Winter 2009

**FRONTIERS OF ENGINEERING**

# The BRIDGE

LINKING ENGINEERING AND SOCIETY



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# The BRIDGE

## NATIONAL ACADEMY OF ENGINEERING





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# The BRIDGE

LINKING ENGINEERING AND SOCIETY

## Editor's Note



## Features



## NAE News and Notes



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# Editor's Note

Andrew M. Weiner

## Crossing New Frontiers

### Papers from the 2009 U.S. Frontiers of Engineering Symposium

Every year the NAE U.S. Frontiers of Engineering (US FOE) Symposium brings together approximately 100 outstanding young engineers, aged 30 to 45, to share ideas and learn about cutting-edge research on a variety of engineering topics. A unique characteristic of FOE symposia is that participants are competitively selected from the full spectrum of engineering disciplines, with the intent of identifying individuals who are emerging as (or are already) engineering leaders in academia, industry, and government. FOE offers them a unique opportunity to learn about significant, up-to-date developments in engineering areas other than their own and to meet and network with promising young engineers in other fields and from a variety of institutions.

The fifteenth US FOE Symposium was held September 10–12, 2009, at the National Academies Beckman Center in Irvine, California. The meeting was organized into independent sessions with the following themes: engineering tools for scientific discovery; nano/micro photonics and new applications; engineering the health care delivery system; and resilient and sustainable infrastructures. Five papers based on this year's presentations are included in this issue of *The Bridge*.

The first session, "Engineering Tools for Scientific Discovery," was chaired by Louise Hamlin of the Jet Propulsion Laboratory, J. Christopher Love of the Massachusetts Institute of Technology, and Naren Ramakrishnan of Virginia Tech. The four talks covered spatial scales ranging from the very small (tools for studying self-assembly mechanisms in nanotechnology) to the very large (instruments for monitoring the behavior of whales and dolphins and instruments for space exploration). Carla Gomes, whose paper is included in this issue (p. 5), described a new interdisciplinary field, computational sustainability, that uses computational and mathematical models, methods, and tools to manage and balance environmental, economic, and societal needs. She provided examples of applications in biodiversity and species conservation, natural resource management, and energy efficiency.

The session on "Nano/Micro Photonics and New Applications," chaired by Michal Lipson of Cornell University and Nelson Tansu of Lehigh University, featured four talks on innovative photonic effects and device concepts and their engineering applications. An article based on one of these presentations is included in this issue. In a paper beginning on p. 14, Lukas Novotny discusses optical antennas, devices that convert energy between freely propagating electromagnetic fields and fields localized at the nanoscale. Although antennas at radio frequencies have a long history, the behavior of metals in the optical range is unique, and the concept of optical antennas has only recently emerged. Optical antennas have the potential to increase the efficiency of light-matter interactions at spatial scales below the usual optical wavelength limit, with applications that include light emitters, photovoltaics, and spectroscopic sensing.

The session on "Engineering the Health Care Delivery System," chaired by Stephanie Guerlain of the University of Virginia and Eva K. Lee of Georgia Tech, included presentations on information technology in the medical and health care sectors, sometimes called health information technology (HIT). Two papers from this session are published here. In an article (beginning on p. 21), David Dorr introduces a care-management model for coordinating the health care of older adults who have chronic illnesses. In this model, care managers, assisted by targeted use of HIT, facilitate communication, coordination, and implementation of flexible protocols in the context of a comprehensive care plan.

In the second paper from this session, provocatively entitled "Why Health Information Technology Doesn't Work," Elmer Bernstam and Todd Johnson review the current status of HIT, which has been touted as a solution to some of the critical problems plaguing U.S. health care delivery. The paper (beginning on p. 30) focuses on social and administrative barriers to the adoption of HIT and research challenges that must be addressed for it to be accepted and used effectively.

The final session, "Resilient and Sustainable Infrastructure," was chaired by Seth Guikema of Johns Hopkins University and Patrick O'Mara of STV. One paper from this session, by Stephanie Chang (p. 36), describes a new research area that encompasses the complexities of infrastructure systems impacted by disasters. The multidisciplinary approach she describes spans engineering, economics, and social science to identify and address interactions among failures in infrastructure systems and the effects of multiple hazards. The information can then be used as a basis for designing more resilient infrastructure systems for the future.

In addition to the presentations, FOE symposia provide lively Q&A sessions, panel discussions, and other activities that promote personal interactions and networking. The dinner speaker, a traditional highlight of FOE programs, was **Bradford Parkinson**, Edward C. Wells Professor of Aeronautics and Astronautics, Emeritus, at Stanford University. Dr. Parkinson delivered an engaging account of the development of the global positioning system (GPS), in which he played a key role.

It was my great privilege to serve as chair of the Organizing Committee for this year's US FOE Symposium. I want to close by expressing my gratitude to Janet Hunziker, NAE Program Officer, and **Lance Davis**, NAE Executive Officer, for their contributions to the planning and implementation of this unique meeting and to thank the sponsors: The Grainger Foundation, Arnold O. and Mabel Beckman Foundation, Air Force Office of Scientific Research, Defense Advanced Research Projects Agency, Department of Defense (Office of the Director, Defense Research and Engineering), National Science Foundation, Microsoft Research, and Cummins Inc.

*Researchers in computing, information science, and many other disciplines are working together to support sustainable development.*

# Computational Sustainability

## Computational Methods for a Sustainable Environment, Economy, and Society

Carla P. Gomes is associate professor, Faculty of Computing and Information Science, Department of Computer Science and Department of Applied Economics and Management, Cornell University.

Carla P. Gomes

The dramatic depletion of natural resources in the last century now threatens our planet and the livelihood of future generations. *Our Common Future*, a report by the World Commission on Environment and Development published in 1987, introduced for the first time the notion of "sustainable development: development that meets the needs of the present without compromising the ability of future generations to meet their needs" (UNEP, 1987). The concerns raised in that report were reiterated by the Intergovernmental Panel on Climate Change (IPCC, 2007). In the fourth Global Environmental Outlook report published later that same year the authors concluded, "there are no major issues raised in *Our Common Future* for which the foreseeable trends are favorable" (UNEP, 2007).

Key issues in the development of policies for sustainable development will entail complex decisions about the management of natural resources and more generally about balancing environmental, economic, and societal needs. Making such decisions optimally, or nearly optimally, presents significant computational challenges that will require the efforts of researchers in computing, information science, and related disciplines, even though environmental, economic, and societal issues are not usually studied in those disciplines.

In this author's opinion, it is imperative that computer scientists, information scientists, and experts in operations research, applied mathematics, statistics, and related fields pool their talents and knowledge to help find efficient and effective ways of managing and allocating natural resources. To that end, we must develop critical mass in a new field, computational sustainability, to develop new computational models, methods, and tools to help balance environmental, economic, and societal needs for a sustainable future.

Examples of computational sustainability problems presented in this short paper range from wildlife preservation and biodiversity to balancing socio-economic needs and the environment to the large-scale deployment and management of renewable energy sources.

*Computational sustainability will give us the tools to balance environmental, economic, and societal needs.*

**Biodiversity and Species Conservation**

The reduction and fragmentation of natural habitats as a result of deforestation, agriculture, urbanization, and land development is a leading cause of species decline and extinction. One strategy for improving the chances of species viability is to protect habitats by creating biologically valuable sites or reserves. Examples include the National Wildlife Refuge System, managed by the U.S. Fish and Wildlife Service, national parks, and conservation reserves established by private groups, such as the Nature Conservancy and the Conservation Fund.

Given the limited resources available for conservation, these sites must be carefully chosen. From a mathematical point of view, the site-selection or reserve-design problem involves optimizing certain criteria, such as habitat suitability for species, while simultaneously satisfying one or more constraints, such as limited budgets (e.g., Ando et al., 1998; Moilanen et al., 2009; Polasky et al., 2008).

In recent years biologists attempting to combat habitat fragmentation have promoted so-called "conservation corridors," continuous areas of protected land that link biologically significant zones. The design of conservation corridors is a special aspect of the site-selection problem, and the objective is to create connected corridors made up of parcels of land that will yield the highest possible level of environmental benefit ("utility") (Onal and Briers, 2005; Williams et al., 2005).

At the Institute for Computational Sustainability (ICS) at Cornell University, we recently formulated this problem mathematically as a so-called "connection sub-graph problem" (Conrad et al., 2007; Dilkina and Gomes, 2009; Gomes et al., 2008). The goal was to design wildlife corridors for grizzly bears in the U.S. northern Rockies to enable movement between three core ecosystems—Yellowstone, Salmon-Selway, and Northern Continental Divide Ecosystems—that span 64 counties in Idaho, Wyoming, and Montana. This large-scale optimization problem places significant demands on current computational methods.

To scale up solutions, we needed a deeper understanding of the underlying structure of the problem. To that end, we developed a budget-constrained, utility-optimization approach using hybrid constraint-based mixed-integer programming that exploits problem structure. Our results showed that we can dramatically reduce the cost of large-scale conservation corridors by provably finding corridors with minimum cost. If more than minimum funding for a corridor is available, this approach guarantees optimal utility. For example, for the grizzly bear problem our solutions are guaranteed to be within 1 percent of the optimal solution for budget levels above the minimum cost.

Complexity in site-selection and corridor-design problems increases when different models for land acquisition over different time periods (e.g., purchase, conservation easements, auctions), dynamic and stochastic environments, and multiple species must be considered. For example, preserving bird habitats and designing bird corridors requires a good understanding of hemispheric-scale bird migrations with complex population dynamics across different climate and weather systems and geographic topologies.

Thus modeling complex species distributions and developing conservation strategies requires new large-scale stochastic-optimization methods. Moreover, to obtain the right model parameters and determine current species distribution, machine learning and statistical techniques must be used to analyze large amounts of raw data (Dietterich, 2009; Elith et al., 2006; Kelling et al., 2009; Phillips et al., 2004).

Gathering biological, ecological, and climatic data is essential to studying complex systems, and the deployment of large-scale sensor networks is becoming a key tool for environmental monitoring (e.g., Polastre et al., 2009; Werner-Allen et al., 2006). The National Science Foundation (NSF) supports several cyber-infrastructure initiatives for massive data collection and data analysis based on large-scale autonomous sensor networks, such as the National Ecological Observatory Network (NEON) and the Long-Term Ecological Research Network (LTER).

Designing a large-scale sensor network also presents computational challenges (e.g., network architecture, operating system and programming environments, data collection, analysis, synthesis, and inference) (Akyildiz et al., 2007). For example, when using sensor networks to monitor spatial phenomena, selecting the best placement of sensors to maximize information gain while minimizing communication costs is a complex problem that requires new techniques (Krause and Guestrin, 2009).

Citizen observation networks have several benefits. They help in collecting data and, at the same time, enable the general public to engage in scientific investigation and develop problem-solving skills. Galaxy Zoo,[1] for example, provides access to a large collection of images and engages the general public in classifying galaxy shapes to improve our understanding of their formation. eBird,[2] a joint initiative of the Cornell Laboratory of Ornithology and the National Audubon Society, engages citizen-scientists in observing birds using standardized protocols. Since eBird was released in 2002, it has been visited by more than 500,000 users and has collected more than 21 million bird records from more than 35,000 unique users in more than 180,000 locations across the Western Hemisphere and New Zealand (Sullivan et al., 2009).

#### Management of Natural Resources

This example concerns the state of marine fisheries. The biomass of top marine predators is estimated to be one-tenth of what it was half a century ago and is still declining (Worm et al., 2006). As a result of overfishing, pollution, and other environmental factors, many important marine species are extinct, with dramatic consequences for the filtration of nutrients by the ocean. Researchers believe that the collapse of major fisheries is primarily the result of mismanagement (Clark, 2006; Costello et al., 2008). Therefore, we must find sustainable ways of managing fisheries.

One approach that has been shown to be effective for counterbalancing the overharvesting of fisheries involves both placing limitations on total allowable catches per species and requiring permits for harvesting specific quantities of fish (individual transferable quotas) (Costello et al., 2008; Heal and Schlenker, 2008; Worm et al., 2009). Complex dynamical models, originally developed as part of dynamical systems theory, can be used to identify the optimal amount of fish that can be harvested annually in a certain fishery, taking into consideration re-generation rates, carrying capacity of the habitat, discount rates, and other parameters.

Dynamical systems theory, which provides tools for characterizing the dynamics and long-term behavior of systems as a function of the system parameters, provides insights into nonlinear system dynamics and identifies patterns and laws, particularly bifurcations (Ellner and Guckenheimer, 2006; Strogatz, 1994). A bifurcation occurs when small changes in the parameter values of a system (e.g., the rate of harvesting fish) lead to an abrupt qualitative change (e.g., the collapse of a fishery). Decisions (e.g., the amount of fish to be harvested) are often based on combinations of continuous and discrete variables. This leads to hybrid dynamical optimization models, which, in principle, provide information on optimal harvesting strategies (Clark, 1976; Conrad, 1999). However, finding such strategies is computationally difficult, especially when considering multiple species.

*The biomass of top marine predators is about one-tenth of what it was 50 years ago.*

#### Balancing Socioeconomic and Environmental Needs

Chris Barrett of ICS has studied the socioeconomic interrelationship between poverty, food security, and environmental stress in Africa, particularly links between resource dynamics and the poverty trap in small-holder agrarian systems (Barrett et al., 2007). Barrett's focus has been on pastoral systems in East Africa that involve herds of cattle, camels, sheep, and

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[1] Available online at *http://www.galaxyzoo.org/*.

[2] Available online at *http://ebird.org/content/ebird*.

goats (Luseno et al., 2003). Due to high variability in rainfall, pastoralists must migrate with their herds looking for water and forage, sometimes traveling as much as 500 kilometers.

The purpose of our studies is to develop a predictive model of the migratory patterns and decision models of these pastoralists. To do that, we use machine-learning methods to determine the structure and estimate the parameters of the models, based on field data about households, water sources, and climate patterns.

Ultimately, these models will help policy makers predict the effects of potential policy interventions and environmental changes, with the goal of improving the livelihoods of thousands of pastoralists. The project involves new technical approaches to large, structural-dynamic, discrete-choice problems that will lead to the development of computational models to support both descriptive studies and predictive policy analyses (Toth et al., 2009).

Other computational sustainability topics in this context include automated decision-support tools for providing humanitarian aid in response to catastrophes, famines, and natural disasters in developing countries. The design of such systems will require the development of intuitive, user-friendly interfaces for use by aid workers.

*Data centers emit more $CO_2$ than Argentina and the Netherlands.*

#### Energy-Efficient Data Centers

The implications of climate change for environmental, economic, and social systems have led to major changes in energy policy in many industrial countries, including incentives for increasing energy efficiency. These incentives present tremendous computational opportunities for helping to increase energy efficiency through the design of intelligent or "smart" control systems for energy-efficient buildings, vehicles, and appliances.

According to the World Business Council for Sustainable Development (2008), buildings account for as much as 40 percent of energy use in industrialized countries. Data centers (i.e., computing facilities with electronic equipment for data processing, storage, and communications networking) are especially inefficient users of energy.

In recent years the shift to digital services has led to a major increase in demand for data centers. The Environmental Protection Agency estimates that in the next decade the demand for data-center capacity will grow at a 10 percent compounded annual growth rate (EPA, 2007). In addition, the costs of data centers in the information technology (IT) sector are estimated to increase at an annual rate of 20 percent, compared to an overall increase in IT of 6 percent (Kaplan et al., 2008).

Data centers also have negative environmental impacts. According to a recent report, the amount of carbon dioxide emissions produced by data centers worldwide exceeds the total emissions of both Argentina and the Netherlands (Kaplan et al., 2008). Thus the IT industry is looking to advanced power-management hardware, smart cooling systems, virtualization tools, and dense server configurations to reduce energy consumption (Katz, 2009).

These new approaches rely heavily on large amounts of data provided by large-scale sensor networks (e.g., Bodik et al., 2008; Hoke et al., 2006; Patnaik et al., 2009; Shah et al., 2008). Some companies are using containers that integrate computing, power, and cooling systems in one module for data centers, instead of raised-floor rooms. Several IT companies are committed to using alternative energy sources, such as hydropower, solar power, and wind power, to bring the carbon footprint of data centers to zero.

On a larger scale, data centers can contribute to reductions in energy use and carbon emissions by facilitating e-commerce and telecommuting, for example, which can eliminate some of the need for paper printing and for freight and passenger transportation.

#### The Smart Grid

Under the Energy Independence and Security Act (EISA) of 2007, the U.S. Department of Energy was charged with modernizing the nation's electricity grid to improve its reliability, efficiency, and security, a concept known as the Smart Grid. Ideally, the Smart Grid will radically transform the industry's business model from a largely non-digital, electromechanical grid to a network of digital systems and power infrastructure and from a centralized, producer-controlled network to a more decentralized system with more interaction between consumers and local producers.

The objectives for the Smart Grid include: enabling active participation by consumers; making possible the easy integration of a variety of generation options (with a focus on renewable sources) and storage options; enabling new products, services, and markets; providing quality power for the digital economy; optimizing assets and operating efficiently; automatically anticipating and responding to system disturbances; and operating resiliently in the event of attacks or natural disasters.

To realize these objectives, the Smart Grid will include smart sensors and controls throughout the transmission and distribution system and a broad communication platform for two-way communications to move data and electricity between utilities and consumers. For example, consumers will have smart meters that can track energy consumption, monitor individual power circuits in the home, control smart appliances, and actively manage energy use.

Planning and operating such a large, complex digital ecosystem will require technological advances in computing and information science related to sensing and measuring technologies, advanced control methods, monitoring and responding to events, support for dynamic pricing, computational aspects of game-theory models and mechanism design, multi-agent based models, improved interfaces, decision-support and optimization tools, and security and privacy tools.

#### Renewable Energy

The development of renewable energy can have an even greater environmental impact than increasing energy efficiency. In recent years technological progress has been made (partly in response to government incentives) in renewable energy sources, such as biofuels and biomass, geothermal, solar, and wind power. For example, EISA set fuel economy standards for vehicles that will require the production of 36 billion gallons of renewable fuels per year by 2022, a fivefold increase over current ethanol production levels.

The logistics and planning of this large-scale domestic-based biofuels production system raise complex stochastic optimization problems—variants of the so-called "facility-location problem"—that must take into consideration feedstock and demand and the dynamics of demand and capacity (Shmoys, 2004). And the stakes are high. Finding good solutions to these problems can make the difference between economic viability and failure. Overall, we will need complex computational models to find the best mix of energy generation and storage technologies.

A larger project will be the development of computational models (Figure 1) that show interactions between different energy sources and the agents directly or indirectly involved (e.g., households, landowners, farmers, ethanol producers, gasoline refiners, food producers) and impacts on the environment (e.g., greenhouse gas emissions, water, soil erosion, biodiversity, etc.).

To begin with, the overall impact of biofuels is not well understood. Take, for example, their impact on land use. Traditional life-cycle studies do not take into account emissions from changes in land use, which are difficult to quantify (Seager et al., 2009; Searchinger et al., 2008; Tilman et al., 2009).

Another example is the impact of wind power, a promising renewable energy source that has raised concerns about damage to bird and bat populations. Research will be necessary to provide guidelines for the

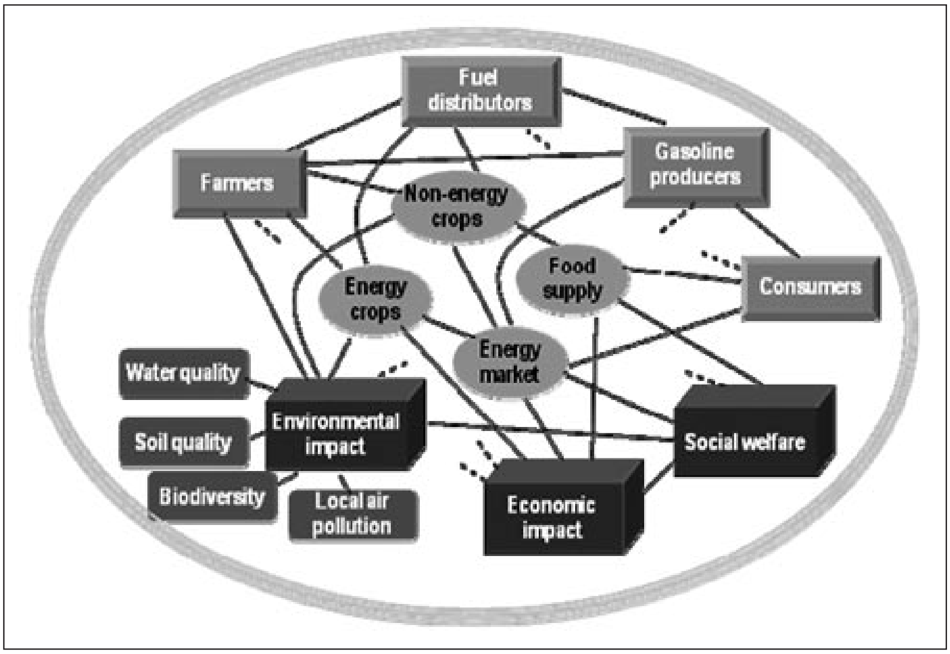


FIGURE 1 Interacting components for biofuel analysis.

location of wind farms, especially because most areas with favorable winds are associated with important migratory pathways.

The research challenge is to develop realistic models that capture multiple impacts and interdependencies without imposing strong (unrealistic) assumptions. In traditional approaches, convexity assumptions force unique equilibria, or at the very least, the set of equilibria are themselves convex (Codenotti et al., 2005; Heijungs and Suh, 2002; Ye, 2008). This has made their algorithmic solution possible, but such models do not capture key aspects of systems. Researchers will have to develop more complex decision models through collaboration with resource economists, environmental scientists, and computer scientists.

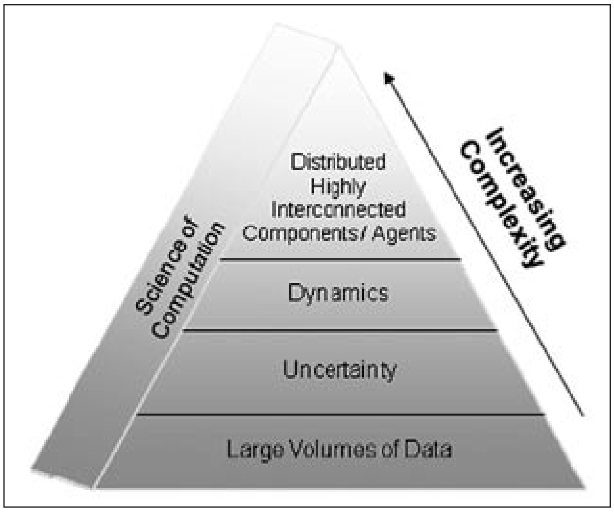


FIGURE 3 Increasing levels of complexity in computational sustainability problems.

### Individual Interests vs. the Common Good

A key issue in environmental policy is balancing individual interests and the common good (e.g., Hardin, 1968). In this area, game-theory models can model the interactions of multiple agents and show the effects of competing interests. In the context of natural resources or climate change on the international level, for example, economic incentives may influence whether a country is motivated to enter an agreement and then abide by it.

Incentive-based policies can also facilitate sustainability challenges on a smaller scale (e.g., the establishment of novel markets for land-conservation activities). To be useful, multi-agent models will have to explore mechanisms and policies for the exchange of goods.

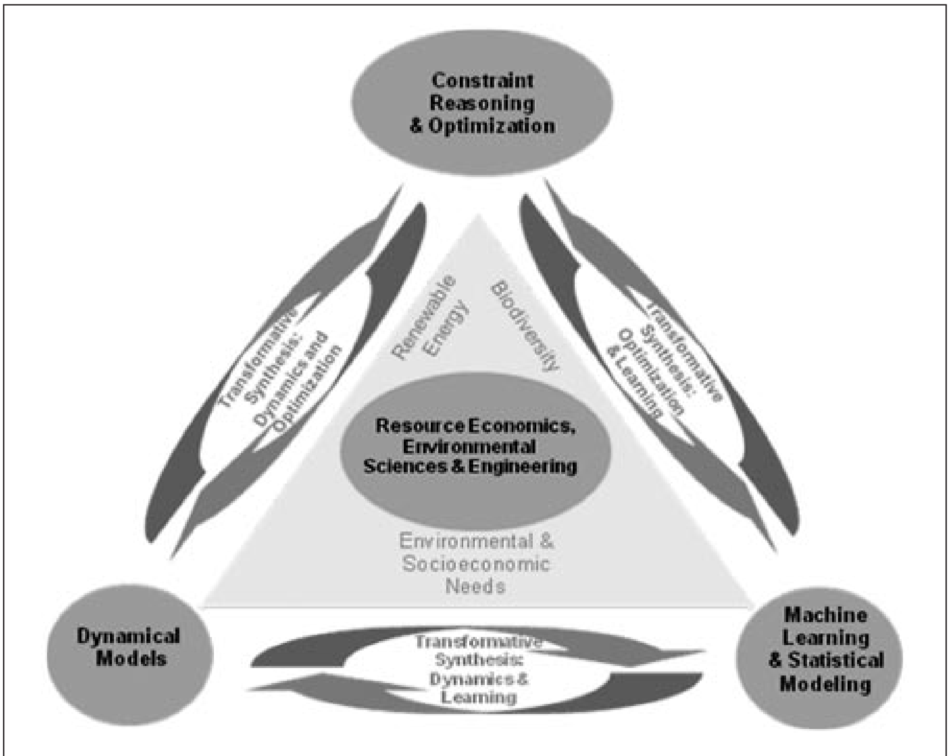


FIGURE 2 Examples of research themes and interactions in computational sustainability that are closely aligned with the research agenda of the Institute for Computational Sustainability at Cornell University.

### The Research Challenges

Research in computational sustainability involves many different areas in computing, information science, and related disciplines. Figure 2 shows some of the areas that are closely related to examples in this article and to the ICS research agenda (ICS, 2010). Figure 3 shows the levels of complexity in computational sustainability, which often addresses large-scale problems based on large volumes of data in highly dynamic and uncertain environments with many interacting components.

Given these complexities, the study of computational sustainability problems requires a fundamentally new approach that is unlike the traditional computer science approach (i.e., the science of computation), which is driven mainly by worst-case analyses. From the perspective of computational sustainability, problems are considered "natural" phenomena that are amenable to scientific methodology, rather than purely mathematical abstractions or artifacts. In other words, to capture the structure and properties of complex real-world sustainability problems, principled experimentation is as important as formal models and analysis (Gomes and Selman, 2005, 2007).

## Summary

The development of policies for a sustainable future presents unique computational problems in scale, impact, and richness that will create challenges, but also opportunities, for the advancement of the state of the art of computer science and related disciplines. The key research challenges are developing realistic computational models that capture the interests and interdependencies of multiple agents, often involving continuous and discrete variables, in a highly dynamic and uncertain environment.

Research in this new field is necessarily interdisciplinary, requiring that scientists with complementary skills work together. In fact, collaboration is an essential aspect of the new science of computational sustainability, an interdisciplinary field that applies techniques from computer science, information science, operations research, applied mathematics, statistics, and related fields to help balance environmental, economic, and societal needs for a sustainable future.

The focus is on developing computational and mathematical models, methods, and tools for making decisions and developing policies concerning the management and allocation of resources for sustainable development. The range of problems encompasses computational challenges in disciplines from ecology, natural resources, economics, and atmospheric science to biological and environmental engineering. Computational sustainability opens up fundamentally new intellectual territory with great potential to advance the state of the art of computer science and related disciplines and to provide unique societal benefits.

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*Antennas in the optical range will improve the efficiency of light-emitting devices.*

# Optical Antennas
## A New Technology That Can Enhance Light-Matter Interactions

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Lukas Novotny

The purpose of optical antennas is to convert the energy of free propagating radiation to localized energy, and vice versa. Although this is similar to what radio wave and microwave antennas do, optical antennas exploit the unique properties of metal nanostructures, which behave as strongly coupled plasmas at optical frequencies. It is hoped that optical antennas can increase the efficiency of light-matter interactions in important applications, such as light-emitting devices, photovoltaics, and spectroscopy.

Electromagnetic antennas, a key enabling technology for devices such as cellular phones and televisions, are mostly used in the radio-wave or microwave regime of the electromagnetic spectrum. At optical frequencies, on the contrary, electromagnetic fields are controlled by re-directing the wave fronts of propagating radiation by means of lenses, mirrors, and diffractive elements. Because this type of manipulation is based on the wave nature of electromagnetic fields, it cannot be used to control fields on the subwavelength scale. In contrast, radio wave and microwave technology predominantly uses antennas to manipulate electromagnetic fields, controlling them on the subwavelength scale and interfacing efficiently between propagating radiation and localized fields.

Recent research in nano-optics and plasmonics has generated considerable interest in optical antennas, and several current studies are exploring ways of translating established radio wave and microwave antenna theories into the optical frequency regime. The introduction of the antenna concept into the optical frequency regime will lead to new technological applications, such as enhancing absorption cross-sections and quantum yields in photovoltaics, releasing energy efficiently from nanoscale light-emitting devices, boosting the efficiency of photochemical or photophysical detectors, and improving spatial resolution in optical microscopy.

## Background

The word *antenna* most likely derives from the prefix *an-* (meaning "up") and the Indo-European root *ten-* (meaning "to stretch") (Tucker, 1931; Watkins, 2000). Therefore, from an etymological perspective, an antenna is that which stretches or extends upward (Klein, 1966). Today, we refer to an electromagnetic transmitter or receiver as an antenna, but these were originally called *aerials* in English (Simpson and Weiner, 1989). In 1983, IEEE defined an antenna as a means of radiating or receiving radio waves (IEEE, 1983).

Radio antennas were developed as solutions to a communication problem, whereas optical antennas were developed for use in microscopy. Analogous to its radio wave and microwave counterparts, we define an *optical antenna* as a device designed to efficiently convert free propagating optical radiation to localized energy, and vice versa (Bharadwaj et al., 2009). In the context of microscopy, an optical antenna, which can concentrate external laser radiation to dimensions smaller than the diffraction limit, can effectively replace a conventional focusing lens or objective.

In a letter to Albert Einstein dated April 22, 1928, Edward Hutchinson Synge describes a microscopic method (Figure 1) in which the field scattered from a tiny particle could be used as a light source (Novotny, 2007b). The particle would convert free propagating optical radiation into a localized field that would interact with a sample surface. If we think of the surface as a receiver, the particle can be viewed as an optical antenna. Synge's method was probably inspired by the development of dark-field microscopy, a technique invented at the turn of the twentieth century by Richard Adolf Zsigmondy, an Austrian chemist (Elsevier, 1966).

In 1988, Ulrich Ch. Fischer and Dieter W. Pohl carried out an experiment similar to Synge's proposal, but instead of a solid metal particle, they used a gold-coated polystyrene particle as a local light source (Fischer and Pohl, 1989). They imaged a thin metal film with 320 nanometer (nm) holes and demonstrated a spatial resolution of ~50nm. Later, laser-irradiated metal tips were proposed as optical antenna probes for near-field microscopy and optical trapping (Novotny et al., 1997, 1998), and since then various other antenna geometries have been studied (e.g., rods and bowties).

## How Optical Antennas Work

Although optical antennas are strongly analogous to their radio-frequency (RF) and microwave counterparts, there are crucial differences in their physical properties and scaling behavior. Most of these differences arise because metals are not perfect conductors at optical frequencies, but are strongly correlated plasmas described as a free electron gas. Optical antennas are also not typically powered by galvanic transmission lines; instead, localized oscillators are brought close to the feed point of the antennas, and electronic oscillations are driven capacitively (Pohl, 2000). Moreover, optical antennas can take various unusual forms (e.g., tips or nanoparticles), and their properties may be strongly shape- and material-dependent due to surface plasmon resonances.

Typically, an optical antenna interacts with a receiver or transmitter in the form of a discrete quantum system, such as an atom, molecule, or ion. Because the antenna enhances the interaction between the receiver

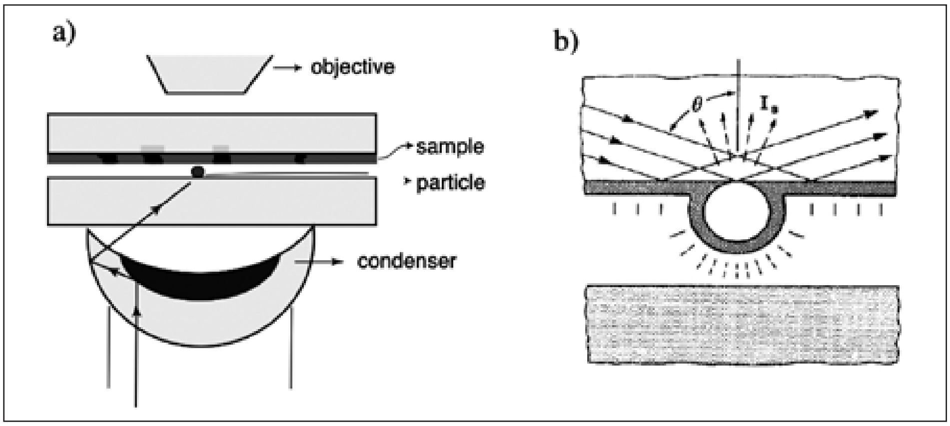


FIGURE 1 (a) Synge's original proposal of near-field optical microscopy based on using scattered light from a particle as a light source. Source: Adapted from Synge's letter to Einstein dated April 22, 1928, cited by Novotny, 2007b. (b) 1988 experiment in which the near-field probe consists of a gold-coated polystyrene particle. Source: Fischer and Pohl, 1989.

or transmitter and the radiation field, it may control the light-matter interaction on the level of a single quantum system. On the one hand, the presence of the antenna modifies the properties of the quantum system, such as its transition rates and, in the case of a strong interaction, even the energy-level structure. On the other hand, the properties of the antenna depend on the properties of the receiver/transmitter. Thus, the two must be regarded as a coupled system. The efficiency of the interaction can be expressed in terms of established antenna terminology, such as antenna gain, efficiency, impedance, directivity, and aperture (Bharadwaj et al., 2009).

## Radiation Enhancement with Nanoparticle Antennas

A spherical nanoparticle is probably the simplest model antenna (Anger et al., 2006; Bharadwaj and Novotny, 2007; Bharadwaj et al., 2007; Kühn et al., 2006). Although this simple antenna geometry is not very efficient, quantitative comparisons can be made by simple analytical means (Bharadwaj and Novotny, 2007). As shown in the inset of Figure 2a, we can consider a transmitter in the form of a single fluorescent molecule optically pumped by external laser radiation. For weak excitation intensities, the radiation rate $\Gamma_{rad}$ can be expressed as

$$\Gamma_{rad} = \Gamma_{exc}\,\eta_{rad} \qquad (1)$$

where $\Gamma_{exc}$ is the excitation rate and $\eta_{rad}$ is the quantum yield. Both $\Gamma_{exc}$ and $\eta_{rad}$ depend on the antenna's properties and the separation, $z$, between antenna and molecule. $\eta_{rad}$ corresponds to the radiation efficiency, and the rates, $\Gamma_i$, can be expressed in terms of powers as $P_i = \Gamma_i\, h\nu_i$, with $h\nu_i$ corresponding to the atomic transition energy.

Figure 2a shows the experimentally recorded photon emission rate of a single dye molecule as a function of its separation from an 80nm silver nanoparticle. The superimposed curve is a theoretical calculation based on a simple electromagnetic model in which the molecule is treated as a classical oscillating dipole (Bharadwaj and Novotny, 2007). The data demonstrate that, as the silver particle is brought closer to the molecule, the fluorescence emission rate first increases and then is suppressed. The initial fluorescence enhancement is due to the antenna effect of the silver particle. The excitation rate, $\Gamma_{exc}$, increases because of the enhanced local fields near the nanoparticle.

However, for separations shorter than $z$ = 10nm, the radiation efficiency $\eta_{rad}$ decreases rapidly as more and more of the energy is absorbed in the silver nanoparticle. At a distance of $z$ ~ 3nm, the rapid decrease of $\eta_{rad}$ wins over the increase of $\Gamma_{exc}$, and the fluorescence of the molecule is quenched. Hence, there is an optimal separation between molecule and antenna.

Figure 2b shows a near-field fluorescence image of single dye molecules dispersed on a flat glass surface. The fluorescence emission rate was recorded pixel by pixel, while the dye sample was raster scanned under a laser-irradiated nanoparticle antenna held at a fixed distance of $z$ ~ 5nm above the sample surface by means of a shear-force feedback mechanism (Anger et al., 2006; Höppener et al., 2009; Karrai and Grober, 1995). The resolution achieved in this type of near-field imaging is determined by the antenna size. With an 80nm silver or gold particle, we typically achieve resolutions of ~ 65nm. The

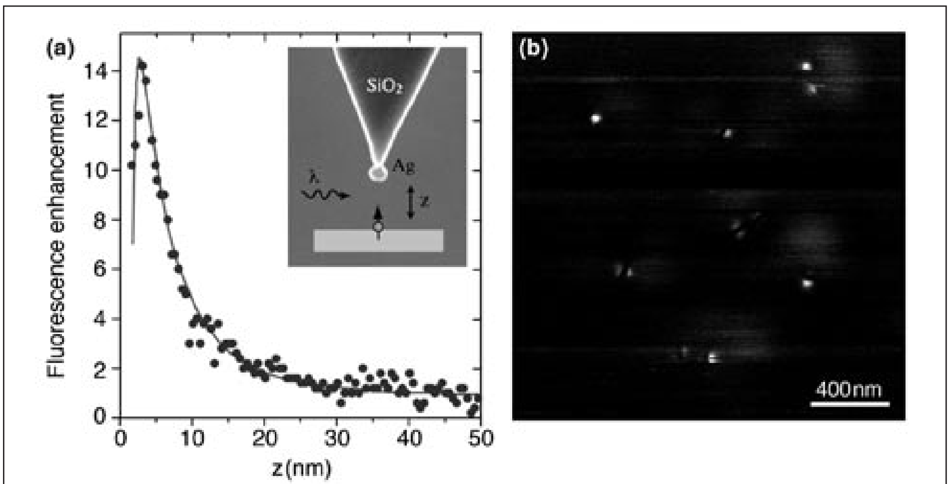


FIGURE 2 Enhancement of the radiation rate of a single molecule with a silver nanoparticle antenna. (a) Normalized fluorescence rate as a function of antenna-molecule separation. Dots are data, and the curve is the result of a theoretical calculation. Inset: scanning electron microscope image of a nanoparticle antenna. The particle is held by a dielectric tip, $\lambda$ = 488nm. (b) Fluorescence rate image recorded by raster scanning of a sample with dispersed dye molecules in a plane $z \approx$ 5nm underneath a nanoparticle antenna. The different fluorescence patterns are due to different orientations of the molecular transition dipole axis. Source: Adapted from Bharadwaj and Novotny, 2007.

different fluorescence patterns in Figure 2b are due to different orientations of the molecular transition dipole axis (Frey et al., 2004; Novotny et al., 2001).

The results of similar experiments performed with other quantum systems, such as quantum dots and carbon nanotubes, are consistent with the results for single fluorescent molecules. An important finding is that for systems with weak intrinsic quantum efficiency ($\eta_i$) the radiation efficiency can be enhanced by the optical antenna. In the example discussed here, in which we assumed $\eta_i = 1$, the antenna can only *decrease* the radiation efficiency. However, for poor emitters, such as carbon nanotubes, the antenna can increase the radiation efficiency by more than a factor of 10 (Hartschuh et al., 2005). In general, the lower the $\eta_i$, the more the antenna increases the overall efficiency, an effect that was first observed by Wokaun et al. in 1983.

This method of increasing the quantum efficiency of weak emitters might be a promising development that could boost the efficiency of organic light-emitting devices (OLEDs), silicon-based lighting, and solid-state lighting (SSL) in the yellow and green spectral region (Pillai et al., 2007; Wetzel et al., 2004).

The nanoparticle antenna is a model antenna, and its predictions have been tested in various recent experiments. However, much higher efficiencies can be achieved with optimized antenna designs, such as the optical half-wave antenna.

### Near-Field Raman Scattering

The hallmark of optical antennas, their ability to influence light on the nanometer scale, leads naturally to nano-imaging applications. In the context of nanoscale imaging, an optical antenna represents a near-field optical probe that can interact locally with an unknown sample surface. For a near-field optical image, the optical antenna is guided over the sample surface in close proximity, and an optical response (e.g., scattering, fluorescence, antenna detuning) is detected for each image pixel.

The vibrational spectra provided by Raman scattering define a unique chemical fingerprint for the material under study. Raman scattering involves the absorption and emission of photons, almost identical in energy; thus a nearby antenna can amplify *both* the incoming and outgoing fields. The total Raman scattering enhancement is therefore proportional to the fourth power of the field enhancement (Novotny and Hecht, 2006).

In tip-enhanced Raman scattering (TERS), optical antennas (e.g., metal tips) are used for point-by-point Raman spectroscopy (Hartschuh, 2008; Hartschuh et al., 2003; Stöckle et al., 2000), similar to the original idea of Wessel (1985). Raman enhancements achieved with metal tips are typically in the range of $10^4 - 10^8$, corresponding to field enhancements of 10 to 100.

Our TERS studies are focused on localized states (due to defects and dopants) in carbon nanotubes (Anderson et al., 2005; Maciel et al., 2008). Figure 3 shows (a) the simultaneously recorded topography and (b) near-field Raman image of a single-walled carbon nanotube sample. The image contrast in the near-field Raman image (c) is defined by the intensity of the G' line (vibrational frequency of $\nu = 2615$ cm$^{-1}$) highlighted in the spectrum.

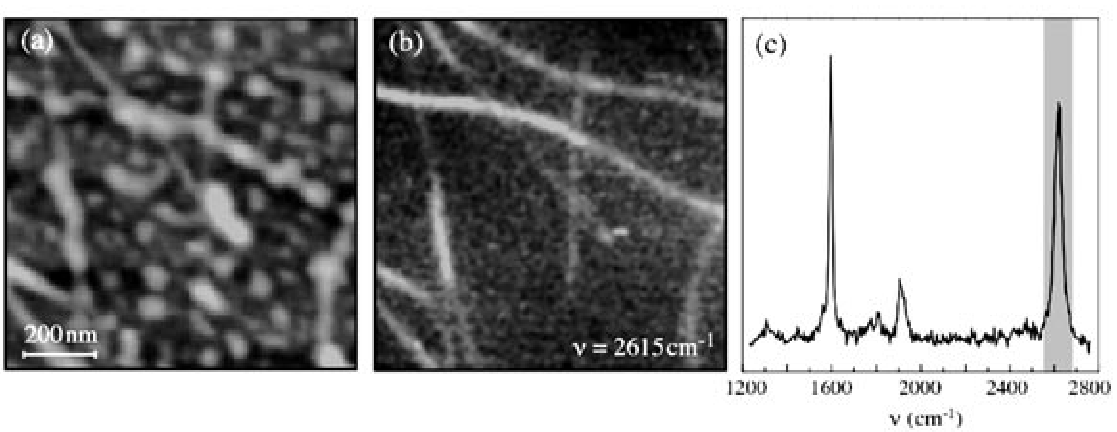


FIGURE 3: Near-field Raman imaging of a single-walled carbon nanotube sample. (a) Topography showing a network of carbon nanotubes covered with small droplets. (b) Raman image of the same sample area recorded by integrating, for each image pixel, the photon counts, which fall into a narrow spectral bandwidth centered around $\nu = 2615$ cm-1 (indicated by shading in 3c). (c) Raman scattering spectrum recorded on top of the nanotube. Source: Adapted from Hartschuh et al., 2003.

## Wavelength Scaling

At optical frequencies, electrons in metals have considerable inertia and cannot respond instantaneously to the driving fields. Typically, the skin depth is on the order of tens of nanometers, comparable to the dimensions of the antenna. Traditional design rules that prescribe antenna parameters only in terms of an external wavelength are thus no longer valid. The metal must be rigorously treated as a strongly coupled plasma, which leads to the antenna "seeing" a reduced effective wavelength (Novotny, 2007a). This effective wavelength, $\lambda_{eff}$, is related to the external (incident) wavelength, $\lambda$, by a surprisingly simple relation

$$\lambda_{eff} = n_1 + n_2 [\lambda / \lambda_p] \qquad (2)$$

where $\lambda_p$ is the plasma wavelength of the metal, and $n_1$ and $n_2$ are constants that depend on the geometry and dielectric parameters of the antenna. $\lambda_{eff}$ is shorter, by a factor of 2 to 6, than the free space, $\lambda$, for typical metals (e.g., gold, silver, aluminum) and realistic antenna thicknesses (Bryant et al., 2008; Novotny, 2007a).

The shortening of wavelength from $\lambda$ to $\lambda_{eff}$ has interesting implications. For example, it implies that the radiation resistance of an optical half-wave antenna is on the order of just a few Ohms (Alu and Engheta, 2008; Burke et al., 2006; Novotny, 2007a). To see this, we note that the radiation resistance of a thin-wire antenna is roughly $R_{rad} = 30\,\pi^2\,(L/\,\lambda)^2$, with L being the antenna length. For a half-wave antenna at RF frequencies, $L = \lambda/2$ and $R_{rad} \sim 73\Omega$. However, for an optical half-wave antenna, $L = \lambda_{eff}/2$ and hence $R_{rad} = (30/4)\,\pi^2\,(\lambda_{eff}/\lambda)^2$. In other words, the radiation resistance at optical frequencies is a factor of $(\lambda_{eff}/\lambda)^2$ smaller than at RF frequencies. For $\lambda_{eff} = \lambda/5$ we find $R_{rad} = 3\ \Omega$.

Figure 4a shows the intensity distribution near a gold half-wave antenna of length L = 110nm and radius R = 5nm resonantly excited at $\lambda$ = 1170nm. The effective wavelength is $\lambda_{eff}$ = 220nm. The induced current density $j = i\,\omega\,\varepsilon_o\,[\varepsilon(\omega) - 1]\,E$ evaluated along the axis of the antenna is found to be nearly 180° out of phase with respect to the exciting field.

The notion of an effective wavelength can be used to extend familiar design ideas and rules into the optical frequency regime. For example, the optical analog of the $\lambda/2$ dipole antenna becomes a thin metal rod of length $\lambda_{eff}/2$. Since $\lambda_{eff}$ for a silver rod of radius 5nm is roughly $\lambda/5.2$ (Figure 4c), this means that the length of a "$\lambda/2$" dipole antenna is surprisingly small, about $\lambda/10.4$. One can similarly construct antenna arrays like the well established Yagi-Uda antenna developed in the 1920s for the UHF/VHF region (Novotny, 2007a; Taminiau et al., 2008).

## Enhanced Light-Matter Interactions

The localized fields near an optical antenna open up new interaction mechanisms between light and matter, such as higher order multipole transitions

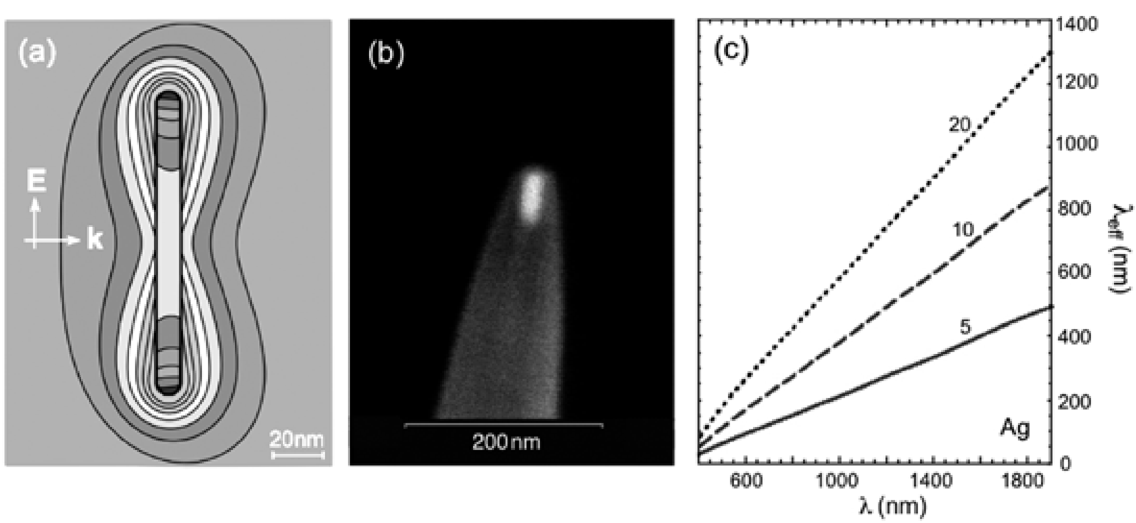


FIGURE 4 Effective wavelength scaling for linear optical antennas. (a) Intensity distribution ($E^2$, factor of 2 between contour lines) for a gold half-wave antenna irradiated with a plane wave ($\lambda$ = 1150nm). (b) Scanning electron microscope image of a half-wave antenna resonant at $\lambda$ = 650nm, fabricated by placing a gold nanorod ~65nm long into the opening of a quartz nanopipette. (c) Effective wavelength scaling for silver rods of different radii (5, 10, and 20nm). Source: Novotny, 2007a.

and momentum-forbidden transitions. These interactions, which are inaccessible in free space, have the potential to enrich optical spectroscopy and provide new strategies for optical sensing and detection. In free space, the momentum of a photon with energy, $E$, is $p = E/c$. However, the momentum of an unbound electron with the same energy is two to three orders of magnitude greater, and the photon momentum can be neglected in electronic transitions.

Near an optical antenna, the photon momentum is no longer defined by its free space value. Instead, localized optical fields are associated with a photon momentum defined by the spatial confinement, $D$, which can be as small as 1 to 10nm. Thus in the optical near field the photon momentum can be drastically increased to a level comparable with the electron momentum, especially in materials with small effective mass, $m^*$. Hence, localized optical fields can give rise to "diagonal" transitions in an electronic band diagram thereby increasing overall absorption strength, which can be useful for devices such as silicon solar cells. The increase of photon momentum in optical near fields has been discussed in the context of photoelectron emission (Shalaev, 1996) and photoluminescence (Beversluis et al., 2003).

The strong field confinement near optical antennas also has implications for selection rules in atomic and molecular systems. Usually, the light-matter interaction is treated in the dipole approximation where the spatial variation of the fields is much weaker than the spatial variation of quantum wave functions. However, the localized fields near optical antennas give rise to spatial field variations of a few nanometers; hence it may no longer be legitimate to invoke the dipole approximation. This is the case in semiconductor nanostructures, for example, where the low effective mass gives rise to quantum orbitals with large spatial extent.

## Conclusions and Outlook

Research in the field of optical antennas is currently driven by the need for high field enhancement, strong field localization, and large absorption cross sections. Antennas for high-resolution microscopy and spectroscopy, photovoltaics, light emission, and coherent control are being investigated. In one way or another, optical antennas make processes more efficient or increase the specificity of gathered information.

As in canonical antenna theory, there is no universal antenna design, and optical antennas have to be optimized separately for each application. However, to achieve the highest level of efficiency, the internal energy dissipation of any antenna must be minimized. For a quantum emitter, such as an atom, molecule, or ion, a good antenna yields a low nonradiative decay rate.

New ideas and developments are emerging at a rapid pace, and it is now clear that the optical antenna concept will provide new opportunities for optoelectronic architectures and devices. Today, the building blocks for optical antennas are plasmonic nanostructures that can be fabricated either from the bottom up by colloidal chemistry or from the top down with established nanofabrication techniques, such as electron-beam lithography and focused ion-beam milling. It is also conceivable that future optical antenna designs will draw inspiration from biological systems, such as light-harvesting proteins in photosynthesis.

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*Health care managers can greatly improve communication and the coordination of care for elders.*

# Managing and Coordinating Health Care

## Creating Collaborative, Proactive Systems


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In the last 100 years, huge advances in public health and medical care have resulted in people living longer, healthier lives. These advances have led to a shift from infectious diseases (pneumonia, tuberculosis, and infectious diarrhea) as the top three causes of death to the sequelae of chronic illnesses as the most common causes of death. For instance, heart disease, the most common cause of death in 2000, is hastened by diabetes, hypertension, and high cholesterol (Anderson and Arias, 2003). In addition, as people age, loss of functional ability and increasing disability become primary determinants of increased use of medical services, loss of independence, and death.

It has been shown that increasing disability and multiple conditions near the end of life, rather than single conditions or age alone, are the primary causes of increased hospitalizations and costs (e.g., Shugarman et al., 2009). Nevertheless, the health care system in the United States still focuses on treating individual conditions and meeting acute needs, rather than on ongoing care and overall health. Thus fixing this system will require changing health care delivery to anticipate these needs, teaching and encouraging people and their families to seek help, and providing care that consistently matches medical knowledge.

One possible “fix” is to add care managers—specially trained nurses and social workers who focus on the broad health picture—into primary care clinics. Care managers support a different approach to health care characterized by coordination, prioritization, and protocols for treatment plans assisted by the targeted use of health information technologies (HIT). With these “fixes,” the health care system would address ongoing changes in a patient’s health as the care manager, supported by HIT, focuses on proactive, collaborative, coordinated care.

## Complexity of Care and the Need for Care Coordination

In this article, we will consider gaps and potential solutions in the care of a hypothetical elderly patient, Ms. Viera. In this example, we consider two alternate courses in the life of a this hypothetical patient based on differences in care delivery (Figure 1). Ms. Viera is a 75-year-old woman with five common chronic conditions: (1) arthritis in her knees and hips; (2) diabetes, which she has had for the last five years; (3) high blood pressure; (4) moderate kidney problems, which have caused some swelling in her legs; and (5) recent difficulty remembering things day to day. She lives alone and can manage the usual household tasks. Socially, she goes to the senior center once a week, has a part-time professional caregiver, and has a daughter who lives about an hour away by car.

At the start of our hypothetical year, Ms. Viera looks back on last year, during which she saw 13 providers, 8 of whom she continues to see regularly. Her regular providers include her primary care provider (PCP), Dr. Smith, a doctor of internal medicine who provides ongoing care with a team of specialists—a rheumatologist for arthritis; a cardiologist; a neurologist, whom she saw in consult for memory loss; a nephrologist for kidney problems and high blood pressure; an orthopedist for her knees; a gynecologist; and an endocrinologist for diabetes. She filled 50 different prescriptions for 8 chronic medications and 4 short-term medications; several of these medications were prescribed by specialists, and some were prescribed by the PCP. She avoided the hospital last year, despite having nearly 90 times the risk of a hospitalization for someone her age with no chronic illnesses (Wolff et al., 2002).

As Figure 1 shows, an enormous number of connections had to be tracked by the patient, the family, and the caregiver—for communication and for changes to medical treatment plans. The coordination of these connections is the primary challenge we address in this paper.

Patients like Ms. Viera represent approximately 5 percent of people over 65, yet they use about 43 percent of all health care resources (Wolff et al., 2002). When we consider re-engineering the system to improve Ms. Viera’s care, we must first and foremost consider the benefit of those changes to her. A major hypothesis in care-coordination research is that carefully planning and arranging care can result in higher quality, more efficient care. Society, patients, and insurers will all benefit by avoiding waste from errors and “defects” in the care delivered.

## A Crucial Juncture

Let us return to the case of Ms. Viera. At the beginning of our year, she is hospitalized briefly for difficulty breathing and dizziness. After about two days,

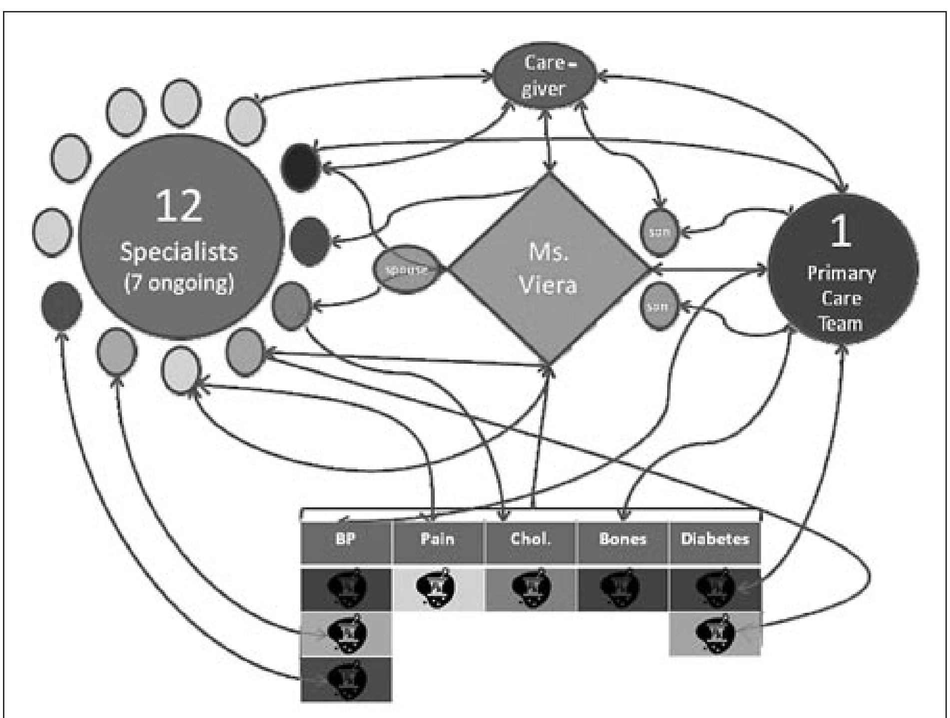


FIGURE 1 An example of average health care and needs for a patient with complex conditions.

she is diagnosed with out-of-control blood sugars and some excess fluid on her lungs. The hospital team stabilizes her by adjusting several medications, and she is discharged back to her home.

Figure 2 shows one potential course her post-hospital convalescence could take. Based on the hypothetical events listed on the left, in the next year, she goes home, appointments are planned, she attempts to resume her usual activities, sees specialists, has dizziness, chest pain, and some difficulties with control of her chronic conditions. In the usual course of care, "System 1" (on the right), the care-coordination tasks and their method of completion are highlighted. Studies show that upon discharge from the hospital, one-third of patients have care plans that are not followed or communicated (e.g., instructions to make an appointment with a physician). In addition, calls from the hospital staff to the PCP, although helpful, frequently do not lead to follow-up unless there is further communication—from either the hospital or primary-care team—directly with the patient. By the time the provider reviews the faxed discharge summary, Ms. Viera has about a 10 percent chance of being rehospitalized.

| Event | System1 : Usual Care |
|---|---|
| Ms. Viera is hospitalized. | Courtesy call made to PCP. |
| Month 1: Ms. Viera goes home. An appointment is planned with her PCP for follow-up. | Ms. Viera receives sheet with instructions to make an appointment; PCP receives a fax in 7 days with discharge info. |
| Month 2: Ms. Viera resumes usual activities and becomes dizzy in the morning | She calls the PCP, an appointment is scheduled, but she goes to the ED due to worsening symptoms. |
| Month 3: Adjustments to medications are made by 3 specialists. | 2 of 3 send reports to the PCP office with plan; these reports are duly filed. When seen by the PCP, she can't remember these changes. |
| Month 6: Ms. Viera has chest pain and calls her PCP for help. | PCP sees patient urgently; BP is out of control and Ms. Viera is hospitalized for observation. |
| Month 12: Review of the year for Ms. Viera and family | After her second hospitalization, she is discharged to rehabilitation and a skilled nursing facility. |

FIGURE 2 A year in the life of Ms. Viera with the usual system of health care.

In the next month, Ms. Viera may increase her activities and develop symptoms from her medications. In the usual system, she may call her PCP and, while waiting for the return call, her symptoms may worsen, and she may go to the emergency department. Upon seeing three of her specialists in follow-up, the lack of information sharing among settings and caregivers leads to new medications being prescribed but not remembered by the patient or family and not reconciled against her old list.

Finally, in month six, Ms. Viera may have a serious new problem—worsening chest pain. In the usual system, all of her other issues may have distracted the primary-care team from controlling her blood pressure, which leads to a repeat hospitalization for monitoring. Although she does not have a heart attack, the changes in her medications and the unfamiliarity of her surroundings in the hospital may lead to a fall and a further need for rehabilitation.

In each of these common scenarios, gaps in coordination lead to increased use of health care and worse health for Ms. Viera. Our primary purposes in this paper are to elaborate on the reasons for our failure to create reliable health systems and to provide suggestions for improvement.

### Developing a Health Care System of Systems

One way to change the current system of coordination "as usual"—which includes many gaps—is to think of health care as a more reliable and effective system of systems. One challenge in creating a reliable system is that gaps are not uniform; they vary over time and from individual to individual based on a wide range of factors, such as social needs, economic conditions, chronic illnesses, personal preferences, and local system infrastructure. Multiple disciplines, such as cognitive engineering, systems science, industrial engineering, and informatics, must be combined to begin to minimize and then close these gaps.

One way to address these problems is to take a close look at the existing health care delivery system and diagnose the gaps through a structured approach by looking at goals of care, current processes, infrastructure, and participants. We have completed a series of studies of the system of primary care, a subset of the overall health care system that focuses on ongoing, outpatient care by a PCP and a primary-care team (Dorr et al., 2005, 2006a,b, 2007b).

In this system, as shown in Figure 1, coordination of care is crucial to ensure that it is ongoing, comprehensive, and relationship-based. In our studies, we first defined the goals of care coordination and then the crucial processes necessary to attain those goals. These processes are usually nonlinear, are initiated through comprehensive assessments, and require iterative follow-up on care plans and patient needs. Finally, the structure is developed, in terms of the team's abilities, the clinic-based technology that ensures (or at least supports) reliability, and defined roles, all relevant to the patient's needs.

*Goal-setting by patients has been shown to improve health outcomes.*

### Identifying Gaps

Because patients have complex needs and there are many potential connections, we first identified the major problems by identifying gaps in the provision of care. We and others have used observations and semi-structured interviews of (1) patients with complex conditions, (2) physicians and nurses, and (3) other health care professionals to identify the most common gaps in care coordination in the primary-care clinic (Bodenheimer, 2008; Dorr et al., 2006b; Wilcox et al., 2007). Principal problems identified in analysis include: (1) a lack of collaboration between patient/family and health-care team; (2) the absence of reliable, complete communication; and (3) failure to prioritize care needs based on both patient input *and* evidence for effective treatment.

Collaboration requires shared decision-making, a process whereby patients are educated about their condition, are offered options, and are provided with tools to help them make decisions. For patients with multiple chronic conditions, decisions must be made frequently and must be coordinated across conditions. Goal-setting by patients—which has been shown to lead to improved health—is done less than 25 percent of the time, and patients report that they do not feel included in decisions more than 50 percent of the time (Bodenheimer and Handley, 2009).

The reasons for frequent gaps in communication include: (1) the patient's need for clear communications that focus on goals and outcomes; (2) the need for multiple inputs (e.g., from specialists and the primary-care team, as well as the patient and family) to complete a communication, which requires cyclical or iterative processes; and (3) the mode of communication either requires more attention than is available (e.g., in-person conversations with the provider) or is not timely (e.g., faxes) (Westbrook et al., 2007). With limited time and attention, failures in communication are common, leading to errors and preventable negative outcomes, such as emergency department visits resulting from unreturned calls or unclear instructions.

Finally, as the severity and risk factors of the patient's condition increase, the prioritization of needs and next steps is crucial. Systems that remind providers and/or patients about every potential treatment or step in a care plan individually lead to *provider/patient fatigue and distraction* and ultimately fail to improve care. In one study, more than 50 percent of patients did not understand directions given to them by their physicians at the end of a visit (Bodenheimer and Handley, 2009).

### Components of a Solution

To understand the components of the solution, we now return to our sample patient, Ms. Viera. Given the same events outlined above over the course of a year, an optimal system, as shown in Figure 3, would address a number of the gaps we identified in the usual system of care.

#### *Reorganizing the Care Team*

The first category is team reorganization (Bodenheimer et al., 2002). In other disciplines, such as crew-resource management (e.g., air crews and other teams

| Event | System2a: High care coordination | System2b: High health information technology |
|---|---|---|
| Ms. Viera is hospitalized. | Care Manager (CM) called by family. | Admitting information sent to PCP, picked up by CM. |
| Month 1: Ms. Viera goes home. An appointment is planned with her PCP for follow-up. | CM assures appointment made and calls 2-4 days post-hospitalization. CM attends PCP visit. | Scheduled outreach for follow-up tracked per protocol and CM need; these remain until communication completed. |
| Month 2: Ms. Viera resumes usual activities and becomes dizzy in the morning | CM takes call, and has patient come in per provider advice; low blood sugars are to blame and medications adjusted. | Blood sugars are tracked over time in the system, with regular follow-up calls scheduled as medications adjusted. |
| Month 3: Adjustments to medications are made by 3 specialists. | On monthly review by CM, Ms. Viera brings in her medications and notes changes. The medication list is updated. | Specialist referrals deemed critical are tracked by system and missing report causes a reminder to be triggered. |
| Month 6: Ms. Viera has chest pain and calls her PCP for help. | Under a CM protocol, her BP was controlled and she is seen, stabilized, and returned home. | Protocols are enforced by system, with reminders about patient goals and follow-up. |
| Month 12: Review of the year for Ms. Viera and family | With Ms. Viera's permission, the daughter comes in for a conference, and helps arrange to keep Ms. Viera at home. | A summary generated by the system helps inform the conference and aids in care planning. |

FIGURE 3 A proactive, collaborative system of coordinated health care.

that work in high-risk, high-attention areas), the crucial requirements for reliable, effective performance include team competencies, thorough training, and well-defined, well-designed functions (Salas et al., 2006). For care coordination, specific roles—such as the role of a care manager—must be defined to address the need for reliable, effective communication and smooth, efficient workflow (Dorr et al., 2006b).

Evidence based on studies of care managers or care coordinators have increasingly shown that they can be crucial to minimizing the exacerbation of disease (Dorr et al., 2005), reducing the number of hospitalizations (Dorr et al., 2008), and improving patient satisfaction with their care (Wilcox et al., 2007). The essential competencies of care managers include the ability to educate patients and motivate them to set and follow goals and care plans, as well as to communicate effectively with members of the team, the patient, and the patient's family.

Processes tested and implemented for the care of patients with specific conditions have been codified in primary-care team protocols that include identification of common conditions (e.g., elevated blood pressure), a treatment plan, and a flow chart. With the protocol, tasks are disseminated to appropriate team members beyond the beleaguered physician by pre-defining, in sequence, the steps that must be ordered manually under the current system. For protocols to be reliable, however, they must include collaboration, prioritization, and the complexity of the patient's needs. Comprehensive assessments of preferences and goals that include multiple conditions and patients' needs have been shown to improve the health of older adults and to facilitate patient decision-making (Boult et al., 1999).

In our sample case, the care manager would facilitate coordination by receiving the call from the hospital, making the post-hospitalization follow-up call to the patient and family, and following protocols and proactively identifying the patient's needs. Care managers can help close the communication loop because they remain focused on the key communication tasks for at-risk patients, follow up on critical referrals to specialists, 07/26/2006 **PATIENT WORKSHEET** Comprehensive

**Problems**

| | |
|---|---|
| Hyperthyroidism | Hypertension |
| status post appendectomy | Appendectomy |
| Diabetes Mellitus, Type 2 | Cholecystectomy |

**Active Medications**

1. - Digitoxin, 0.1mg, Tablet; 3 TABLET
2. - Testing; No dose found
3. - Testing; No dose found
4. - Entex LA (Guaifenesin/PPA HCl), 400-75mg, Tablet SA; 1 TABLET; BID

**Allergies**

Penicillins; Reaction(s): Urticaria (Hives)

No Known Drug Allergies; Reaction(s): Unknown

Penicillins; Reaction(s): Urticaria (Hives)

**Disease Management**

| Readiness for Change | |
|---|---|
| 07/22/2003 | Precontemplation |

**Preventive Care**

| Pap Smear | | Pneumovax |
|---|---|---|
| No Data | - | 01/01/2003 |

**Clinical Laboratory Data**

| HgbA1c (<=7.0) | | UAProtein | | uAlb/Cr (<30) | | 24 Urine Albumin (<30) | |
|---|---|---|---|---|---|---|---|
| No Data | - | 06/01/2001 | Negative | No Data | - | No Data | - |
| | | 12/18/2000 | Positive | | | | |
| | | 11/06/2000 | Negative | | | | |

| Serum Cr | | Serum K | | Lipid Profile | LDL (<100) | Trig (<150) | HDL (>45) | CHOL (<200) |
|---|---|---|---|---|---|---|---|---|
| 02/03/2005 | 1.5 | 10/03/2004 | 4.1 | 04/26/2003 | 107 | 93 | 50 | 176 |
| 01/26/2005 | 4.3 | 08/12/2004 | 3.4 | 04/06/2003 | 154 | 85 | 41 | 212 |
| 10/03/2004 | 6.4 | 04/26/2003 | 4.2 | 02/24/2003 | 149 | 151 | 41 | 220 |
| 04/26/2003 | 1.1 | 02/05/2003 | 6.0 | 02/06/2003 | 168 | 189 | 33 | 239 |

| TC/HDL Ratio | | HCT | | hsCRP | | Homocysteine | |
|---|---|---|---|---|---|---|---|
| 04/26/2003 | 3.5 | 02/05/2003 | 35.9 % | 04/06/2003 | 0.6 mg/L | 04/06/2003 | 6 umol/L |
| 04/06/2003 | 5.2 | 10/02/2002 | 37.7 % | 02/24/2003 | 1.2 mg/L | 03/15/2002 | 5 umol/L |
| 02/24/2003 | 5.4 | 08/23/2002 | 36.0 % | | | | |
| 02/06/2003 | 7.2 | 08/06/2002 | 39.0 % | | | | |

**Clinic Data**

| Date | Weight | BMI (<25) | Weight Class | Blood Pressure (<130/80) (clinic data only) | |
|---|---|---|---|---|---|
| No Data | - | - | - | 01/25/2001 | 145/74 mmHg |

| Heart Rate | |
|---|---|
| 01/25/2001 | 86 |

Last Foot Exam: No Data - Last dilated retinal exam: No Data -

**Reminders**

**Lab**

[ ] Urine Albumin Test - Should be done yearly for Patients with Diabetes.
[ ] Lipid Panel - Do Lipid Panel every 3-12 months until LDL < 100 for Patients with Diabetes and LDL < 130.
[ ] HgbA1C (should be done on all Patients with Diabetes).

FIGURE 4 Comprehensive summary sheet.

and arrange conferences to consolidate communication. In the usual flow of things, the clinical staff must attend to many urgent needs as they arise and therefore have limited time to perform these less urgent, but no less important, tasks. Research has shown that trained care managers can accomplish these tasks and hence greatly improve the effectiveness and efficiency of health care delivery.

*Health Information Technology*

The number of patients that can be followed by a care manager is limited. Studies have shown that 2 to 5 percent of patients in a usual primary care clinic meet the criteria of Ms. Viera's case: an at-risk patient diagnosed with multiple comorbid illnesses in need of ongoing care coordination. In a clinic of seven physicians, more than a thousand patients may meet these criteria, which could easily overwhelm care managers.

The primary goal of care coordination is to monitor, over time, the active care and treatment plan for patients and to take necessary steps to ensure that the plan is completed successfully. For example, health information technology (HIT) can greatly increase the likelihood of success. Key process points can be defined and programmed to remind care managers about crucial tasks. Whereas electronic health record systems usually focus on individual clinic visits and work flow and relegate hundreds of items to unstructured to-do lists, in our example, HIT functions can be adapted to help prioritize tasks by (1) identifying crucial elements that should be shared by members of the primary-care team, (2) ensuring that relevant information is delivered to the correct team members in the appropriate format, and (3) reminding clinicians about uncompleted tasks. To start the process, HIT, using filtering and prioritized data flow, must identify all patients under care management and the state of their current treatment plans and goals.

In our studies, by using HIT, care managers were able to follow an average of 350 patients at a time, approximately 1,000 per year (Dorr et al., 2007a). Patients under care management received prioritized messages about their hospital stay, were given automatic follow-up after sentinel events that persisted beyond an individual call or visit, and were moved to the top of the queue for attention when necessary.

The HIT system can embed protocols, although they must be flexible enough to accommodate the needs of care managers; for example, care managers only need the next step defined and a reminder sent to address a patient's rapidly changing status. Even for individual patients, care managers must identify the highest priority tasks and should be reminded about these first (Dorr et al., 2006a). For Ms. Viera, who sees 12 specialists a year, the care manager would designate which of these referrals are critical and directly affect the care plan; HIT would then remind the caregiver about these elements only.

Finally, summaries of the complex care and needs of patients are crucial to addressing emerging issues quickly and integrating the patient's history with anticipated care needs in one place. Figure 4 shows this summary mechanism, the patient's worksheet (which, by itself, has been shown to improve adherence with evidence-based treatments for chronic and preventive illness by 17 to 30 percent) (Wilcox et al., 2005).

*With the help of HIT, care managers can follow 350 patients at a time.*

**Building a Sustainable Model**

Once a patient's needs and potential solutions have been identified, we work to implement them into a model of care. In seven intervention clinics at Intermountain Healthcare, a large, integrated health-delivery system, we installed care managers, trained them, and adapted HIT over a period of two years to develop the protocols and system described above. Over the next four years, patients seen by care managers lived longer, had 24 to 40 percent fewer hospitalizations, and had significantly better control of their conditions than similar patients at clinics without care managers (Dorr et al., 2005, 2008). The clinics with care managers also achieved higher efficiency levels, as measured by clinical output (patients seen and complexity of conditions treated). Lower costs that resulted from greater efficiency covered the costs of the care managers *and* the costs of expanding the program (Dorr et al., 2007b).

Unanticipated effects included variations in referral patterns and care-management patterns that led to some variations in outcomes. For instance, patients with predominantly social or financial problems did not have significantly fewer hospitalizations or emergency department visits, despite the care managers' efforts. A positive unanticipated effect was a result of integrating a set of providers and patients. A number of patients described the care manager as "a life-saver," and a number of providers said they "could not imagine practicing without the care manager."

**Maintenance and Sustainability of the Care-Manager Model**

The next step is to determine the maintenance and sustainability of the care-manager model. In our qualitative studies, we defined core aspects of successful care management and embedded these in a training- and HIT-enhancement program. The core components of the model were defined as: (1) a trained care manager; (2) a supportive, trained team; and (3) specialized HIT. We then created a training and HIT support program (for details, see *caremanagementplus.org*). To date, more than 75 clinical teams have participated in the training and have been working on improving their HIT systems. In all, 73 percent of the teams were able to implement the core components of the model.

Further work is being done on sustainability, which can be a problem because many care-management tasks are not specifically reimbursed, despite their value. Changes in the reimbursement system (e.g., payments for the "medical home," a comprehensive model of primary care) or direct payments for care coordination may enable many more primary care teams to adopt these models.

## Conclusions

Successful models of coordinated care that meet identified needs and improve patient health can be created by identifying gaps in current care systems, developing solutions that meet a particular patient's needs, and developing change-management processes. We have shown that one successful model is to use care managers to augment primary-care teams and HIT to remind care managers and clinicians about prioritized tasks. The next steps will be to explore ways to ensure sustainability and to reinforce changes in the current health care system.

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*Health information technologies, and health informatics in general, may be headed for a bust.*

# Why Health Information Technology Doesn't Work

Elmer V. Bernstam

Todd R. Johnson

Elmer V. Bernstam and
Todd R. Johnson

To improve the quality of our health care while lowering its cost, we will make the immediate investments necessary to ensure that within five years all of America's medical records are computerized. This will cut waste, eliminate red tape, and reduce the need to repeat expensive medical tests… it will save lives by reducing the deadly but preventable medical errors that pervade our health care system.

—Barack Obama
George Mason University, January 8, 2009

Widespread dissatisfaction with health care in America and rapid advancements in information technology have focused attention on information technology, which has dramatically improved efficiency and safety in other industries, as an obvious part of the solution to our health care woes. However, there is increasing evidence that the adoption of health information technology (HIT) will not guarantee comparable benefits in health care.

In fact, unmitigated enthusiasm for HIT may even be dangerous. Similar enthusiasm has repeatedly threatened the field of artificial intelligence (AI),

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resulting in cycles of excitement and disappointment (referred to as "AI winters"). Motivated by a desire to avoid "HIT winters," we will briefly review the effects of HIT and the "semantic gap," that is, the difference between "health data" and "health information." In addition, we identify significant social and administrative barriers to the adoption of HIT in the context of the technical issues; because HIT is embedded in a social context, these technical issues must be resolved in a socially and administratively acceptable way. We conclude with research challenges that must be addressed before the full promise of HIT can be realized.

## Effects of Health Information Technology

HIT is an "easy sell" to an American public increasingly dissatisfied with the U.S. health care system. Indeed, based on some evidence that HIT can improve the quality of health care (Chaudhry et al., 2006), prevent medical errors (Bates et al., 2001), and increase efficiency (Chaudhry et al., 2006), there seem to be some good reasons for optimism.

Unfortunately, many, perhaps most, HIT projects have failed (Littlejohns et al., 2003), and evidence shows that HIT can worsen health care quality in some ways by increasing errors (Koppel et al., 2005; Levenson and Turner, 1993), decreasing efficiency, and perhaps even increasing mortality (Han et al., 2005). The term "e-iatrogenesis" has been coined to describe the unintended deleterious consequences of HIT (Weiner et al., 2007).

Enough negative evidence has accumulated to prompt the Joint Commission (formerly the Joint Commission on Accreditation of Healthcare Organizations) to issue a "Sentinel Event Alert" (defined as "unexpected occurrence[s] involving death or serious physical or psychological injury, or the risk thereof") cautioning health care organizations about potential hazards associated with the implementation and use of HIT (Joint Commission, 2008).

## We've Been There Before: AI Winters

During the 1950s, we were faced with a different problem—the cold war. At that time, the government considered IT a promising solution (at least a partial solution) to the problem of tracking Russian communications. It was thought that if researchers could develop automated translation, we would be able to monitor Russian communications and scientific reports in "real time." There was a great deal of optimism about this, and there were "…many predictions of fully automatic systems operating within a few years" (Hutchins, 2006).

Although many promising applications were found for the poor-quality automated translations that resulted, the optimistic predictions were not realized. To this day, the fundamental problem of context and meaning remains unsolved, making disambiguation difficult and resulting in some amusing failures. Anecdotal examples include: "The spirit is willing, but the flesh is weak" was translated from English → Russian → English as "The vodka is good, but the meat is rotten," and "out of sight, out of mind" came out as "blind idiot."

*Based on negative evidence, health care organizations should be cautious about how they use HIT.*

In 1966, the influential Automatic Language Processing Advisory Committee (ALPAC) concluded that "there is no immediate or predictable prospect of useful machine translation" (NRC, 1966). As a result, research funding was stopped, and little research was done on automated translation in the United States from 1967 to 1976, when it was revived and supported until 1989 (Hutchins, 2006). Interestingly, disappointment in automated translation in the 1960s was not an isolated event. Similar "AI winters" occurred with respect to connectionism (1970s), expert systems (1990s), and other AI topics.

So, although there is tremendous interest in HIT, and even good evidence that it can be useful, some will certainly be disappointed with the results. A recent report by the National Research Council concluded that ". . . current efforts aimed at the nationwide deployment of health care IT will not be sufficient to achieve the vision of 21st century health care, and may even set back the cause if these efforts continue wholly without change from their present course" (NRC, 2009). Thus, there is also good reason for concern that HIT (and the field of biomedical informatics, in general) may be headed for a bust. However, an "HIT winter" would be unfortunate, because there are real benefits to pursuing research and implementation of HIT.

## The Semantic Gap

Loosely speaking, philosophers who study information draw a distinction between data (syntax) and information, defined as meaningful data (i.e., data + meaning or, alternatively syntax + semantics) (Floridi, 2005). The fundamental problem is that existing technology can store, manipulate, and transmit data but not information. Thus the utility of HIT is limited to the extent to which data approximates meaning, and, unfortunately, there is a large gap between health care data and health care information. Because the difference between data and information is meaning (semantics), we call this the "semantic gap."

Interestingly, Claude Shannon hinted at this issue in 1948 in a seminal paper, "A Mathematical Theory of Communication." This "mathematical theory of communication" came to be known as information theory. Shannon wrote that "[f]requently, the messages have *meaning*; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem." Thus, Shannon's "information theory" explicitly refers to data rather than information in the philosophical sense.

Consider the differences between banking data and health care data, an account at a bank versus a patient's record (Table 1). One difference is that concepts relevant to health are vague compared to banking concepts. The proper interpretation of the symbols relevant to health care requires significant background knowledge. For example, a patient can be "sick" in many ways, including derangements in vital signs (e.g., extremely high or low blood pressure), prognosis associated with a diagnosis (e.g., any patient with myocardial infarction [heart attack] is sick), and other factors. Two clinicians who are asked to describe the same "sick" individual may legitimately focus on different facts or data.

In contrast, the balance in a bank account (e.g., $1,058.93) is relatively objective and is captured by the symbols. If we assume that all transactions (credits and debits) to the account are in the same units (dollars and not pounds or Euros), we need only the numbers and the mathematical operations of addition and subtraction to compute and report the balance. Even though these symbols abstract away the rich semantic complexity of the balance, such as its current purchasing power or that the money can be used to purchase goods and services, this is of no consequence to the successful automation of bank accounts. Thus data-manipulating machines (IT) are much better suited to manipulating bank accounts than they are to manipulating clinical descriptors.

Twenty-five years ago, S. Marsden Blois (1984) argued that the difficulty of using computers in medicine was due to the nature of medical concepts and medical descriptions. Most medical concepts do not

**TABLE 1 Comparison of Health "Data" and Banking Data**

| | Banking Data | Health Data |
|---|---|---|
| Concepts and descriptions | Precise<br>*Example*<br>Account 123 balance = $15.98 | General, subjective<br>*Example*<br>Sick patient |
| Actions | Usually (not always) reversible<br>*Example*<br>Move money A → B | Often not easily reversible<br>*Example*<br>Give a medication<br>Perform a procedure |
| Context | Precise, constant, or irrelevant to the task<br>*Example*<br>US $ | Vague, variable<br>*Example*<br>Normal lab values differ by lab. No two cells, organs, tumors, or patients are identical. |
| User autonomy | Well-defined and constrained<br>*Example*<br>What I can do with my checking account = what you can do with yours | Variable and dependent on circumstance<br>*Example*<br>Clinical privileges depend on training, changes over time, and circumstances |
| Users | Clerical staff, account holder | Varied, including highly trained professionals |
| Workflow | Well-defined, documented, and explicit | Highly variable, implicit with many undocumented tasks and exceptions |

have explicit definitions in terms of necessary and sufficient conditions. Thus they are difficult to describe in the formal languages required by computer systems. For instance, a 2000 definition of a myocardial infarction (heart attack) is nine pages long and contains many imprecise terms, such as: "prolonged," "usually," and "experienced observer." Other medical concepts, such as "sharp pain," may be even more difficult to map to formal representations.

#### Social and Administrative Barriers to the Adoption of Health Information Technology

Manipulating data instead of information has many consequences for HIT. The problem for American clinics and hospitals is not usually a shortage of computers. Most hospitals and even small private practices use computers to manage financial and administrative data, and many hospitals have functioning e-mail systems and maintain a Web presence. In addition, many clinicians use personal digital assistants (McLeod et al., 2003), and some communicate with patients via e-mail. In contrast, however, most clinical records are kept on paper.

There are many barriers to the adoption of HIT. Hospitals that have not implemented electronic medical records most frequently cite financial concerns, including the lack of adequate capital for purchasing equipment (74 percent), maintenance costs (44 percent), and unclear return on investment (32 percent) (Jha et al., 2009). Additional barriers include a mismatch between costs and benefits, cultural resistance to change, lack of an appropriately trained workforce to implement HIT, and many others (Hersh, 2004).

To some, clinicians' resistance to computerization appears to be irrational. However, given the mixed evidence regarding the benefits of HIT, caution seems increasingly reasonable. Thus many clinical enterprises are not computerized because of rational skepticism about the costs and benefits of current HIT, not because of an irrational resistance to technological progress.

#### Research Challenges

Significant research will be necessary to address serious problems before HIT becomes more attractive to clinicians. Many of these problems are outlined in a recent National Research Council report (NRC, 2009). First, there is a mismatch between what HIT can represent (data) and concepts relevant to health care (data + meaning). This very difficult, fundamental challenge subsumes multiple AI problems (e.g., context or common sense) that have proven very difficult to solve. HIT can manipulate form, but not meaning—hence the term "formal methods." Until we have true information technology, rather than data technology, the benefits of HIT will be limited to applications in which formal methods (i.e., methods that manipulate form) suffice.

A second research challenge is to define appropriate applications for HIT, as well as policies, procedures, and methods of implementation. Clearly, HIT can be helpful in many ways. For example, computerized alerts and reminders can improve compliance with preventive-care guidelines (Shea et al., 1996) and may be cost effective when used in this way (Bernstam et al., 2000). Similarly, examples of reductions in the number of medication errors and other benefits have been published (e.g., Bates et al., 2001). Therefore, in spite of its limitations, current HIT can be useful when applied to suitable problems.

*Reasoning by analogy across domains is natural for humans but difficult for computers.*

A third research challenge is to evaluate HIT as a clinical intervention. An instructive example is that a commercial electronic health record was associated with increased mortality at one institution (Han et al., 2005), but no such association was found at another institution that implemented the same system in a similar care setting (Del Beccaro et al., 2006). Thus outcomes depend on the interplay among HIT, its implementation at a particular institution, and the nature of the institution (e.g., workflow, patient mix, policies, availability of specialists, etc.).

A computer system cannot be considered in isolation. Its effects must be evaluated in the context of a specific organization. Any system that can affect clinical decisions has the potential to worsen as well as to improve outcomes. Therefore, these systems should be evaluated as clinical interventions, just as drugs, medical devices, and procedures are evaluated.

Fourth, HIT must augment human cognition and abilities. This has been elegantly expressed as the "fundamental theorem of informatics": human + computer > human (Friedman, 2009). In other words, there must be a clear and demonstrable benefit from HIT. Clearly, it can be beneficial in some situations, and in some ways human cognition and computer technology are complementary. Computers excel at precise, efficient manipulation of data, whereas we excel at discovering, storing, and processing meaning. Thus there are tremendous opportunities for effective human-machine collaboration. For example, monitoring (e.g., waveforms) is much easier for computers than for humans. In contrast, reasoning by analogy across domains is natural for humans but difficult for computers.

Defining scenarios, with all relevant parameters, in which HIT is beneficial and demonstrating that using HIT is *reliably* beneficial in these scenarios remains a research challenge. In its present form, HIT will not transform health care the same way that IT has transformed other industries, partly because of the large semantic gap between health data and health information (concepts). In addition, it is worth noting that many problems with health care will only be solved by changes in health care policy, financing, and so forth.

To address the research challenges described above will require unprecedented collaboration among disciplines that have traditionally worked independently and have fundamentally different methods, values, and domains of study. Nevertheless, many promising interdisciplinary approaches have been developed. For example, seemingly simple safety devices, such as checklists, which were pioneered in aviation, have been applied to health care with dramatic results (Pronovost et al., 2006). Statistical process control, simulation, and other engineering methods have also been successfully applied to certain aspects of health care (NAE and IOM, 2005).

## Health Information Technology and U.S. Competitiveness

True HIT (i.e., health information technology, not health data technology) is critical for U.S. competitiveness in biomedicine—both for biomedical research and for clinical care. Clinical trials are increasingly being conducted in countries with large populations (i.e., large subject pools) and lower regulatory barriers (compared to those in the United States), such as India (Glickman et al., 2009). Barring substantial changes in our values, privacy concerns, and expectations, we simply cannot compete. For example, because of privacy concerns, the United States has no universal patient identifier. As a result, it is very difficult to identify subjects across clinical trials or patients who move between hospitals and other care settings. In contrast, unique patient identifiers in other countries have greatly facilitated clinical research.

Similarly, the high cost of health care in the United States encourages "medical tourism." Many Americans travel abroad for care that is too expensive for them to obtain in the United States (Wapner, 2008). Some foreign hospitals actually specialize in providing care to Americans who come for a high-cost procedure, such as coronary artery bypass surgery.

True HIT can help address both of these problems. If we can collect clinical information (meaningful data) as a byproduct of routine care, we can then learn from experience, rather than relying solely on clinical trials. In parallel, we can leverage this information to improve care processes. Thus we would fulfill the promise of HIT described by President Obama.

## Conclusions

Clearly we must improve health care in fundamental ways, and HIT will be important in transforming the health care system. However, disappointment seems inevitable, because the promises made on behalf of HIT are not likely to be fully realized in the near future. Historical precedents for such cycles of enthusiasm and disappointment with technology include AI, for which boom and bust cycles appear to be the rule rather than the exception.

Realizing the promise of HIT to improve health care will require an unprecedented level of collaboration among communities that have traditionally had little in common, speak different languages, and have very different world views. Thus we are faced with both challenges and opportunities to find fresh perspectives on fundamental problems in the health care domain. In the process, we may also solve some fundamental information (i.e., computer science) problems related to context and meaning.

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*Designing resilient infrastructure systems will require collaborative efforts by engineers and social scientists.*

# Infrastructure Resilience to Disasters

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Urban societies depend heavily on the proper functioning of infrastructure systems such as electric power, potable water, and transportation networks. Normally invisible, this reliance becomes painfully evident when infrastructure systems fail during disasters. Moreover, because of the network properties of infrastructure, damage in one location can disrupt service in an extensive geographic area. The societal disruption caused by infrastructure failures is therefore disproportionately high in relation to actual physical damage.

Engineers have long tried to design infrastructure to withstand extreme forces, but recently they have begun to address the need for urban infrastructure systems that are *resilient* to disasters (e.g., NIST, 2008). Conceptually, resilience entails three interrelated dimensions: lower probabilities of failure; less-severe negative consequences when failures do occur; and faster recovery from failures (Bruneau et al., 2003). The emphasis on consequences and recovery suggests that improving the resilience of infrastructure systems is not only a technical problem, but it also has societal dimensions.

The consequences of recent disasters have demonstrated that urban infrastructure systems in the United States and other developed countries (not to mention in developing regions of the world) remain highly vulnerable. Moreover, infrastructure failure is often a primary cause of economic and human losses in disasters. Consider, for example, the consequences of infrastructure failures caused by wind, storm surges, and levee failures in New Orleans during Hurricane Katrina. Table 1 provides a few other examples to illustrate the frequency and range of infrastructure failures in disasters.

Because infrastructure failures are clearly a primary cause of disruptions in disasters, strategies for improving the disaster resilience of communities must focus on improving infrastructure resilience. Yet few standards or guidelines have been developed for this, partly because of the complexity of the problem (American Lifelines Alliance, 2006).

### Research on Infrastructure in Disasters

Much of the early work on infrastructure in disasters was on understanding the mechanics of how components of infrastructure systems (e.g., bridge piers, buried pipes, electric power transformers, and other substation equipment) perform when subjected to extreme forces or conditions. This basic understanding was then extended to the performance of component assemblages (e.g., bridges, pipeline networks, substations). Studies ranged from field work to laboratory simulations with scale models and computer-based analyses.

As a result of these studies, new engineering designs, materials, and retrofitting strategies were developed to improve the ability of infrastructure elements to withstand natural hazards. New technologies were also developed, such as sensors for monitoring structural health and detecting damage and real-time system controls.

While these remain active areas of inquiry, new research themes have emerged to address some of the complexities of infrastructures, which include societal as well as technical issues. How, for instance, will the failure of one bridge affect businesses throughout the urban area that rely on the transportation system? How will the failure of one infrastructure system

**TABLE 1 Examples of Infrastructure Failures and Consequences in Disasters**

| Event | Location | Infrastructure Failure and Consequences | Source |
|---|---|---|---|
| 1993 Great Midwest floods | Des Moines, Iowa | Businesses suffered greater economic losses from infrastructure outages (water, electric power, and wastewater services) than from physical flooding of their facilities. | Webb et al., 2000 |
| 1994 Northridge earthquake ($M_W$=6.7) | Los Angeles, California | Damage to bridges, which closed portions of four major freeway routes, accounted for $1.5 billion in losses from business interruption (a quarter of the total). | Gordon et al., 1998 |
| 1995 Great Hanshin-Awaji earthquake ($M_W$=6.9) | Kobe, Japan | Extensive infrastructure failures, including outages of electric power and telecommunications (1 week), water and natural gas (2–3 months), commuter railway (up to 7 months), and highway systems and port infrastructure (approx. 2 years). It took 10 years for the city population to recover. Economic activity, especially at the port, has still not fully recovered. | Chang (in press); Chang and Nojima, 2001 |
| September 11, 2001 World Trade Center terrorist attack | New York City | Widespread disruption in lower Manhattan to emergency service facilities, transportation (including subways), telecommunications, electric power, and water. | O'Rourke et al., 2003 |
| August 14, 2003 blackout | Portions of U.S. Midwest, Northeast, and southern Ontario | Power outages began in northern Ohio and cascaded through the electric power grid to cause the largest blackout in North American history (affecting 50 million people). Losses amounted to an estimated $10 billion. Water supply, telecommunications, transportation, hospitals, and other dependent infrastructures were disrupted. | McDaniels et al., 2007; U.S.-Canada Power System Outage Task Force, 2006 |
| 2004 Hurricanes Charley, Frances, and Jeanne | Central Florida | Port closures disrupted delivery of fuel and emergency materials. Electric power outages lasted for more than a week. The supply of emergency generators was not large enough to meet demand. | American Lifelines Alliance, 2006 |

disrupt other infrastructure systems? How can repairs following a disaster be planned so they minimize social and economic losses? Such questions have prompted research that is, by necessity, interdisciplinary.

### Challenges of Interdisciplinary Research

Interdisciplinary inquiry is inherently difficult for many reasons, ranging from intellectual issues, such as differences in communication and attitudes, to organizational issues, such as funding mechanisms and academic structures. Interdisciplinary research at the intersection of engineering and the social sciences is especially challenging (NRC, 2006).

One basic hurdle has been different disciplinary concepts of the term "infrastructure." To structural engineers, for example, infrastructure comprises constructed elements, such as pipes and bridges, described in terms of materials and design properties that condition their responses to physical forces. To economists, infrastructure—often referred to as "public capital"—comprises an input to economic production measured in dollars (e.g., Munnell, 1992) and often quantified at the state or national level. These fundamental differences reflect different ways of conceptualizing and measuring infrastructure.

*The complexities of infrastructure include societal as well as technical issues.*

Overcoming these challenges has required more collaborative, interdisciplinary research than in past engineering studies. It has also required researchers to pay greater attention to issues of time, space, and context. These trends are illustrated below in an example from the field of earthquake engineering.

### Water Systems in a Los Angeles-Area Earthquake

The Los Angeles Department of Water and Power (LADWP), the largest municipal utility in the United States, provides potable water to 3.9 million people through 11,700 kilometers of infrastructure in one of the most seismically active regions of the country. Over the last several years, researchers affiliated with the Multidisciplinary Center for Earthquake Engineering Research (MCEER), a research center funded by the National Science Foundation, have been studying the potential consequences of major earthquakes on the LADWP water system. Highlights of three of these studies[1] illustrate some key challenges and breakthroughs.

#### *Modeling Potential Physical Damage*

The first study, conducted by geotechnical engineers, developed a model of potential physical damage to the LADWP network (Romero et al., 2009). Geographic information system (GIS) technology was used to visualize the spatial dimensions of seismic ground waves, peak ground deformation, fault rupture, soil liquefaction, and landslides, as well as the network itself. The model, the Graphical Iterative Response Analysis for Flow Following Earthquake (GIRAFFE), assesses damage to network components (pipes, tanks, reservoirs, etc.) and performs hydraulic modeling of water flows through the damaged network. GIRAFFE also estimates serviceability—defined as the ratio of post-earthquake to pre-earthquake water flow—for each service area.

In 2008, results for one hypothetical event, a $M_w$ 7.8 earthquake on the southern San Andreas Fault, were used as part of the largest emergency preparedness exercise in U.S. history. In that scenario, overall water serviceability 24 hours after the earthquake was estimated to be as low as 34 percent (after reserves in storage tanks had been depleted). LADWP has now adopted GIRAFFE, trained its personnel to use it, and is applying the results in its system decision making.

#### *Modeling the Post-Earthquake Damage-Repair Process*

In a related study, systems engineers modeled the damage-repair process to estimate the duration of water outages (Brink et al., 2009). A discrete-event simulation model was developed that mimics the actual post-earthquake restoration process, including the movements of repair crews over time and their activities, which are subject to personnel and material constraints. Data were derived from extensive consultations with LADWP engineering staff.

The restoration model was then run in tandem with the GIRAFFE damage and water-flow model to simulate serviceability in 12-hour increments as repairs were

[1] The MCEER-LADWP research program also involved other studies (not described here) that analyzed regional seismicity, modeled performance of the electric power transmission system, and investigated forms of business resilience and resilient behaviors.

made over time and space; uncertainties were handled through multiple discrete simulations. The results showed substantial variations in how restoration might proceed, and LADWP concluded the restoration model would be helpful in planning for resource allocations following a disaster.

*Modeling the Effects of Water Outages on Businesses*

Urban planners used the models described above and other MCEER engineering studies to investigate the consequences of water outages, including impacts on the economy (Chang et al., 2008). For example, an agent-based simulation model accounts for how different types of businesses would be affected by water outages. Inputs include water serviceability ratios and restoration times based on the studies described above, as well as characteristics of businesses per se. Data were derived from surveys of impacts on businesses in previous disasters. Impacts from water outages were estimated in the context of other types of earthquake-related disruptions, specifically damage to buildings and power outages. Results for a $M_w$ 6.9 Verdugo Fault scenario indicated that water outages could account for an estimated $467 million in direct business losses, or about 1.5 percent of the estimated total economic losses.

## Critical Factors in Interdisciplinary Studies

The studies described above have demonstrated the feasibility and promise of interdisciplinary research on infrastructure resilience for developing the capability of modeling post-disaster losses and recoveries over time. Based on the experience of developing GIRAFFE, the restoration model, and other models, we have identified factors that promote interdisciplinary research in this area:

- **GIS technology** helps bridge disparate datasets and models by providing a common platform for information sharing and data integration.
- **The concept of infrastructure "services"** is critical for linking physical damage to societal impacts. This concept, which differs from both the traditional engineering concept of infrastructure and the traditional economic concept of infrastructure, reflects an intermediate representation that connects them.
- **A research center approach** makes it possible to address the entire scope of a complex problem through the coordinated efforts of a multidisciplinary team, convened and sustained over several years. This coordination is necessary to identifying critical gaps in knowledge, involving appropriate researchers, and overcoming disciplinary barriers.
- **Collaboration with the end user,** that is, with LADWP, the infrastructure organization itself, is essential. LADWP engineers contributed in important ways to framing questions, developing data, and ultimately, to applying outcomes to decision-making.

Without all of these factors in place, this interdisciplinary research could not have been conceived or conducted.

*A major challenge is understanding interdependecies, how failures in one infrastructure system lead to failures in another.*

## Challenges on the Horizon

Where is the current frontier in research on infrastructure resilience to disasters? In this author's opinion, much remains to be understood and addressed about the performance of engineered elements and systems. In addition, the nexus between engineering and social sciences has just begun to be explored through interdisciplinary research, and many important questions remain to be answered. In this context, three new challenges have been gaining attention.

*Interdependencies*

The first challenge is interdependencies—understanding and addressing how failures in one infrastructure system lead to failures in another. Loss of electric power, for example, commonly leads to disruptions in water, transportation, and health care systems, among others (McDaniels et al., 2007). There are several types of interdependencies: physical linkages (e.g., pump stations in water delivery systems that require electricity); cyber linkages (e.g., computerized system controls that rely on telecommunications); geographic linkages (e.g., pipelines located on transportation bridges); and "logical" linkages (e.g., infrastructure elements related through economic markets driven by human decision-making) (Rinaldi et al., 2001).

The technical understanding of these interdependencies is still in its early stages, and many infrastructure organizations have been reluctant to share information about their vulnerabilities for security reasons. Nevertheless, an understanding of infrastructure interdependencies is critical for cities deciding on strategic investments in infrastructure improvements that will have the greatest payoff in terms of resilience.

### *Multi-hazards*

The second new challenge is multi-hazards. Because infrastructure systems are vulnerable to multiple stressors (e.g., wind, ice, flood, earthquake, terrorism, deterioration), it is important to find solutions and support decisions that consider them in that context. Synergies in risk-reduction technologies may reduce the costs of pre-disaster retrofitting and post-disaster repairs. Methods are also needed to assess how the deterioration of infrastructure over time affects disaster risk.

### *Sustainability*

The third challenge, sustainability, is the consideration of infrastructure resilience in a long-term environmental context. It can be argued that disaster resilience is an inherent characteristic of sustainability. On one level, designing and building infrastructure that is able to withstand disasters will reduce their negative environmental impact, such as debris from damaged structures, spills of hazardous materials and other contaminants, and the carbon footprint of reconstruction activities. Infrastructure designers should, therefore, include such life-cycle environmental impacts in their decision-making (Guikema, 2009).

On another level, because infrastructures are long-lived, infrastructure resilience will require the capacity to meet demands that may change drastically over their life cycles. Such changes may include urban growth and increases in populations. Climate change will also be important, for example, through rising sea levels that redefine coastlines and through changes in the occurrence probabilities of hazardous events, including hurricanes, extreme rainfalls, droughts, temperature extremes, landslides, and floods. Climate change will not only put coastal infrastructure, such as port and harbor facilities, at risk. In many cities, climate change will also stress water supplies, wastewater treatment facilities, and transportation systems (Infrastructure Canada, 2006).

In addition, infrastructure systems themselves have substantial effects on the environment. For example, building flood-control levees, paradoxically, encourages development in hazardous floodplains. Thus the vulnerability of New Orleans to Hurricane Katrina was partly attributable to decisions, such as levee construction, that were made over a period of many decades to protect against relatively frequent storms, but that increased the city's vulnerability to very large, albeit rare, catastrophic storms (Kates et al., 2006).

In addition, the capacity of Louisiana's coastal wetlands to help buffer wind and storm surges was substantially degraded over decades by the construction of levees, shipping channels, oil and gas industry facilities, and other infrastructures (e.g., Kousky and Zeckhauser, 2006). Some have suggested that flood protection should not only comprise building levees, but should also be designed to encourage marsh restoration (Guikema, 2009). Others have proposed the decommissioning of existing infrastructures—such as the selective dismantling of dams and levees—along with ecosystem restoration as an approach to addressing the problems of aging infrastructure and the ecological degradation it has caused (Doyle et al., 2008).

Still others have pointed out that compact city designs intended to promote sustainability (e.g., to promote energy efficiency and reduce emissions of greenhouse gases) may actually undermine disaster resilience by putting more people in high-density developments located in floodplains and other hazardous locations (Berke et al., 2009).

## Unanswered Questions

How can infrastructure systems be designed to both reduce risk and support more sustainable cities? How can infrastructure systems be designed for disaster resilience—for today, as well as for the future? These questions may be the most difficult, and the most important, to answer. Addressing them will require interdisciplinary research that spans the distances between engineering fields and between engineering and the social sciences.

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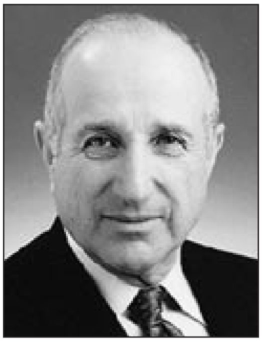
# What Is Engineering Leadership?
## A Personal Essay



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Bernard M. Gordon

The quality or capability of leadership is much misunderstood these days. Sometimes equated with mere process management, leadership is in reality much more. In fact, leadership is a positive, recognizable human trait, and those who possess it are able to influence others to accomplish goals they might not otherwise accomplish. Leaders make the difference between mundane performance and genuinely creative, competitive accomplishment. They are the ones who break barriers and initiate real change. And they are the ones who unleash the creative potential of the group.

According to the dictionary, *leadership* requires "charisma, dominance, forcefulness, and verbal primacy." According to the thesaurus, *leader* is synonymous with "chief, commander, superior, or chieftain," the antithesis of a "follower, myrmidon, acolyte, or adherent." Although the ability to lead is subject to development and improvement, leadership is ultimately a manifestation of an individual's personal characteristics, motivation, and will.

Unfortunately, in a society that places perhaps too much value on consensus and is working obsessively to impose an egalitarian outlook on a world of inherently unique individuals, leadership is often perceived either as the same as structured management or as an alien imposition characterized by stridency and egotism. Thus, the idea of leadership is either devalued or feared, and those who would be leaders are suspect.

As a consequence, schools hesitate to anoint young people as leaders; instead they stress shared accomplishment. Most employers provide defined roles for their employees in a hierarchy or process matrix that rarely has a place for a unique, catalytic, sometimes revolutionary leader. Schemes that have no acknowledged leaders also have no "losers." Unfortunately, they also have fewer winners in the long run, because leaders are the ones who get things done.

And leaders do get things done! How? That's the magical, hard-to-specify capability. Real leaders may on occasion appear to be dictatorial, but they are not and should not be dictators. A real leader succeeds not by ordering others to do his or her will but by inspiring them—through example and through a pervasive influence over the social fabric of a group or organization.

Historically, a leader in an engineering environment has been an individual with the vision to conceive and build a new or better product (i.e., a radar system, bridge, computer, or automobile) and who actually leads engineers to carry out the necessary, detailed work (Gordon, 1984). Often given a title, such as project engineer or chief engineer, a leader is usually the one who had the idea for the central improvements that would make the radar system, bridge, computer, or automobile a superior device. Moreover, the leader is the one who can inspire others to carry out his or her vision. A leader understands how to break a project into pieces that can be accomplished by individuals. Thus, he or she is responsible for sequentially supervising individual team members to ensure that they have proper direction to do what needs to be done . . . and on time.

In current practice, creativity and leadership are often separate. Companies hire researchers or designers to develop breakthroughs, but they then try to take those breakthroughs to market using a matrix model in which specialized functionaries—some of whom are engineers—try to translate the vision into practical reality. Unfortunately, this often results in missteps, and sometimes disaster. For instance, a company in the business of making a complex product that includes technologies A, B, and C, might subdivide the work amongst people with skills matching those three technical areas. However, without a highly competent project engineer to coordinate their efforts and reconcile competing claims and interests, the respective groups are unlikely to produce an end result that meets the original goals. Somewhere in the process there must be a dynamic agent of change—a leader—who either creates or adopts the idea and drives it to completion, mastering problems and people along the way.

## Characteristics of Engineering Leadership

An *engineering* leader must have all of the characteristics of other leaders—a degree of guile, didacticism, and energy coupled with patience, perseverance, and determination. In addition, he or she must have a quality unique to the engineering profession—technical knowledge and vision that enables him or her to grasp the central requirements of even the largest tasks and adapt (and shape the organization he or she leads) to meet the probable challenges that may emerge. Even though a leader rarely has sufficient knowledge to master every aspect of a project, he or she must be prepared to delve into any portion of the task at any time without losing sight of the whole. In short, engineering leaders must be alert for possible problems and missteps, able to grasp challenges and assess solutions, and, above all, capable of adapting to evolving circumstances.

To this complex mix, one must add a bit of magic—the creativity described by Professor William Gordon (no relation to the author) under the term *synectics*. Sounding almost like a Buddhist philosopher, Gordon (1961) suggests that successful, creative leaders must be able to fully identify with their product or invention and almost embody the product or vision they seek to create. At this visceral level, the entire spectrum of talents and creativity required of engineering leaders comes into focus. The leader is the linchpin in the creative efforts of his or her team, the seed crystal around which everything else coalesces, the helmsman who steers the project. This determined creativity—a continuum of impulses—is at the heart of engineering leadership. It may not be the dominant trait of a leader, but it must be present.

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*A leader is the seed crystal around which everything else coalesces.*

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## The Road to Leadership

Becoming an engineering leader is an evolutionary process. To paraphrase an old navy adage, "To learn to lead, one must first learn to follow." Thus, it is vital that would-be engineering leaders grow as engineers by successfully completing increasingly significant and demanding tasks.

In my case, I first learned to "follow" at the Eckert-Mauchly Computer Corporation, which built the Univac I, the world's first commercial computer. With a master's degree in electrical engineering from the Massachusetts Institute of Technology (MIT), I was assigned to design the standard circuits of the Univac, as well as circuits for the acoustic memory (this was long before the development of solid-state memory and even magnetic core memory). My assigned tasks were important and challenging for an engineer with only a few years of experience.

I was an intermediate-level person in the Univac project. I didn't conceive or "architecturalize" the Univac. I didn't lay out the logic. I merely designed the circuits, a task appropriate to my capabilities—challenging but not impossible. In point of fact, I designed the circuits assigned to me better than my bosses could have because I had some previous related experience, and at MIT I had acquired a broad background in pulse circuitry, mathematics, and polynomial transfer (pole-zero) functions that enabled me to invent a scheme that avoided some of the problems that had arisen in acoustic delay lines.

Still, I was far from being able to comprehend the whole. The bosses of the project, the conceptual experts—in this case **Presper Eckert**, John Mauchly, and James Wiener, the chief engineer—were clearly and absolutely in charge. They had the vision, and they fully understood the challenges we faced, both technical and financial—and I learned a lot from them.

*Leadership, a fundamental human attribute, will always elude an absolute definition.*

James Wiener was a hard-driving taskmaster who expected and got superior results from his subordinates. Presper Eckert taught me that with a broad theoretical background and the right attitude you could design anything. He regularly inspired me, and I grew from the experience.

John Mauchly set me straight when I thought I had achieved something important. Prior to my work on the design of the entire acoustic memory, Mauchly had given me the task of designing a coupling network to connect the electronic drive and the piezoelectric crystal. He told me to go home and figure out the optimal coupling ratio. So, I developed a set of simultaneous equations, setting the derivatives equal to zero to optimize everything, and I came back on Monday morning with a few pages of figures and announced proudly, "Here is the optimum."

He didn't even read my derivations. Instead, he turned to the last page, read the result, and said, "This is bull****," and pushed it back in my direction.

Somewhat flustered, I replied, "How can you say that?"

He said, "Of course, it's bull****! You are getting out more power than you put in!" He was right, of course, and, chastened, I "went back to the drawing board."

From my early work on the Univac, my work for a subsequent employer, and then in my own business, the tasks I undertook became increasingly complex, and I gradually learned to lead others. My technical experience was important, but learning about the needs of others—customers and the people who worked with me—was also important. As an engineering leader bringing complex products to market, I have consciously emulated my early bosses who were talented and learned taskmasters as well as determined and ambitious visionaries.

## Engineering Leadership Defined

Since I have deliberately associated the word "magic" with the way engineering leaders get things done, I must admit that a completely airtight "specification" for an engineering leader cannot be created. Leadership, a fundamentally human attribute, will always elude an absolute definition. Nevertheless, I believe that most or all of the attributes or characteristics spelled out below are necessary for anyone who is or hopes to become an engineering leader (Gordon and Levy, 1985).

- **Vision**–the ability to foresee results and to be imaginative in conceiving and developing products.
- **Knowledge**–a breadth and depth of understanding and a facility in mathematics, engineering, physical sciences, history, and philosophy.
- **Courage**–a willingness to risk one's professional reputation and possibly incur financial, social, and psychological penalties.
- **Intelligence**–knowing how to apply the results of experience and training to solve new problems.
- **Economic sense**–an understanding and "feel" for the financial consequences of every aspect of a project.

- **Responsibility**–accountability for results, both good and bad, and attentiveness to even minute details.
- **Self-esteem**–a high self-regard and a sense of personal worth.
- **Talent**–the ability to make the most of inherited and developed gifts.
- **Discipline**–the exercise of self-control and orderliness and the quality of being self-motivated, a self-starter, even under adverse conditions.
- **Empathy**–the ability to be sympathetic, tactful, and diplomatic with colleagues in times of stress as well as times of ease.
- **Persuasiveness**–the ability to communicate directive and expository messages effectively and fluently both orally and in writing.
- **Forcefulness**–the ability to motivate and stimulate others, assume a take-charge attitude, and take command.
- **Integrity**–honesty with oneself and with others and the maintenance of high ethical standards.
- **Loyalty**–the quality of remaining loyal to the people being supervised, as well as to the supervisors.
- **Competitiveness**–the determination to win and not to accept defeat.
- **Commitment**–total dedication to the successful completion of a project and the drive to overcome any obstacles, even if this requires personal sacrifice.
- **Resourcefulness**–the ability to make do with available resources, to innovate, and to invent.
- **Perseverance**–the determination to complete a project, to overcome delays and obstacles.
- **Pride**–a feeling of satisfaction and accomplishment for contributing to the success of others and in completing the task.
- **Judgment**–the ability to learn from successful and unsuccessful experiences.

### Creating Engineering Leaders

Some engineering leaders may develop on their own while working in industry, but their development can and should be nurtured by academic programs. However, with the present disconnect in many institutions between academia and engineering practice, this will require a dramatic change of attitude that will take time. In discussions about leadership with academics, I frequently find that they initially do not have the foggiest notion of what I am talking about.

*Without leadership, even very bright people may achieve mediocre results.*

For example, when I describe how a chief or leader *must force* someone to do what needs to be done, they completely misunderstand what *force* means and show signs of discomfort and distaste with the idea of compulsion. In fact, ideally, the individual does *not feel* he or she is being forced. (On rare occasions, one might have to say, "Get this done by 4 p.m.—or else.") One can force others to do something they would not have done without your influence in numerous ways, such as setting an example, inspiring them, challenging their egos (perhaps even saying you have doubts that they'll be able to come up with a solution). In other words, the real compulsion must eventually come from the individual being supervised.

Many people in academia misunderstand why leaders are important. At some engineering schools, they believe that if you put 10 smart people in a room, they will naturally and cooperatively end up producing something of value. In my experience, that is possible, but not likely. A human version of entropy is always at work, and without the right kind of input and the addition of energy or force, even very bright people often achieve mediocre results. Some people in the academic environment do not understand the difference between the kind of person who has a brilliant idea and the kind of person who actually decides to act on that brilliant idea and make sure it is realized. Similarly, they do not understand the gulf between a great idea or brilliant invention and a practical, economically viable end product.

An engineering leader is the kind of person who takes the brilliant idea or invention, determines its worth, and carries it forward. I do not mean a "manager" who may be assigned to "take charge" of a brilliant idea. Management skills are rarely sufficient to capitalize on brilliant ideas because management, by its nature, is process oriented—managers often try to make every activity fit into a known, repeatable, reliable process. Thus, managers are often suspicious of inventive or new ideas.

Sometimes academics think, and convey to their students, that engineering is, or should be, all fun and games. In fact, engineering is generally hard, aggravating work. It means having nothing else in your head, waking up in the middle of the night, and personal stress. However, it also has major rewards. Some might say that building the first analog-to-digital converter or fetal monitor or a 3D explosive-detection system, all of which my companies accomplished and which have had an impact on millions of lives, would have been done by others within a few years if I hadn't pursued them. However, *we* actually did them, and knowing that provides real satisfaction.

## Looking Ahead

Fortunately, in recent years, a number of technical academic institutions have realized the need for a renaissance in engineering education and have initiated programs that incorporate more practice, teamwork, mentorship, and character development. They recognize that the world needs individuals who are not only smart but also strong, disciplined, and organized. An engineering leader combines these capabilities and can orchestrate the talents of others. And the results can be magical.

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# NAE News and Notes

## NAE Members Receive National Medals of Technology and Innovation and National Medal of Science

President Barack Obama presented the 2008 National Medals of Science and National Medals of Technology and Innovation on October 7, 2009, at a ceremony in the East Room of the White House. Four NAE members were among the recipients of these prestigious awards.

**Esther Sans Takeuchi**, professor of electrical engineering, chemical and biological engineering, and chemistry, State University of New York, received the medal "for her seminal development of the silver vanadium oxide battery that powers the majority of the world's life-saving, implantable cardiac defibrillators and her innovations in other medical battery technologies that improve the health and quality-of-life of millions of people."

**John E. Warnock**, chairman, and **Charles M. Geschke**, chairman of the board, Adobe Systems Inc., were honored for their contribution to the "desktop publishing revolution." They developed a stream of pioneering software products that leverage Adobe's strength in transforming how people create, process, and engage with information, thereby bringing publishing tools to everyday Americans.

**Dr. Rudolf Kalman**, Professor Emeritus, Swiss Federal Institute of Technology, received the **National Medal of Science** for the Kalman filter, a device that measures trajectory in avionics and space travel. The Kalman filter, a mathematical

Esther Sans Takeuchi, 2008 National Medal of Technology and Innovation Laureate.

John E. Warnock and Charles M. Geschke, 2008 Technology and Innovation Laureates.

Rudolf Kalman, 2008 National Medal of Science Laureate. *All Photos by Ryan K. Morris, National Science and Technology Medal Foundation.*

technique that removes "noise" from series of data, revolutionized the field of control theory and has become ubiquitous in engineering systems. Kalman's ideas enabled a broad range of technologies with unprecedented accuracy that are being used in previously unimagined ways. Recognition of the Kalman filter's utility began in the early 1960s with aerospace and military applications such as guidance, navigation, and control systems and was quickly applied to systems and devices in nearly all engineering fields. Applications of the filter include target tracking by radar, global positioning systems, hydrological modeling, atmospheric observations, time-series analyses in econometrics, and automated drug delivery.

## NAE Newsmakers

Three NAE members were awarded the **2009 Nobel Prize in physics** for the technologies that enable digital photography. Half of the prize was awarded to **Charles K. Kao**, Standard Telecommunication Laboratories, Harlow, United Kingdom, and Honorary Professor, Department of Information Engineering, Chinese University of Hong Kong, "for groundbreaking achievements concerning the transmission of light in fibers for optical communication." The other half was split between **Willard S. Boyle**, retired executive director, Communications Research Division, and **George E. Smith**, retired head, MOS Device Department, AT&T Bell Laboratories, "for the invention of an imaging semiconductor circuit—the CCD sensor."

**Anil K. Chopra**, Johnson Professor of Structural Engineering, University of California, Berkeley, has been included in International Water Power & Dam Construction's list of the "**60 most influential people in the Industry**." According to the announcement, "these people have helped shape the course of the global hydro and dams business over the last 60 years."

**Randal E. Bryant**, dean and University Professor, School of Computer Science, Carnegie Mellon University, was awarded the **Phil Kaufman Award** from the Electronic Design Automation Consortium and the Institute of Electrical and Electronics Engineers (IEEE) Council on Electronic Design Automation. The award was presented to Dr. Bryant on November 4 in recognition of his "seminal technological breakthroughs in the area of formal verification—the use of mathematical techniques to prove that a hardware or software design functions as intended."

The Association for Computing Machinery (ACM) Special Interest Group on Computer Graphics and Interactive Techniques (SIGGRAPH) presented its **2009 Steven Anson Coons Outstanding Service Award** to **Robert L. Cook**, vice president, Advanced Technology, Pixar Animation Studios. Mr. Cook is the original author and co-architect of RenderMan, the software recognized as the industry standard for computer graphics animation and visual effects. He was also cited for his work on behalf of the SIGGRAPH community.

**Thomas Kailath**, Hitachi America Professor of Engineering Emeritus, Department of Electrical Engineering, Stanford University, was elected a **Foreign Member of the Royal Society**. Every year, the Royal Society elects 44 Fellows and eight Foreign Members, including just a few engineers. The induction ceremony, with traditions going back to 1660, took place on July 10. In April of this year, Professor Kailath received the **Padma Bhushan Award** from the president of India in a ceremony in New Delhi; the Padma Bhushan is the third highest civilian honor bestowed by the government of India. On November 6, Dr. Kailath was awarded the **Blaise Pascal Medal for Computer and Information Sciences** by the European Academy of Sciences.

**Pradeep K. Khosla**, dean, College of Engineering, Carnegie Mellon University, received the **2009 Academic Excellence Award** on October 11 at the Pan IIT Entrepreneurship Conference in Chicago. Dr. Khosla was unanimously selected from a field of more than 200 nominees to receive the Academic Excellence Award from Pan IIT, a global organization representing alumni from all Indian Institutes of Technology campuses.

**Edward I. Moses**, principal associate director, Lawrence Livermore National Laboratory, is the recipient of the **2009 Edward Teller Medal**, presented by the American Nuclear Society. Dr. Moses shares the honor with Ricardo Betti, University of Rochester. Dr. Moses was cited for "leadership in the development and completion of the National Ignition Facility." Established in 1991, the Edward Teller Medal is awarded for pioneering research and leadership in inertial fusion sciences and applications.

**Richard A. Tapia**, University Professor and Maxfield-Oshman Professor in Engineering, Rice University, received the annual **Hispanic Heritage Award for Math and Science** at a ceremony on Capitol Hill in Washington, D.C. Dr. Tapia was cited for his international reputation for research in the computational and mathematical sciences and his national leadership in education and outreach. The Hispanic Heritage Awards were created by the White House in 1988.

The **David Feldman Award** given by the IEEE Components, Packaging and Manufacturing Technology (CPMT) Society, has been awarded to **C.P. Wong**, Regents' Professor of Materials Science and Engineering, and the Charles Smithgall Institute Endowed Chair, School of Materials Science and Engineering, Georgia Institute of Technology, for his leadership in the IEEE and CPMT Society for the last 22 years.

*Submissions for Newsmakers should be sent to dthorp@nae.edu or mailed to Dennis Thorp, NAE Membership Office, 500 Fifth Street NW, Washington, DC 20001.*

## Highlights of the 2009 NAE Annual Meeting

NAE Class of 2009

NAE members, foreign associates, and guests gathered in Irvine and Newport Beach, California, this October for the 2009 NAE Annual Meeting. The meeting began on Saturday afternoon, October 3, with an orientation session for new members. In the evening, the 66 new members and 8 new foreign associates were honored at the NAE Council dinner at The Island.

NAE chair **Irwin M. Jacobs** opened the public session on Sunday, October 4, with brief remarks about the importance of engineering innovation to our economic health and well-being. He also stressed the importance of NAE members volunteering their time, expertise, and funds to further NAE's efforts and goals (see p. 51).

President **Charles M. Vest** then delivered his annual address. He noted that the United States still does not have a sense of urgency and commitment to investing in education, research, and other aspects of our innovation capacity. He also said that the recommendations of *Rising Above the Gathering Storm* should be updated and implemented and that we must take action to develop the next generation's brainpower and transform our innovation system to meet 21st century grand challenges (see p. 53). Executive Officer **Lance Davis** then introduced the members and associates of the NAE Class of 2009 as they were inducted into the academy.

The program continued with the presentation of the 2009 Founders Award and Arthur M. Bueche Award. The winner of the Founders Award, was **John R. Casani**, special assistant to the director of the Jet Propulsion Laboratory. Dr. Casani was cited for his "distinguished innovation and leadership in robotic spacecraft engineering and project management that has enabled the first four decades of planetary and deep space exploration." The Bueche Award was then presented to **Sheila E. Widnall**, Institute Professor, Massachusetts Institute of Technology, for her "remarkable academic career in fluid dynamics combined with the highest levels of public service and for championing the role of women in engineering." Acceptance remarks by Drs. Casani (see p. 58) and Widnall (see p. 61) followed.

After a break, Dr. Vest introduced the Armstrong Endowment for Young Engineers–Gilbreth Lecturers, outstanding young engineers selected from speakers at recent NAE Frontiers of Engineering symposia. Jeffrey J. Welser, director, SRC Nanoelectronics Research Initiative, IBM Almaden Research Center, spoke on "The Quest for the Next Information-Processing Technology." Yoky Matsuoka, associate professor of computer science and engineering, University of Washington, describe cutting-edge research on "Neurobotics: Interfacing Robot and Nervous Systems to Enhance Human Movement."

Distinguished Guest Lecturer Charles Elachi

The Distinguished Guest Lecture, "Innovation in Robotic Space Exploration," was then presented by **Charles Elachi**, director of the Jet Propulsion Laboratory. The last event of the day was a reception for members and guests.

At the Annual Business Session on Monday morning, Dr. Vest brought members up do date on current administrative and programmatic matters of interest. He described actions that had been adopted by the NAE Council to modify NAE membership procedures and provided an overview of NAE's programmatic priorities, including projects specific to NAE and collaborative projects with the National Research Council and Institute of Medicine.

The business session was followed by "Rebuilding a Real Economy: Unleashing Engineering Innovation," a forum moderated by Ali Velshi, chief business correspondent for CNN and co-host of "Your Money." The discussion was focused on unleashing technological innovation to create products and services with real market value.

The panelists included **Jean-Lou Chameau**, president of Caltech and former provost of Georgia Tech; Peter Diamandis, chairman and CEO of the X-Prize Foundation; Judy Estrin, former CTO of Cisco, serial entrepreneur, and author; **Chad Holliday**, chairman and CEO of DuPont; Steve Koonin, U.S. Under Secretary of Energy for Science, former vice president of BP, and former provost of Caltech; Raymond Lane, managing partner of Kleiner, Perkins, Caulfield, and Byers and former president of Oracle; and Tony Tan Keng Yam, chairman of the Singapore National Research Foundation, executive director of the Government of Singapore Investment Corporation, and former deputy prime minister.

On Monday afternoon, members and foreign associates participated in NAE section meetings at the Beckman Center and the Newport Beach Marriott Hotel and Spa. The final event of the meeting was the annual reception and dinner dance, held at The Island. Music was provided by That Vibe.


Forum panel. Left to right: Jean-Lou Chameau, Peter Diamandis, Judy Estrin, Chad Holliday, Steve Koonin, Raymond Lane, and TonyTan Keng Yam. Ali Velshi is the moderator. *Photos by Tom Sullivan.*

# The Importance of Engineering Innovation Remarks by NAE Chair Irwin M. Jacobs

Irwin M. Jacobs

Welcome. I want to add my congratulations and those of the NAE Council to all of our new members and foreign associates and their families and friends. Needless to say, this is a very impressive group. I found it very exciting to read through your citations and note the breadth and impact of your research, teaching, and leadership activities.

We live in a time of great need for technical innovation (and less financial innovation) to boost the economy, help preserve our environment, improve education, expand health care, and indeed raise standards of living and quality of life worldwide. Engineering is one important key to innovations with true economic value. The importance of engineering innovation is reflected in the name of this year's NAE Annual Meeting Forum, "Rebuilding a Real Economy: Unleashing Engineering Innovation."

I want to mention the citations of several members whose work has directly affected me and who have strongly supported innovation. I should note that I played no role in their elections.

In the early 1970s, a few years after starting Linkabit, I was fortunate to lead the ARPA team that extended the ARPANET to Europe via satellite. While visiting Europe with **Bob Kahn** to launch the project, we found that the PTTs [phone companies] were friendly but did not see any potential in a packet-switched network. Luckily, several government labs and universities did. Professor **Peter Kirstein**, University College London, played a key role in this successful effort. His citation reads, "For contributions to computer networking and for leadership in bringing the Internet to Europe." It was great working with him, and in doing so, I got hooked on e-mail.

Another result of Peter's efforts was the first demonstration of the Internet protocol. In November 2007, at the Computer History Museum, we celebrated the 30th anniversary of this event, which linked the ARPANET, SATNET, and packet-radio network. The packet radio seemed quite far out at the time, but we now all carry a much more powerful version of it in our pockets.

In the early days of Qualcomm, we developed a continent-wide, satellite-based truck-tracking and communication system called OmniTRACS. The first customer to purchase a system was Schneider National. However, the company would need an entire logistics and management information system to justify the cost and gain full value. I note that **Chris Lofgren**, president and CEO of Schneider National, is being cited "For development and implementation of supply-chain engineering concepts, software and technology for truck transportation, and third-party logistics." I should note that Schneider drivers quickly overcame their Big Brother concerns about the system as Schneider shared the benefits of improved productivity with them. The success of OmniTRACS enabled us to move on to the application of code division multiple access (CDMA) to cellular technology.

I also note the citation of Professor **Gurindar Sohi** of the University of Wisconsin, "For contributions to the design of high-performance, superscalar computer architectures." That caught my eye because, based on his pioneering work, superscalar processors are now embedded on cell phone chips that run on batteries and are carried in our pockets.

With four billion subscribers worldwide, new uses for mobile phones are driving many innovations that have an economic and social impact. Last year, I described a project using smart phones to teach Algebra 1. We are now into our third year of the project, with more students and subjects, and the results continue to be very positive. A key to this success is that students have phones with them outside of school as well as in class. Academic social networking has a valuable feature—students helping one another and posting elegant solutions to problems.

In the September 26th issue of *The Economist* there were several articles on the value of rapidly expanding communications in developing countries. They mentioned one farmer who accessed an application called "Farmer's Friend" to check on timing for planting tomatoes and another, who was dealing with an aphid infestation, on how to make a pesticide using soap and paraffin. They also mentioned the benefits of Google Trader, a text-based system that matches buyers and sellers of agricultural produce and commodities. Sellers send a message to say where they are and what they have to offer to potential buyers within 30 kilometers for the next seven days. A Mr. Makawa says his father used the service to look for a buyer for some pigs, which he sold to pay school fees. In the first five weeks, these services had a total of more than one million queries.

I must admit that in reading through the citations, I came across several terms I did not recognize. Of course, all I had to do was Google them, which did the job. Two of our new members are from Google. **Sergey Brin**, co-founder and president of technology, is cited "For leadership in development of rapid indexing and retrieval of relevant information from the World Wide Web." **Sanjay Ghemawat**, Google Fellow, is cited "For contributions to the science and engineering of large-scale distributed computer systems."

Many other innovations in key areas are addressed in the citations, including innovations in energy, bioengineering (including one on engineering molecular assembly lines), communications, computers and the Internet, environmental engineering, micro- and nano-engineering, robotics and manufacturing, and many other areas that impact our lives. Finally, although we live in an increasingly digital world, there was even a citation for "high-speed analog microelectronics."

NAE, of course, does much more than recognize achievements. It also draws on your expertise to assist with many projects each year. You have received information on our NAE Matching Challenge, a campaign to increase funds available for new efforts. You may ask why NAE needs independent funds and funds targeted to specific projects.

An example of a privately funded NAE study is the recently completed *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. This study surveys the extent and nature of efforts to integrate engineering into U.S. K-12 education and explores the potential of expanding those efforts. Funding will also support follow-on projects.

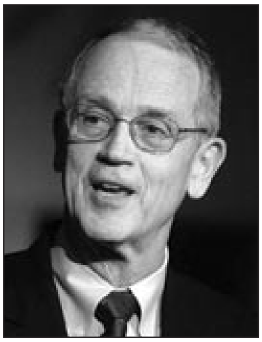
Last year, I described High Tech High (HTH), a charter school system in San Diego that is mentioned in the K-12 study. HTH selects students by lottery, does not track them, and yet graduates and sends almost 100 percent of them to college, with about 30 percent studying STEM subjects. A key component of HTH is project-based learning, often involving engineering design. HTH is now introducing a virtual classroom component and electronic texts.

NAE Independent Funds, our only truly discretionary resource, support these and other projects. They provide seed money for exploring and launching new initiatives and ensure the continuity of our operations. These philanthropic funds are critical to NAE. They provide more than 30 percent of our budget and are highly leveraged as externally funded studies and projects are developed.

For instance, NAE Independent Funds supported the pre-project planning for our highly successful "Grand Challenges for Engineering" project funded by NSF. They also supported the early planning and provided supplementary funding for the "Engineer of 2020" project (also largely funded by NSF); based on book sales, this was one of NAE's most successful projects. Finally, NAE Independent Funds also made possible the creation of the NAE Center for the Advancement of Scholarship in Engineering Education (CASEE). I invite you to participate actively in these projects and, when you can, to contribute to their support.

Again, congratulations and welcome to the academy.

# A Time for Fundamental Change
# Remarks by NAE President Charles M. Vest



Charles M. Vest

It is a great pleasure to participate in this 45th induction ceremony of the National Academy of Engineering, the first ever held outside Washington, D.C. And it is a special privilege to welcome the families, friends, and guests of those who are being inducted today as members and foreign associates of NAE.

Your election to the National Academy of Engineering signals that our members, through a very rigorous process, have concluded that you are among the most brilliant, accomplished, and distinguished members of your profession. We are proud to welcome you as colleagues in the academy, and we all hope that this is a deeply meaningful event in your professional lives. Election to NAE is a rare and singular honor, but membership also has additional significance. It is an opportunity for national service. Indeed, it is a call to national service.

We are chartered by the U.S. Congress, together with the National Academy of Sciences, the Institute of Medicine, and our joint operating arm, the National Research Council, to provide independent, objective advice to the federal government on matters of science, technology, and medicine. But we are not a government organization, and we are not part of the federal government. We are an independent, non-profit organization. In return for providing objective analyses and experience-based advice of the nation's most accomplished engineers, through studies conducted in an objective, nonpolitical manner, we have been granted a special, respected role as advisors to the nation.

We perform this function largely by conducting rigorous studies of specific issues, either when requested by the government, or, from time to time, when we ourselves choose to examine an issue we believe to be particularly important. Of course we call on our members to provide leadership for these studies. The National Academies can be thought of as an unparalleled think tank centered on engineering, science, and medicine. This is the primary service we will expect of you.

When I was elected to NAE in 1993, I received a note from John Armstrong, the former vice president for research of IBM. John's note said, "Congratulations on your election to the NAE. I just can't wait to put you on a committee!" You can see that John is less subtle in these matters than I am, but the message is identical.

In his *New York Times* column one year ago, Tom Friedman contrasted the Wall Street bailout with the need for a green future. He wrote, ". . . we don't just need a bailout. We need a buildup. We need to get back to making stuff based on real engineering not just financial engineering." That was one year ago.

Two weeks ago, he wrote about the visionary work of one of our fine Silicon Valley companies that produces photovoltaic solar cells. A great story, but every manufacturing job associated with the company is in another country, specifically Germany. Friedman then noted that while many in the United States continue to treat renewable energy largely as a fairy tale, the renewable energy industry in Germany, with more than *50,000 new jobs, is now second only to its automobile industry*.

What is this about? It is a harbinger of a nation that has for too long ignored many of the greatest challenges of our age. It is about a nation in which far too many citizens and leaders assume that because we have been king of the mountain throughout their lives, the future will be no different. It is about the most innovative nation on the planet failing to harness that innovation in some of the most important directions. It is about a nation that for decades has given up on providing a world-class education to its primary and secondary students and is now tearing into the core of its great public system of higher education. It is about a nation that properly and generously shows the rest of the world how to build the foundations of strong economies while it stubbornly forgets its own lessons at home. It is about a nation increasingly unable to find a proper balance between short-term gain and long-term vitality. It is about a body politic that thinks globalization is an evil out on the horizon, when in fact it has been the reality of our businesses and industries for decades and must be shaped as a source of economic strength. It is about a nation in which someone seems to arise every morning and ask, "What new thing can we do today to become even less hospitable to people from other countries who want to visit, study, or become part of our society?"

I have asked myself if I could really stand here this morning and go through this litany yet again. After all, our National Academies report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* presents the clearest summary of these issues and provides the strongest recommendations for changing course. The report has had some impact, but its findings were released in 2006, and we still have not seen broad, fundamental change.

The time really has come to slay the dragon of complacency. There is little slack left, and other nations are not biding their time. I really am worried. Indeed, I am frightened. But deep inside me there is still a spark of optimism, based in the first instance on something Winston Churchill once said, "You can always count on the Americans to do the right thing . . . after they have exhausted all the other possibilities."

I also have a sense of underlying optimism because this generation of young people is idealistic and is attracted to addressing the grand challenges of the 21st century. And we surely can make them aware that this is indisputably the most exciting era in engineering and science in human history.

So how do we get back on track? The short answer is, we update the recommendations of *Rising Above the Gathering Storm* and implement them. But today I would like to explore three essential components of any reasonable strategy for moving forward: developing brainpower, unleashing innovation, and grappling with scale.

## Developing Brainpower

Our age is both global and knowledge driven. As the world has become wealthier and generally better educated, science and engineering talent and knowledge are being distributed more broadly. North America, Europe, and Asia each accounts for roughly one-third of the world's R&D expenditures. China now leads the world in the number of young engineering professionals; India leads the world in the number of young professionals in finance and accounting; and the United States leads the world, by a small margin, in the number of young life-science professionals.

But coupling science and engineering gives us a misleading picture. The global trends in the engineering workforce are very different from those in the scientific workforce. In the early 1980s, China, Japan, and the United States each graduated about 75,000 bachelors-level engineers per year. By 2002, the most recent year for which accurate data are available, first degrees in engineering in the United States had dropped to about 60,000; in Japan they had grown to more than 100,000 graduates per year; and China had leaped to about 250,000 first engineering degrees per year. Yes, there is a wide variance in the nature and quality of engineering education, but the trend is very important.

You might say, "Of course China should have many more engineers than we do. After all, their population is nearly 1.5 billion, and they are rapidly industrializing." I agree, so let's look at a more important indicator, the fraction of college graduates who earn degrees in engineering. Broadly across Asia, Europe, and the United States the fraction of graduates with first degrees in the natural sciences is approximately 12 percent in each region. However, the fraction of graduates with first degrees in engineering is 20 percent across Asia, 12 percent across Europe, but only 4.5 percent in the United States.

I believe that the low fraction of our students majoring in engineering is something we really need to worry about. The fact is that we have been filling in the corresponding gap in our engineering workforce for many years by importing talent from other countries. Well more than half of the engineering and science Ph.D. students in U.S. universities come from other countries, and these immigrants have assumed major leadership positions in our universities and in our entrepreneurial industries.

We are grateful and should celebrate the leadership and contributions of these talented immigrants and the traditional openness of our country, campuses, and industries. But we cannot necessarily count so heavily on them going forward. Many more are beginning to return home because of perceived higher speed of professional growth and better opportunities to start their own businesses.

We also need to make our borders more welcoming and especially to implement the *Gathering Storm* recommendation to increase the number of H1-B visas issued each year, and we should offer H1-B visas to students who earn doctoral degrees in STEM fields.

But our fundamental task must be to increase the number of U.S.

citizens entering these fields. This requires two things: *inspiration* and *improved education*. We must inspire the next generation to contribute to a better world and a stronger economy through engineering and science; and we must somehow become serious about improving our public K–12 education.

There are productive roles here for the National Academy of Engineering. NAE's Grand Challenges for Engineering is proving to be an effective organizing framework for inspiring the next generation. And the Grand Challenges are a wonderful example of how seeds planted by NAE can be leveraged through the passionate work of others. Several engineering deans and university presidents around the country have picked up the agenda of inspiration and run with it. Next spring there will be six coordinated summits in different parts of the country that will bring students, faculty, and leaders of industry and government together to focus on two or three of the NAE Grand Challenges.

With the leadership of Dean Tom Katsouleas at Duke, Dean Yannis Yortsis at USC, and President Rick Miller at Olin College, there is a national movement to establish a program of Grand Challenge Scholars among engineering undergraduates to "foster undergraduate research, study, and experiential learning related to the National Academy of Engineering Grand Challenges for Engineering." In addition, there are undergraduate project courses, and even reorganizations of curricula around the country building on our Grand Challenges report.

Let me return now to improving education. This is a very complicated issue, but I want to point out one shining example. *Rising Above the Gathering Storm* recommended bringing to national scale a program started several years ago in Dallas by businessman and philanthropist Peter O'Donnell that provides modest financial incentives to teachers to qualify to teach science and math at the AP level. The program also provides a modest payment of a few hundred dollars to students who pass AP subjects in math, science, and English. The results of this simple program have been simply amazing.

Following the release of *Gathering Storm*, while waiting for the federal government to consider setting up an AP program, a nonprofit, private-sector organization—the National Math and Science Initiative (NMSI)—was established with financial support form ExxonMobile, the Gates Foundation, and the Dell Foundation. During its first year, the NMSI AP program is in 67 schools in seven states; and 13,000 exams were taken by AP students in science, math, and English, an 80.1 percent increase over the previous year. There was also a 51 percent increase in the number of AP exams passed, which is more than nine times the national average. The percent increases among women and underrepresented groups was even higher. This program will be expanded in the coming years. NMSI's second component, UTEACH, now operating in universities in 14 states, aspires to meet the *Gathering Storm* goal of graduating 10,000 K–12 teachers appropriately educated in the disciplines they teach.

My point is that there are things that can be done. Individuals can make a difference. And the work of NAE and the National Academies can be leveraged by private groups, as well as by the federal government.

**Unleashing Innovation**

The United States is facing an economic crisis unmatched in recent memory, and there is general consensus that this crisis was precipitated by building far too much of our economy on vaporous transactions that did not create real value. To emerge from this financial crisis and set a sound 21st century course, we must turn our attention to unleashing engineering innovation to create products and services that add actual value.

As a nation we must refocus on the real economy, and that will require a re-energized innovation system to generate new knowledge and technology and move them successfully to the competitive world marketplace. We must become more productive and efficient at the things we already do well, create new industries, and transform others. We need to address energy, environment, security, and health care delivery in order to sustain our economic stability and quality of life. Our innovation system itself must evolve to meet these large-scale challenges.

Tomorrow, in our Forum, a distinguished panel will explore the roles of academia, entrepreneurs, venture capitalists, global corporations, challenge prizes, and governments in unleashing technological innovation to rebuild a real economy and meet 21st century challenges. It will be an exciting event.

But let me offer a few comments now. The American innovation system, as I think of it, is a loosely organized system that creates new knowledge and technology through research and educates young men and women to understand and create this new knowledge and technology and move it to market as new products, processes, and services.

This system, which has been an enormous success from any perspective, derives largely from the 1945 Vannevar Bush report, *Science—The Endless Frontier*, which established universities as the primary element of the nation's basic research infrastructure and recommended the establishment of a National Science Foundation. That report still accurately describes a large part of technological innovation in the United States, especially the chain that runs from universities through entrepreneurs and venture capitalists.

However, during the last 40 years, the core of the innovation system involving large corporations has changed substantially about every decade. In the 1970s, central corporate research laboratories dominated; in the 1980s, corporate R&D was transformed and absorbed into a new style of product development in response to the challenge of Japanese consumer manufacturing; in the 1990s, large companies acquired innovation by buying start-up companies often spun off from research universities; and now in the early 2000s, globally open innovation has begun to play a major role.

Several things suggest that we may see another shift in the U.S. innovation system:

1. The scientific basis of new technologies will increasingly come from the life sciences and information technology.

2. Macro-scale systems challenges, especially energy, will drive innovation in the coming decade.

3. Venture capital may now be too risk averse and may not fit some large-scale systems.

4. Globalization of R&D investments, education, and a high-quality workforce will continue apace.

5. Economic growth may require a new enabling technology analogous to IT and the World Wide Web in the last century.

6. We will need transformative breakthroughs to address many global grand challenges, such as energy, health care, and security.

Perhaps our current innovation system will simply continue to evolve. More likely, it will be augmented or readjusted to tackle large-scale 21st century challenges. For example, a 2004 NAE study proposed that Discovery Innovation Institutes be located on the campuses of research-intensive universities. These institutes would conduct engineering research and innovation on a large scale and would have direct linkages to industry and government to guide use-inspired research and more efficiently move new ideas, discoveries, and technologies into practice. Such institutes would be especially suitable to addressing complex, large-scale, long-lived challenges such as energy. Indeed, DOE recently proposed something similar.

In higher education there are many experiments under way to foster and enhance innovation capacity and new modes of thought. Olin College of Engineering, near Boston, has operated now for seven years with an untraditional, design-oriented curriculum and an organizational structure without the usual disciplines. Finland is constructing the entirely new Aalto University, which will combine technology, economics, and art and design. Singapore is establishing a new university in partnership with MIT that will be focused heavily on science, engineering, information systems, and architecture, with a special emphasis on the role of design, broadly defined.

In California, Singularity University is the working name of a joint effort by NASA, Google, and several leading thinkers, such as NAE member **Ray Kurzweil**, to cross-educate students from the emerging disciplines of nanotechnology, biotechnology, and information technology and prepare them to attack the great challenges of our times.

Another intriguing attempt to drive innovation to achieve large goals is the work of the X-Prize Foundation. In 1996, the $10 million Ansari X-Prize for the first nongovernmental group to achieve human space flight went to **Burt Rutan**, who in turn was financed by **Paul Allen,** both NAE members. The goal of the X-Prize Foundation is to spur innovation to solve other highly challenging and important societal problems by leveraging the financial and intellectual resources of contest entrants. The DARPA Grand Challenge Program has a similar structure.

Finally, there are many emerging Web-based platforms for developing and using the collective input of large numbers of people to forge new ideas, solve problems, and, in a broad sense, innovate. For example, *Rosetta@home* is a website that enables thousands of people around the world to play a massive computer game whose real purpose is to use their collective brainpower to solve highly complex problems of protein folding and bimolecular design.

## Grappling with Scale

Driven by relentless change, globalization, and distributed intelligence, the new generation will undoubtedly reshape our innovation system, and it will be none too soon. I am optimistic that we can move forward on developing brainpower and unleashing engineering innovation, but it is less clear to me how we can adapt our industrial and innovation base to meet large-scale national goals. For example, how will we deploy a modern electrical transmission and distribution system capable of intelligent operation and adaptation to highly variable renewable energy sources? How will we reinvent our manufacturing base?

A primary historical lesson from the 20th century is that the answer is not central planning. Government-generated technology road maps or other grand detailed plans, in my view, are not the way to go. But neither is the anything-goes, political interest-generated collection of regulatory regimes that break the current electrical grid into a multiplicity of overly independent segments. Somehow we must establish a common vision of the so-called Smart Grid and set common regulatory standards and common technology standards that can be met in various ways by regional entities and the private sector. This is another kind of social/technical grand challenge for our nation.

Finally, it is time for healthy but objective debate about how far we can move into a service economy. It is empirically evident, and possibly desirable, that the fraction of our workforce employed in the service sector, broadly defined, is approaching 70 percent. But can we truly prosper without some form of transformed manufacturing base?

Efficient, low-cost manufacturing is the essential element in the deployment of batteries, solar cells, and other green technologies. Is it really okay if the manufacturing jobs in emerging green industries are established in other countries to begin with, rather than following the past trend of starting here and moving overseas as the industry matures and margins become thin? Many thinkers, including a number of NAE members, believe that we must find a new manufacturing paradigm, perhaps based on emerging advances in fields like robotics and biological synthesis of materials and devices, where we might establish a lead. In any event, these are fundamentally important questions about the innovation system that I hope we in NAE can help address.

## Conclusion

Once again, congratulations on your election to the National Academy of Engineering. I hope that this is a deeply meaningful event for each of you. NAE asks that you recognize your membership as an opportunity to serve your nation and world by contributing to well-informed, objective, independent advice on important issues involving technology. Developing and transmitting such advice is an important form of engineering leadership.

You come to this task at a moment in history when it is urgent that we sustain and enhance the technological welfare of the nation so that we can compete in the global, knowledge-based economy *and* maintain our prosperity. You also come to this task at a time when the frontiers of engineering, on both the small and large scale, are not only enormously exciting, but also critically important to meeting the great challenges of energy, environment, productivity, health care, food, water, and security.

Thank you for your attention.

# 2009 Founders Award Acceptance Remarks by John R. Casani

Irwin Jacobs, John R. Casani, and Charles M. Vest.

*The 2009 Founders Award was presented to* **John R. Casani***, special assistant to the director, Jet Propulsion Laboratory, for "distinguished innovation and leadership in robotic spacecraft engineering and project management that has enabled the first four decades of planetary and deep space exploration."*

It is a great honor to be here tonight to receive the National Academy of Engineering Founders Award. I want to begin by expressing my profound appreciation to the Academy, the nominators, and the Award Committee for this great recognition. When **Chuck Vest** called to let me know, I was truly amazed. This is an award that few would ever anticipate—certainly not I.

Although I am surprised to be receiving the Founders Award, you may be surprised to learn that you have bestowed this esteemed engineering award on a person who began college in liberal arts and did not switch to engineering until the end of the sophomore year. While such redirections in college are not unusual, most of them go the other way. How I came to choose an engineering education and how that choice affected my career as an engineer and as an engineering manager will be the focus of my remarks this evening. It is my hope that my experience may reveal some clues as to how we might encourage talented young people to succeed in engineering careers.

Although I've always had an abiding interest in gadgetry and was drawn to all things mechanical growing up, I was never introduced to, or even aware of, the field of engineering. No one in my family or circle of friends ever knew of anyone who was an engineer, much less actually met one. My father owned a wholesale confectionary business in Philadelphia, and all of his friends and all of my relations were business people.

In fact, my father placed a high value on a liberal arts education, and he had very much wanted to go to college himself. His biggest disappointment in life was that he was denied that opportunity when his family decided he should join the family business as soon as he was discharged from the Army at the end of World War I. His mother was a college graduate, as was my mother, and my father was determined that every one of his children would get a college education. Because he was interested in literature, he steered all of us in that direction.

I was sent to a Jesuit high school in Philadelphia where the curriculum consisted of four years of Latin, three years of classical Greek, four years of English literature and English composition, American history, algebra, and high school physics. There were no courses in any other science, like chemistry or biology, and the subject of engineering was never once broached. Interestingly enough, the class I liked best in four years of high school was a senior class called physics. (Today it would probably be called something else.)

I graduated from high school thinking I wanted to be a physicist, not even knowing that engineering was a college curriculum. It might seem nearly impossible—that after a good high school education I had no idea a person could study engineering in college. Maybe today it *would* be impossible. But I would venture to say that even today, more people than you might think are similarly uninformed. In my case, I think my lack of awareness was directly related to my family and my high school's lack of interest or understanding of engineering. By contrast, my guess is that most of you in this room grew up in an atmosphere in which science and engineering were not unknown topics of conversation at the dinner table. Not so in my house.

So it was that I matriculated in liberal arts at the University of Pennsylvania in 1950, still unaware that engineering was a choice. At the end of the sophomore year, each student was required to declare a major. By that time all I knew for certain was that I didn't want to be a physicist. I was otherwise at a loss as to what direction I should take. I suggested to my dad that the best course of action for me would be to drop out of school and join the Air Force, with the thought that I would be better able to make a curriculum choice after I had matured for a couple of years. He would hear none of it and sent me back to school, telling me not to come home until I had picked a major.

I returned to school and shared this dilemma with a casual friend, who happened to be a freshman who was studying electrical engineering. He was enthusiastic about his studies and invited me to check out the Moore School (of Electrical Engineering). To make a long story short, I did just that and was intrigued by what I saw. The dean agreed to accept me as an entering sophomore for the fall semester, provided I went to summer session to make up math. I entered the Moore School, attended the summer session, and started down the road to an education in engineering. To his credit, my father said, "Great!"

Three years later I graduated with a bachelor of science in electrical engineering from the University of Pennsylvania Moore School of Electrical Engineering, now the College of Engineering and Applied Sciences. My first job after graduating was in Rome, New York, at the Rome Air Development Center, where I worked in electronic countermeasures. It was an exciting time for me, but not exciting enough to hold me through a harsh winter. After a week of temperatures that never got warmer than five degrees below zero, Fahrenheit, I started exploring other opportunities. Come June, I was on my way to California and a new job at the Jet Propulsion Laboratory.

When I left Philadelphia to head west, I assured my folks I was only going to be gone for a few years and would return with stories to amaze them about life on the frontier. To my circle of acquaintances, California was a magical place that few of them would ever visit. I had every expectation of eventually returning to my roots. As it turns out, I'm still in California, 53 years later, and I have never looked back.

I started work at JPL on July 11, 1956, and 53 years later, I'm still there and loving every moment of it. I can't imagine a better career, and I am grateful to the people of JPL, NASA, and many in the aerospace community who gave me the opportunity to do things that had never been done before. I suppose you could say that I'm one of those people who does not have a life; rather, my life is what I do.

In 1956, JPL was doing work for the Army Ballistic Missile Agency in Huntsville, Alabama, and I was given the task of figuring out how to integrate an experimental radio-inertial guidance system into a Corporal missile for a test flight at White Sands. That was a big assignment for a kid just one year out of school! And it was a golden opportunity, because it put me into direct contact with all the technical disciplines involved in developing the CODORAC—or coded Doppler, ranging, and command—guidance system inertial platform: for example, gyro and accelerometers, phase-locked loop tracking, pseudo-noise generators, radar beam splitting and spread spectrum modulation, antenna tracking and pointing, telemetry and command, and a host of other emerging technologies that turned out to be quintessential to the as-yet unforeseen challenges of robotic spacecraft.

The California Institute of Technology was managing and operating JPL for the Army at the time. When NASA was created as part of the Space Act of 1958, Caltech's contract with the Army was novated to the new agency. At the same time, the National Advisory Committee for Aeronautics (NACA) was decommissioned, and the Ames and Langley research centers were assigned to NASA.

My first job under NASA was as systems engineer for the *Pioneer 3* and *4* spacecraft, designed to fly by the moon to test an optical limb sensing mechanism as a possible triggering device for use on a subsequent mission. Although *Pioneer 3* suffered a launch vehicle failure and ultimately ended up in the South Atlantic Ocean, it returned data that revealed the outer van Allen radiation belt, distinct from the belt discovered by *Explorer 1*. *Pioneer 4* worked as intended and showed that the limb crossing detector would not serve its intended purpose.

Next, I was assigned to lead the design team for Ranger-class spacecraft and, a few years later, the design team for Mariner-class spacecraft. I was the project engineer for the first two Ranger launches as well as the project engineer for the first two Mariner spacecraft. After that, I progressively moved through a sequence of increasingly responsible project management roles, always under the guidance and mentoring of a remarkable group of managers and pioneers in spacecraft development and management.

It is literally true that I was fortunate enough to be in the right place at the right time. My mentors were the giants of robotic space exploration, including Jack James, Gene Giberson, **Bill Pickering**—who was JPL director and a founding member of NAE—and **Bud Schurmeier** and **Bob Parks**, who also were NAE members. I truly believe that my career progression was carefully preprogrammed by them. Each assignment seemed to provide just the right experience at just the right time to prepare me for the next assignment. I also believe the fundamentals of my early education, which included the liberal art of respectful argumentation, contributed directly to my selection for career development and ultimately to the success I have enjoyed as a manager of complex spacecraft projects.

What might this story tell us about how we might encourage promising young engineers? Earlier this year the AIAA sponsored a conference on the problem of employee retention in the engineering industry, noting that most young professionals today will hold five or six different jobs over the course of their careers. That probably is not too different from what I had expected when I started working. But I stayed in the same company, enjoying a full and satisfying career without moving on. Why is that?

It may be that many companies don't or can't offer what I had working at JPL: an environment that encourages professional growth with managers and leaders who actively lay the groundwork for employee success; a series of jobs with ever-increasing responsibility; a sense that, even as an employee, you "owned" the job; recognition for good performance; a sense of doing something that matters; and, most of all, the challenge and satisfaction of doing what has never been done before—of making history. I know that those are the elements that to this day keep me at JPL. I may be naïve, but it seems to me that employers who provide employees with a sense of responsibility, job ownership, recognition, and support will likely be rewarded with less frequent turnover—and we all will be rewarded with a solid cadre of committed, highly qualified engineers to address the important challenges that face our nation and our world.

The Founders Award is not the end of my career, but it is most certainly a very high point. I want to again thank the Academy for this great distinction and all of you for your kind attention.

# 2009 Arthur M. Bueche Award Acceptance Remarks by Sheila E. Widnall

Irwin Jacobs, Sheila E. Widnall, Charles M. Vest, and A. Galip Ulsoy.

*The 2009 Arthur M. Bueche Award was presented to* ***Sheila E. Widnall****, Institute Professor, Massachusetts Institute of Technology, for "a remarkable academic career in fluid dynamics combined with the highest levels of public service, and for championing the role of women in engineering."*

I am deeply honored to receive the Arthur M. Bueche Award and to join the list of previous winners, many of whom have been my colleagues and mentors. I feel most fortunate.

I often characterize my life in the engineering and scientific community as surfing on the leading edge of a wave, a wave of heightened sensitivity and activity to increase the role of women in science and engineering and the role of the many people who have reached out to help make this new role a reality.

In my case, I was very fortunate. When I won the science fair in Tacoma, Washington, I was approached by the owner of a local specialty construction firm who had a Ph.D. in civil engineering from MIT. He said, "You should go to MIT." And I said, "OK, where's that?" He and his fellow Seattle alumni made it all possible through their scholarship support.

At MIT, my strongest mentor was Professor **Holt Ashley**, a colleague of many of you. When I was a sophomore, he said to me, "You should go to graduate school." And I said, "OK." He made it all possible for me. Only now do I realize what that takes.

Then there was **Bob Cannon**, who came up to me on the podium after I had won the Outstanding Young Man of the Year Award from AIAA. He said, "I'd like you to come to Washington and be the first director of the Office of University Research at DOT." And I said, "OK." Holt Ashley was instrumental in getting AIAA to start a Congressional Fellow's Program so that my husband Bill could have a position with the House Committee on Science dealing with the NASA budget.

Then there was the call from Bill Carey, the executive officer of AAAS. He said, "Are you a member of AAAS?" I said, "No." And he said, "Would you be willing to join?" I said, "Why would I do that?" He said, "We'd like you to run for the board." And I said, "OK." Following my service on the board, I was president of AAAS.

I think you might be hearing a theme playing in the background. It's a theme from "Oklahoma"—I'm just a girl who can't say no. And it has served me well!

Through the AAAS connection, I met David Hamburg, the former president of the Institute of Medicine who served as president of AAAS. At that time, David was president of the Carnegie Corporation of New York. He asked me to serve as a trustee. I said—let's hear it!—"OK."

David had an incredible public policy agenda. One of his strong areas of focus was the role of the scientific and engineering community in providing advice to the government on important scientific, technical, and public policy issues. To that end, Carnegie Corporation established the Carnegie Commission on Science, Technology, and Government. Members of this commission included Bueche Award winners, **Norm Augustine**, **Bill Perry**, and **Guy Stever**. I felt privileged to serve. **Jack Gibbons** was also active with the commission in his role as head of Office of Technology Assessment for the U.S. Congress.

I served as vice chair of the Board of Trustees of the Carnegie Corporation. Warren Christopher was chair. Fast forward to fall and the election of 1992. With the election of Bill Clinton, Warren Christopher was asked to help identify cabinet members and other senior officials for the new administration. Carnegie lost four board members—Bob Rubin to Treasury, Donna Shalala to HEW, Warren Christopher to State, and me to the Air Force. The Carnegie Commission on Science, Technology and Government contributed **Bill Perry** to Defense, and Jack Gibbons was tapped as presidential science advisor.

In December 1992, David Hamburg called me and said, "Sheila, I've got a great idea, and I've talked it over with Sam Nunn and Les Aspin—who had been tapped as secretary of defense—and they think it's a great idea. I said "David, what is it?" He said, "We think you should be secretary of the Air Force." And I said, "David, that's a great idea!" When the offer began to gel, I was windsurfing in Aruba. I went to the board shop and made two phone calls to ask my mentors for advice. Both calls were to Bueche Award winners, **Chuck Vest** and **Bob Seamans**.

I probably should also mention my week sailing in the Caribbean with **Jerry Wiesner**. Under the stars, we had long discussions of why women would want to go into science and technology. Jerry was instrumental in opening doors for women faculty and students at MIT in those early days.

So what's my message? That at critical points in my life, members of the scientific and engineering community reached out to me and gave me incredible opportunities for growth. Every woman I have spoken to on this issue reports that someone reached out to encourage her to advance her career. Given the statistics, in most cases, that someone would have been a man.

I urge members here today to include young women in their web of support. The leverage of increasing the role of all women and tapping into their potential will be enormous. I don't know any other way it can happen. Former Bueche Award winners have been my family, my mentors, and my supporters.

I have also actively encouraged young women to pursue careers in science and engineering. In my AAAS presidential lecture, "Voices from the Pipeline"—available on the Web at *http://web.mit.edu/aeroastro/www/people/widnall/webpublications.html*—I described the environment facing women who want to enter science and engineering fields and identified the aspects of that environment that make them feel less than welcome. In my later work, a lecture called "Digits of Pi," I gave Sheila Widnall's list of top 10 issues that make women students feel less than welcome and, more important, less than capable.

At MIT, we made an important discovery—that the Math SAT under-predicts the performance of women students. Being data driven, we applied this knowledge, and in one year the number of women admitted rose from 26 percent to 38 percent. Their performance validated our expectations based on the data. By the way, the percentage has continued to climb. Women now comprise 48 percent of MIT undergraduates and a majority of the undergraduate students in half of our engineering departments. Clearly, we are in a time of intense change.

In many ways, the engineering community is also surfing at the leading edge of a wave, poised to tackle the incredibly complex problems facing our society—problems of energy, environment, sustainability, and the health and strength of our industrial base, which provides jobs to support the dignity of the American workforce. Interaction with government and the larger society is essential to ensuring that appropriate and effective policies are conceived and implemented. NAE and the extended Academy complex play a crucial role at this interface and are deserving of your support.

So guys, I recommend you get out your surfboards!

# 2009 U.S. Frontiers of Engineering Symposium

On September 10–12, NAE welcomed 110 mid-career engineers to the 2009 U.S. Frontiers of Engineering (US FOE) symposium at the Beckman Center in Irvine, California. NAE member **Andrew M. Weiner**, Scifres Family Distinguished Professor of Electrical and Computer Engineering at Purdue University, chaired the organizing committee and the symposium.

Talks at the symposium covered topics in the areas of engineering tools for scientific discovery, nano/micro photonics and new applications, engineering the health care delivery system, and resilient and sustainable infrastructure. A proceedings volume with papers from the meeting will be published in mid-February 2010.

On the first afternoon of the meeting, participants broke into small groups for "get-acquainted" sessions where each one presented and answered questions about a slide describing his or her research or technical work. These sessions gave attendees an opportunity to meet and learn about each other's work relatively early in the program. On the second afternoon, attendees had another opportunity for informal interaction through discipline-, or topic-based, "salons" (e.g., materials, product/process development, energy/environment, information/communication, etc.). There were also groups on engineering education and a movie and discussion group about infrastructure, which provided a lead-in to the plenary session on the next day.

The dinner speaker this year was Dr. **Bradford W. Parkinson**, Edward C. Wells Professor of Aeronautics and Astronautics, Emeritus, at Stanford University. His fascinating talk was about the challenges of developing the global positioning system (GPS), its military and civilian applications, and its place in our future.

For the first time, six engineers from Mexico attended the symposium under the auspices of the United States-Mexico Foundation for Science. They hoped to learn more about the program and, eventually, to initiate their own domestic FOE program and establish ties with engineers in the United States.

Andrew Weiner will continue to serve as chair for the 2010 US FOE symposium, which will be hosted by IBM at IBM Learning Center in Armonk, New York, on September 23–25, 2010. To topics will be cloud computing, biosensing and bioactuation, engineering and music, and autonomous space systems.

Funding for the 2009 U.S. FOE symposium was provided by The Grainger Foundation, Arnold O. and Mabel Beckman Foundation, Air Force Office of Scientific Research, Defense Advanced Research Projects Agency, Department of Defense (ODDR&E), National Science Foundation, Microsoft Research, and Cummins Inc.

NAE has hosted annual U.S. Frontiers of Engineering meetings since 1995, and bilateral programs that now include Germany, Japan, India, and China. The meetings bring together outstanding engineers (30 to 45 years old) in industry, academe, and government at a relatively early point in their careers. FOE facilitates the establishment of contacts and collaboration among the next generation of engineering leaders and gives them an opportunity to learn about developments, techniques, and approaches at the forefront of a wide range of engineering fields.

For more information about the symposium series or to nominate an outstanding engineer to participate in a future Frontiers meeting, contact Janet Hunziker at the NAE Program Office at (202) 334-1571 or by e-mail at *jhunziker@nae.edu*.

# First China-America Frontiers of Engineering Symposium


Participants in first China-America Frontiers of Engineer Symposium.

NAE added a fourth bilateral meeting to its Frontiers of Engineering portfolio with the inaugural China-America Frontiers of Engineering (CAFOE) Symposium (CAFOE) on October 17–21 in Beijing and Changsha, China. The Chinese Academy of Engineering (CAE) was co-organizer of the event, which was supported by The Grainger Foundation, Hunan University, and Hunan Province. NAE member **Zhigang Suo**, Allen E. and Marilyn M. Puckett Professor of Mechanics and Materials, Harvard University, and Zhihua Zhong, president of Hunan University, were co-chairs.

Consistent with the tradition of bilateral FOE symposia, CAFOE brought together approximately 60 engineers, ages 30 to 45, from U.S. and Chinese universities, companies, and government laboratories. During the meeting, presentations were made on leading-edge developments in food safety, energy-saving technologies, sustainable and disaster-resilient infrastructure systems, and intelligent transportation systems.

In the first session, Engineering and Public Health: Ensuring Food Safety, speakers noted that the interconnectedness of food production, processing, and distribution has created serious challenges for the development and implementation of engineering processes and systems that protect public health. The specific topics included: integrated risk analysis for controlling food safety; the application of risk assessment methodologies to food safety, specifically dealing with high degrees of uncertainty and critical gaps in knowledge; the analysis of genetically modified organisms in China; and practical constraints in the adoption of novel food safety technologies.

The focus of the second session, New Energy-Saving Technologies, was on sustainable energy. Fuel cells, which can generate electricity with zero emissions, is an important technology for a sustainable energy future. The first two speakers described recent developments in solid-oxide fuel cells, particularly new electrolyte materials that enable cells to operate at intermediate temperatures. A third speaker described the state of the art in hydrogen storage based on metal-hydride compounds and advances in metastable hydrides and chemical-regeneration methods. The fourth speaker described direct coal-liquefaction and carbon dioxide-abatement technologies in China.

Sustainable and Disaster-Resilient Infrastructure Systems, the subject of the third session, included talks on advances in new materials, sensor technology, nanotechnology, and computer technology that make next-generation infrastructure more robust, resilient, and sustainable. Presentations focused on (1) advanced materials, seismic response-modification devices, and state-of-the-art sensors that improve seismic safety and durability for highway bridges; (2) the evaluation and mitigation of recent disruptions in the Chinese electric power grid infrastructure from earthquakes, wind storms, and ice storms; (3) intelligent sensors for mitigating natural hazards, controlling energy use, and managing assets in complex infrastructure systems; and (4) the use of monitoring, evaluation, design, and control in designing infrastructure systems to resist earthquake and wind-induced loading.

The last session, Intelligent Transportation Systems (ITS), highlighted efforts to add information and communications technology to transport infrastructure and vehicles to improve transportation efficiency, reduce environmental impacts and energy consumption, and improve safety and comfort. Speakers addressed several topics: improved signal processing and roadside computational equipment that can improve tactical and strategic arterial management and provide high-quality traveler information; major ITS developments in China, with a focus on technologies developed for the 2008 Beijing Olympic Games; techniques for estimating U-turn capacity at medians; and consumer electronic devices carried by passengers and vehicles (e.g., Bluetooth™ devices) to obtain high-fidelity travel-time data on freeways, arterials, and airport security lines.

A poster session was held on the first afternoon to give participants a chance to meet and talk in an informal setting and to share information about their research and technical work.

Distinguished guests at the symposium included Chunxian Zhang, secretary of the Hunan Provincial CPC Committee and director of the Standing Committee of the People's Congress of Hunan Province, and Qian Zhou, governor of Hunan Province and vice secretary of the Hunan Provincial CPC Committee. Mr. Zhang welcomed participants to the symposium at the opening ceremony, and Mr. Zhou addressed the group at a banquet on the first evening. The dinner address that evening by Dr. Baitao Sun, deputy director of the Institute of Engineering Mechanics, China Earthquake Administration, was on the 2008 Sichuan earthquake and its implications for engineering. NAE president **Charles M. Vest** and CAE president **Kuangdi Xu** were honorary chairs of the symposium.

Special events for the participants included a reception for U.S. attendees at the CAE headquarters in Beijing where guests were treated to a magnificent banquet and tour of the new CAE building, a thoroughly modern facility with elements of traditional Chinese design. The next day, the group flew to Changsha in Hunan Province, the site of the meeting. On the afternoon of the second day, participants took a break from technical sessions for a tour of Hunan University, which included stops at Yuelu Academy, founded in 976, the forerunner of Hunan University; the State Key Laboratory of Advanced Design and Manufacturing for Vehicle Bodies; and the State Key Laboratory of Chemo/Biosensing and Chemo-metrics. The dinner that followed was at the West Lake, Xihulou, Restaurant, reputed to be one of the largest restaurants in the world.

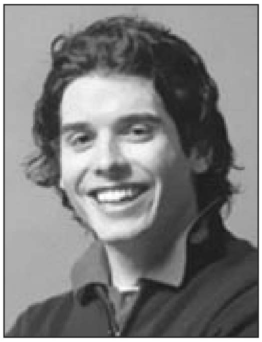
After the symposium ended, attendees who were not scheduled to leave until the following day visited the Hunan Provincial Museum, which has a collection of objects excavated from the Mawangdui Han Tombs, as well as relics from several Chinese dynasties. This was followed by a visit to a shopping area and a traditional Hunan dinner at the Fire Palace.

CAFOE symposia will be held every two years. The next meeting will be at the National Academies Beckman Center in Irvine, California, in late March 2011. Zhigang Suo and Zhihua Zhong will continue to serve as symposium co-chairs.

For more information about CAFOE or the symposia series or to nominate an outstanding engineer to participate in future Frontiers meetings, contact Janet Hunziker at the NAE Program Office at (202) 334-1571 or by e-mail at *jhunziker@nae.edu*.

## Mirzayan Technology and Policy Fellows

Carrie Brubaker



David Lukofsky

Zach Pirtle

Carrie Brubaker is a Ph.D. candidate in biomedical engineering at Northwestern University, where she recently completed her M.S. in the same field. She is conducting doctoral research on the synthesis and characterization of marine mussel-inspired adhesive hydrogel materials and their use in wound healing and surgical/biomedical applications. In recognition of her research program and graduate student leadership activities, Carrie received a "50 for the Future" award from the Illinois Technology Foundation in April 2009.

Prior to attending Northwestern, Carrie was employed by the Ministère de l'Education Nationale (France) as an English language teaching assistant. She graduated Phi Beta Kappa from UCLA with a B.S. in biochemistry and a B.A. in French and Francophone studies.

As a former teacher, graduate student, and a woman in engineering, she is interested in the processes by which science and technology policy decisions impact various groups, both in the United States and internationally. Carrie enjoys swimming, travel, French lit, and unique dining experiences.

During her fellowship, she is working with the NAE program on diversity in the engineering workforce and the PGA Committee on Women in Science, Engineering and Medicine. She is actively evaluating a career in academia.

David Lukofsky earned a Ph.D. in engineering physics from the Thayer School of Engineering at Dartmouth. As part of his dissertation, he collaborated with the Naval Research Laboratory in Washington, D.C., to develop a wireless, all-optical communication link in water. For this project, he drew on his undergraduate education in electrical engineering and biomedical instrumentation, for which he earned a degree in his native Canada at Dalhousie University. David spent last summer reporting on science and technology issues at an NPR-member station as part of an AAAS Mass Media Fellowship.

In the coming years he intends to continue communicating on science issues to a broad audience—to encourage the development of green energy resources on both sides of the U.S.-Canadian border. He is fluent in English and French and is competent in Spanish. In his spare time, he likes to spend time snowboarding with friends enjoying fresh New England and Canadian powder. He is a fan of David Suzuki, David Attenborough, and Oprah Winfrey.

David is working with the NAE Committee on U.S.-China Cooperation on Electricity from Renewables and with the PGA Science and Technology for Sustainability Program.

Zach Pirtle is completing his M.S. in environmental engineering; he has a B.S.E. in mechanical engineering and a B.A. in philosophy from Arizona State University. His M.S. concentration is in earth systems engineering and management, and in his research he developed a robustness analysis framework for evaluating multi-model ensembles. Zach spent the 2008–2009 academic year in Mexico as a Fulbright-Garcia Robles Scholar studying the potential role of nanotechnology in furthering Mexico's development goals and reducing inequities. As an undergraduate, he interned with the Consortium for Science, Policy and Outcomes and with Honeywell Aerospace.

At NAE, Zach is working for the Center for Engineering, Ethics, and Society, which will give him an opportunity to apply and unify his interests in engineering, philosophy, and science policy. He hopes to work as an engineer and eventually earn a Ph.D. in the philosophy of science. He enjoys racquetball and travel and is proud to be a fourth-generation Arizonan.

## 17th News and Terrorism Workshop

Janet Napolitano, secretary of the U.S. Department of Homeland Security, and Charles M. Vest, NAE president.

Janet Napolitano, secretary of the U.S. Department of Homeland Security (DHS), addressed the participants at the NAE "News and Terrorism: Communicating in a Crisis" workshop on September 23 in Baltimore, Maryland. Conducted by NAE in collaboration with DHS and the Radio-Television Digital News Foundation, this was the 17th in a series of interactive workshops on the effective communication of information in a crisis—particularly a crisis involving terrorism.

Napolitano told the attendees, "The plain fact of the matter is that the media—and when I say the media, I mean all forms of media—hard print, television, radio, text, Twitter, etc.—can and need to be accurate sources of information so that as rumors spread or conspiracy theories arise . . . we can jointly get accurate information out about what the risks really are."

In his opening remarks, NAE president **Charles Vest** noted the importance of the media having access to engineering and technical expertise. "When catastrophe strikes or we have a terrorist attack, we turn to the media. We trust the media as our source [of information], and all of a sudden you folks are really on the hot seat. . . . Suddenly, you are in the position of having to be an expert on things with a lot of science and technology at their root that you've not necessarily thought about before."

A mix of 111 journalists, government officials, public information officers, private sector representatives, and engineering, science, and medical experts attended. The event was moderated by former CNN anchor Aaron Brown.

## The Irwin M. Jacobs Matching Gift Challenge

NAE's discretionary financial resources ensure that advice on national policy remains independent and support our efforts to (1) increase the number, quality, and diversity of U.S. engineering graduates and (2) rebuild our national capacity for 21st century innovation and global competitiveness. To help us meet these goals, **Irwin** and Joan **Jacobs** have issued an ambitious challenge to the NAE community: a $500,000 matching gift to encourage new and increased support for NAE's Independent Funds.

NAE Independent Funds give us the flexibility to meet the immediate and emerging needs of NAE programs and enable us to initiate projects that our members and committees consider vital to the nation's future. For example, two influential reports on fundamental issues, *Rising Above the Gathering Storm* and *America's Energy Future*, were both funded this way. Discretionary funds also enable us to expand the dissemination of our reports to include more key stakeholders and lawmakers, state and local communities, businesses, and academic institutions.

From January 1, 2009, to December 31, 2009, Irwin and Joan Jacobs will match all new gifts to NAE Independent Funds and all increases in gifts (from 2008), dollar for dollar, up to $500,000. Pledges of $10,000 or more that are fulfilled by December 31, 2010, will also be matched.

The goal of the Jacobs' challenge is to raise NAE's baseline of annual unrestricted support, broaden the donor base, and encourage the participation and engagement of NAE members and friends. If all challenge funds are leveraged, the total could reach more than $1 million.

Thanks to the generosity of Irwin and Joan Jacobs, and of all the donors who have taken advantage of their challenge so far, we are moving closer to our goal. As of November 1, about 200 members had contributed more than $260,000.

To make a gift or for more information, please visit *www.nae.edu/JacobsChallenge* or contact Radka Z. Nebesky, senior director of development, at 202/334-3417 or *rnebesky@nae.edu*.

## NAE Calendar of Events

**2010**

| | |
|---|---|
| January 4 | 2010 NAE Awards<br>Call for Nominations |
| January 28 | News and Terrorism Workshop<br>St. Louis, Missouri |
| February 5 | Membership Policy Committee Meeting<br>Irvine, California |
| February 8 | The National Academies Corporation Board/Advisory Board Meetings<br>Irvine, California |
| February 9–11 | NAE Council Meeting<br>Irvine, California |
| February 14–20 | Engineers Week |
| February 16 | NAE National Meeting |
| February 19 | National Science Foundation and Ethics Education in Science and Engineering<br>San Francisco, California |
| February 25 | NAE Regional Meeting<br>University of Miami |
| March 4 | NAE Regional Meeting<br>Sun Microsystems/Tufts University<br>Boston, Massachusetts |
| March 6–7 | Engineering Toward a More Just and Sustainable World<br>Session at the Association for Practical and Professional Ethics Annual Meeting<br>Cincinnati, Ohio |
| March 11–13 | Indo-America Frontiers of Engineering Symposium<br>Agra, India |

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

## In Memoriam

**ALAN G. DAVENPORT**, 76, Emeritus Professor and founding director, Boundary Layer Wind Tunnel Lab, University of Western Ontario, died on July 19, 2009. Dr. Davenport was elected a foreign associate of NAE in 1987 for "pioneering contributions to the design of wind sensitive structures, description of the urban wind climate, and wind tunnel testing of structures."

**COLEMAN DUPONT DONALDSON**, 86, independent consultant, died on Friday, August 7, 2009. Dr. Donaldson was elected to NAE in 1979 for "research on supersonic diffusers, viscous vortex motion and turbulent transport phenomena, with application to solution of practical engineering problems."

**JOHN J. GILMAN**, 83, research professor, University of California, Los Angeles, died on September 10, 2009. Dr. Gilman was elected to NAE in 1975 for "contributions to dislocation behavior of ceramics, disclination behavior of polymers, leadership in development and production of metal glasses."

**WILLIAM C. GOINS JR.**, 88, retired senior vice president, O'Brien-Goins-Simpson & Associates Inc., died on May 22, 2009. Mr. Goins was elected to NAE in 1990 in recognition of his "pioneering contributions to blowout prevention leading to safe economical drilling of high pressure oil-gas wells."

**IRA G. HEDRICK**, 94, retired senior vice president, Grumman Corporation, died on January 14, 2008. Mr. Hedrick was elected to NAE in 1974 for "contributions to aerospace technology, particularly in the area of structures and materials."

**DAVID C. HOGG**, 87, retired head, Antenna and Propagation Research, AT&T Bell Labs; retired chief, Radio Met Research, Environmental Research Laboratory, National Oceanic and Atmospheric Administration; and retired lecturer, University of Colorado, died in Calgary, Alberta, Canada, on August 9, 2009. Dr Hogg was elected to NAE in 1978 for "contributions to the understanding of electromagnetic propagation at microwave frequencies through the atmosphere."

**KENNETH J. IVES**, 82, Emeritus Professor of Civil and Environmental Engineering, University College London, died on September 8, 2009. Dr. Ives was elected to NAE as a foreign associate in 2003 for "contributions to the theory and practice of water-treatment technology throughout the world."

**HENRY R. LINDEN**, 87, Max McGraw Professor of Energy and Power Engineering and Management, Illinois Institute of Technology, died on September 13, 2009.

Dr. Linden was elected to NAE in 1974 for "contributions to methods of fuel conversion and energy utilization."

**THOMAS L. MARTIN JR.**, 88, President Emeritus, Illinois Institute of Technology, died on October 8, 2009. Dr. Martin was elected to NAE in 1971 for "creative application of modern communications technology to advance engineering education."

**PETER MURRAY**, 89, retired director, Nuclear Programs, Westinghouse Electric Corporation, Washington, D.C., died on July 26, 2009. Dr. Murray was elected to NAE in 1976 for "contributions to the understanding and engineering application of materials in high-flux radiation and high-temperature corrosion environments."

**THEODORE H.H. PIAN**, 90, Professor Emeritus of Aeronautics and Astronautics, Massachusetts Institute of Technology, died on June 20, 2009. Dr. Pian was elected to NAE in 1988 for "pioneering research and continued development of hybrid finite element methods for the analysis of structures."

**LYMON C. REESE**, 92, Nasser I. Al-Rashid Chair Emeritus, Department of Civil Engineering, University of Texas, died on September 14, 2009. Dr. Reese was elected to NAE in 1975 for "contributions in geotechnical engineering and education."

**ROBERT J. SPINRAD**, 77, retired vice president, Technology Strategy, Xerox Corporation, died on September 2, 2009. Dr. Spinrad was elected to NAE in 1993 for "contributions to the application of computers to data acquisition, analysis, and control for scientific experiments."

# 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 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

**An Assessment of the Small Business Innovation Research Program at the Department of Defense.** The SBIR program allocates 2.5 percent of 11 federal agencies' extramural R&D budgets to fund R&D projects by small businesses, providing approximately $2 billion annually in competitive awards. At the request of Congress, the National Academies conducted a comprehensive study of how well the SBIR program has stimulated technological innovation and how well small businesses have met federal research and development needs. Drawing substantially on new data, this review focuses on the SBIR program at the U.S. Department of Defense and provides recommendations for improvements. The review series includes separate reports of the SBIR program at the National Science Foundation, National Institutes of Health, U.S. Department of Energy, and National Aeronautics and Space Administration, as well a comprehensive review of the entire program.

NAE members on the study committee were **Jacques S. Gansler** (chair), professor and Roger C. Lipitz Chair in Public Policy and Private Enterprise, University of Maryland, College Park; **Trevor O. Jones**, chairman and CEO, ElectroSonics Medical Inc; **Duncan T. Moore**, professor, Institute of Optics, University of Rochester; and **Charles R. Trimble**, chairman, U.S. Global Positioning System Industry Council. Hardcover, $90.25.

**Avoiding Technology Surprise for Tomorrow's Warfighter: A Symposium Report.** On April 29, 2009, the National Research Council held a one-day symposium to investigate challenges confronting the scientific and technical intelligence (S&TI) community and discuss potential solutions for overcoming them. This report captures comments and observations by representatives of combatant commands and supporting government organizations, as well as symposium participants. The group identified concepts and trends for improving the U.S. Department of Defense technology warning capability. Topics included the globalization of science and technology, challenges to U.S. warfighters that could result from technology surprise, examples of past technological surprises, and the strengths and weaknesses of current S&TI analysis.

NAE members on the study committee were **Ruth A. David** (chair), president and chief executive officer, ANSER (Analytic Services Inc.); **Stephen W. Drew**, Drew Solutions LLC; and **Leslie Greengard**, professor of mathematics and computer science and director, Courant Institute of Mathematical Sciences, New York University. Paper, $21.00.

**Toward a Universal Radio Frequency System for Special Operations Forces.** The U.S. Special Operations Command (SOCOM) was created in aftermath of the failed attempt in 1980 to rescue American hostages held by Iran. Special operations forces (SOF) often operate alone in austere environments using only the equipment they can carry, which makes equipment size, weight, and power needs especially important. This report reviews the state of the art for both handheld and man-packable, platform-mounted radio-frequency systems and determines which frequencies could be provided by handheld systems. The report committee also discusses whether or not a system that fulfills SOF's unique requirements could be deployed within a reasonable time. Several recommendations are included to address these and other issues.

NAE members on the study committee were **Jacques S. Gansler** (chair), professor and Roger C. Lipitz Chair in Public Policy and Private Enterprise, University of Maryland, College Park; **Alton D. Romig Jr.**, executive vice president, deputy laboratory director, and chief operating officer, Sandia National Laboratories; **Dwight C. Streit**, vice president, Northrop Grumman Space Technology; and **David A.**

**Whelan**, vice president, Deputy-GM Phantom Works, and chief scientist, Integrated Defense Systems, Boeing Company. Paper, $15.00.

**Review of the DOE National Security Labs' Use of Archival Nuclear Test Data: Letter Report (QMU Phase II).** In 2006, Congress and the National Nuclear Security Administration of the U.S. Department of Energy requested an evaluation of the quantification of margins and uncertainties framework used by the national security laboratories in support of their activities related to stewardship of the nuclear weapons stockpile. The first part of the request resulted in a full-length report, *Evaluation of Quantification of Margins and Uncertainties Methodology for Assessing and Certifying the Reliability of the Nuclear Stockpile*. The present letter report, in fulfillment of the second part of the request, provides a high-level overview of how archival underground nuclear test data are used in the application of QMU, specifically for the evaluation of margins and uncertainties in developing baselining codes, informing annual assessments, assessing significant-finding investigations, and more. The study committee's analysis includes findings and recommendations.

NAE members on the study committee were **John F. Ahearne** (chair), Executive Director Emeritus, Sigma Xi, The Scientific Research Society; **B. John Garrick**, independent consultant, Laguna Beach, California; and **Richard L. Garwin**, IBM Fellow Emeritus, IBM Thomas J. Watson Research Center. Free PDF.

**Evaluation of Future Strategic and Energy Efficient Options for the U.S. Capitol Power Plant.** The steam and chilled water required to heat and cool historic buildings in Washington, D.C., and related equipment is generated and distributed by the Capitol Power Plant (CPP) District Energy System, portions of which are 50 to 100 years old and require renewal. This report provides comments on interim consultant-generated options for the delivery of utility services to the U.S. Capitol Complex, as well as recommendations for realizing those options and suggestions for additional analyses.

NAE members on the study committee were **Steven J. Fenves** (chair), University Professor Emeritus of Civil and Environmental Engineering, Carnegie Mellon University, and **Roy Billinton**, Emeritus Professor, Department of Electrical and Computer Engineering, University of Saskatchewan, Canada. Paper, $15.00.

**Assessing Medical Preparedness to Respond to a Terrorist Nuclear Event: Workshop Report.** A nuclear attack on a large U.S. city by terrorists—even with a low-yield improvised nuclear device (IND) of 10 kilotons or less—would cause a large number of deaths and severe injuries. The large number of injured from the detonation and radioactive fallout would overwhelm local emergency response and health care systems, even assuming that these systems and personnel were not themselves incapacitated by the event. The U.S. Department of Homeland Security recently contracted with the Institute of Medicine to hold a workshop, summarized in this volume, to assess medical preparedness for a nuclear detonation of up to 10 kilotons. This report provides a candid, sobering look at our current state of preparedness for an IND and identifies several key focus areas for national efforts to improve the overall level of preparedness.

NAE member **James M. Tien**, Distinguished Professor and dean, College of Engineering, University of Miami, was a member of the workshop committee. Paper, $54.75.

**The Disposal of Activated Carbon from Chemical Agent Disposal Facilities.** At facilities where stockpiles of chemical agents are being destroyed, effluent gas streams pass through large activated carbon filters before being vented to ensure that residual trace vapors of chemical agents and other pollutants do not escape into the atmosphere in amounts that exceed regulatory limits. All carbon will have to be disposed of for final closure of these facilities. In March 2008, the Chemical Materials Agency asked the National Research Council to study, evaluate, and recommend the best methods of disposing of used carbon from the operational disposal facilities. This report includes descriptions and discussion of various approaches to handling carbon waste streams from the four operating chemical agent disposal facilities. The approach used at each facility must be chosen based on local regulatory practices, facility design and operations, and the characteristics of agent inventories, as well as public involvement in decisions about facility operations.

NAE member **Walter J. Weber Jr.**, Gordon M. Fair and Earnest Boyce Distinguished University Professor, University of Michigan, was a member of the study committee. Paper, $21.00.

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