaired the workshop organizing committee. Other NAE members on the organizing committee were **Richard L. Garwin**, IBM Fellow Emeritus, IBM Thomas J. Watson Research Center, and **John P. Holdren**, Teresa and John Heinz Professor of Environmental Policy, Harvard University. Paper, \$38.25.

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