

Winter 2017

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LINKING ENGINEERING AND SOCIETY

Humans and Computers Working Together to Measure Machine Learning Interpretability

Jordan Boyd-Graber

Agile Fractal Systems: Reenvisioning Power System Architecture

Timothy D. Heidel and Craig Miller

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Applications of Insights from Biology and Mathematics to the Design of Material Structures

Jenny E. Sabin

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***The Bridge* Mission Statement**

The Bridge publishes articles on engineering research, education, and practice; science and technology policy; and the interface between engineering and technology and society. The intent is to stimulate debate and dialogue both among members of the National Academy of Engineering (NAE) and in the broader community of policymakers, educators, business leaders, and other interested individuals. *The Bridge* relies on its editor in chief, NAE members, and staff to identify potential issue topics and guest editors. The quarterly journal has a distribution of about 7,000, including NAE members, members of Congress, libraries, universities, and interested individuals. Issues are available at www.nae.edu/Publications/Bridge.aspx.

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LINKING ENGINEERING AND SOCIETY



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The National Academies of
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The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

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Note from the Editors



Ronald M. Latanision (NAE) is editor in chief of *The Bridge* and senior fellow, Exponent Failure Analysis Associates.



Cameron H. Fletcher is managing editor of *The Bridge*.

New Bridge Policy

We appreciate suggestions for and feedback on *The Bridge*. For the most part these are positive, but in the past few months concerns were raised by two of our members about inaccuracies published in a *Bridge* article. We take such concerns very seriously. Previously, we have invited readers to communicate their concern to us and we shared it with the author. This was effective as author and reader communicated in reaching a resolution, which might include the reader's submission of an op-ed or a stand-alone article for publication in a subsequent issue.

In response to the current concerns we have made the decision to subject future articles to review by experts in the areas addressed in each issue. Guest editors, who themselves have expertise in the selected theme, will be asked to enlist colleagues to review (in aggregate) the articles for each issue. This policy will be effective with the spring 2018 issue.

It is important to note that formal peer review is neither appropriate nor necessary for *The Bridge*, which is clearly distinct from other academy publications:

- *The Bridge* was established in 1969 as a member newsletter (and is still classified as such); there was therefore no need to consider peer review. In 1983 then-NAE president Robert M. White introduced the publication of “interesting and provocative papers on engineering and technology issues,” with the goal of “[making] *The Bridge* a more vital forum for matters of interest to members.”
- *The Bridge* website states that “*The Bridge* publishes opinion and analysis on engineering research, education, and practice; science and technology policy; and the roles of engineering and technology in society. The intent is to stimulate debate and dialogue within the NAE membership and the broader outside community of policymakers, educators, business leaders and other interested citizens.”
- The inside front cover of every issue states that articles “reflect the views of the authors and not necessarily the position of the National Academy of Engineering.”
- While it is no longer appropriate to call it a member newsletter, it is not a technical journal. It is best referred to as a quarterly or periodical.

We believe the new policy addresses the concerns raised and will strengthen the quality of the NAE's flagship quarterly.

As ever, we appreciate and encourage the respectful engagement and input of our readers. It would please us enormously if the contributions in our issues stimulated member thought and conversation on important contemporary engineering issues. Letters, comments, and submissions can be addressed to us at RLatanision@exponent.com and CFletcher@nae.edu.

Editor's Note



Robert D. Braun (NAE) is dean of the College of Engineering and Applied Science, University of Colorado Boulder.

Engineering US Competitiveness

There's no better collection of brainpower gathered in one place each year than the US Frontiers of Engineering Symposium (US FOE). This year's event was hosted September 25–27 by United Technologies Research Center (UTRC) in East Hartford, Connecticut. About 100 outstanding engineers under the age of 45 met for an intensive 2½-day symposium to discuss cutting-edge developments across fields of engineering.

The goal of the Frontiers symposia is to bring together engineers from all disciplines and sectors—industry, academia, and federal labs—to facilitate cross-disciplinary exchange and promote the transfer of new techniques and approaches across fields in order to sustain and build US innovative capacity. Engineering, now more than ever, is critical to US leadership in the 21st century global economy, and the US FOE is a crucial part of the equation for the United States to remain at the cutting edge in technology research, development, and innovation.

The four focus areas for this year's meeting were

- Machines That Teach Themselves
- Energy Strategies to Power Our Future
- Unraveling the Complexity of the Brain
- Megatall Buildings and Other Future Places of Work.

The meeting was introduced by **C. D. Mote, Jr.**, president of the National Academy of Engineering, and with a welcome address by Michael McQuade, senior vice president, Science and Technology, United Technologies Corporation (UTC).

The first session, *Machines That Teach Themselves*, was chaired by Rajan Bhattacharyya, a senior research engineer at HRL Laboratories. Emma Brunskill (Stanford University) kicked off the session with a talk entitled “Reinforcement Learning and Learning to Promote Learning,” followed by Suchi Saria (Johns Hopkins University), who asked, “Can Machines Spot Diseases Faster than Expert Humans?” The final talk in this session was by Jordan Boyd-Graber (University of Maryland), on “Humans and Computers Working Together to Measure Machine Learning Interpretability.”

After the first of several breakout sessions where participants had a chance to discuss this and other topics in more depth, the US FOE hosted two government officials: Sohi Rastegar from the National Science Foundation led a discussion on finding the emerging frontiers of research and innovation, and William C. Regli from the Defense Advanced Research Projects Agency (DARPA) described DARPA's disruptive way of thinking.

The second session, *Energy Strategies to Power Our Future*, was cochaired by Katherine Dykes (the Department of Energy's National Renewable Energy Laboratory) and Jeremy Munday (University of Maryland). Tim Heidel (National Rural Electric Cooperative Association) examined the nation's power grid in a presentation on “Reenvisioning Power System Architecture.” Bouchra Bouqata (GE Renewable Energy) considered opportunities, trends, and challenges in big data analytics as applied to wind energy.

We then broke for the evening's keynote speech, always a highlight of the US FOE. We were lucky to hear from David E. Parekh, UTRC corporate vice president and director, who talked about navigating uncertainty in today's world of innovation, with fascinating examples from his own career.

On the second day of the meeting, we picked up where we left off with *Energy Strategies to Power Our Future*. “Across Dimensions and Scales: How Imaging and Machine Learning Will Help Design Tomorrow's Energy Conversion Devices” was the title of a talk by Mariana Bertoni (Arizona State University), and the session concluded with a presentation by Khurram Afridi (University of Colorado Boulder) on “Wireless Charging of Electric Vehicles.”

The third session, Unraveling the Complexity of the Brain, was cochaired by Xue Han of Boston University and Maryam Shanechi from the University of Southern California (USC). Ellis Meng (USC) opened with an account of “Technologies to Interface with the Brain for Recording and Modulation,” followed by Jose M. Carmena (University of California, Berkeley), who explored “Brain-Machine Interface Paradigms for Neuroscience and Clinical Translation.” Konrad Paul Kording (University of Pennsylvania) talked about “Rethinking the Role of Machine Learning in Biomedical Science,” and Azita Emami (California Institute of Technology) delivered a presentation on “Efficient Feature Extraction and Classification Methods in Neural Interfaces.”

The final day of the meeting was kicked off by Greg Hayes, UTC chair and chief executive officer. After his remarks, the session on Megatall Buildings and Other Future Places of Work was cochaired by Maria Paz Gutierrez, University of California, Berkeley, and Marija Trcka of UTC. Stephen Nichols (Otis Elevator Company) talked about the development of his industry in “Evolution of Elevators: Digital Interaction, Physical-Human Interface, Intuitive Behavior, and Megatall Buildings.” Michael H. Ramage (University of Cambridge) described “Supertall Timber: Functional Natural Materials for High-Rise Structures.” Jenny E. Sabin (Cornell University) rounded out the session with an explanation of “Applications of Insights from Biology and Mathematics to the Design of Material Structures.”

In addition to the topics and presentations, the meeting featured lively discussions, Q&A, and networking opportunities.

As chair of the past three US FOE symposia, I would like to express my sincere gratitude to the NAE staff who continuously make this program a success through their peerless dedication. Janet Hunziker, NAE senior program officer, and others went to great lengths to make our community gathering so fruitful each year. I also thank the sponsors of this year’s symposium: The Grainger Foundation, Microsoft Research, DARPA, NSF, Air Force Office of Scientific Research, DOD ASDR&E–Laboratories Office, and Cummins. Special gratitude is due to our gracious host, United Technologies Research Center, whose facilities were key to the collaborative spirit of this event.

This year’s meeting was my last as chair. It has been an honor to chair the organizing committee for the US FOE Symposia and meeting operations for the past three years. This program has meant a great deal to me since my first exposure to the NAE was through the US FOE as a young engineer in 2000. The program continues to make a positive impression on me each year. Seeing firsthand the energy, innovative spirit, collegial cooperation, and growing entrepreneurial prowess of our profession never gets old.

Looking forward, I encourage you to nominate eligible colleagues for next year’s symposium, September 5–7, 2018, to be chaired by Dr. Jennifer West of Duke University and hosted by MIT Lincoln Laboratory in Lexington, Massachusetts.

New!

Electronic Delivery of *The Bridge* and *NAE Annual Report*

Effective with the spring 2018 issue, *The Bridge* will be delivered electronically to overseas recipients, or you may choose to download each issue in PDF format at www.nae.edu/Bridge.aspx. This will ensure timely receipt and reduce the number of undeliverable dispatches.

Also beginning in 2018, the *NAE Annual Report* will be posted electronically rather than mailed to all NAE members.

To ensure electronic delivery of the NAE’s flagship quarterly, please send your email address to Ms. Penny Gibbs at PGibbs@nae.edu.

Having a clear metric based on interpretability allows algorithms to adapt their presentations to best aid human collaboration.

Humans and Computers Working Together to Measure Machine Learning Interpretability



Jordan Boyd-Graber is an associate professor in the University of Maryland Computer Science Department, Institute of Advanced Computer Studies, iSchool, and Language Science Center.

Jordan Boyd-Graber

Machine learning is ubiquitous: it is involved in detecting spam emails, flagging fraudulent purchases, and providing the next movie in a Netflix binge. But few users at the mercy of machine learning outputs know what's happening behind the curtain. My research goal is to demystify the black box for nonexperts by creating algorithms that can inform, collaborate, and compete in real-world settings.

This is at odds with mainstream machine learning. Topic models, for example, are sold as a tool for understanding large data collections: lawyers scouring Enron emails for a smoking gun, journalists making sense of Wikileaks, or humanists characterizing the oeuvre of Lope de Vega. But topic models' proponents never asked what those lawyers, journalists, or humanists needed. Instead, they optimized held-out likelihood.

The Need for Improved Interpretability

When my colleagues and I developed an interpretability measure to assess whether topic model users understood the models' outputs, we found that interpretability and held-out likelihood were negatively correlated (Chang et al. 2009)! The machine learning community (including me) had fetishized complexity at the expense of usability.

Understanding what users want and need offers technical improvements to machine learning methods, and it also improves the social process of machine

learning adoption. A program manager who used topic models to characterize National Institutes of Health (NIH) research investments uncovered interesting synergies and trends, but the results were unrepresentable because of a fatal flaw: one of the 700 clusters lumped urology together with the nervous system, anathema to NIH insiders (Talley et al. 2011). Algorithms that prevent nonexperts from fixing such obvious problems (obvious to a human, that is) will never overcome the social barriers that often hamper adoption.

These problems are also evident in supervised machine learning. Ribeiro and colleagues (2016) cite an example of a classifier to distinguish wolves from dogs that detects only whether the background is snow. More specifically for deep learning, Karpathy and colleagues (2015) look at the computational units responsible for detecting the end of phrases in natural language or computer code.

These first steps at interpretability fall short because they ignore utility. At the risk of caricature, engineers can optimize only what they can measure. How can researchers actually measure what machine learning algorithms are supposed to be doing?

Question Answering

A brief detour through question answering (QA) can shed light on the answer to that question. Question answering is difficult because it has all the nuance and ambiguity associated with natural language processing (NLP) tasks and it requires deep, expert-level world knowledge.

Completely open-domain question answering is considered AI-complete (Yampolskiy 2013). Short-answer QA can be made more interactive and more discriminative by giving up the assumptions of batch QA to allow questions to be interrupted so that answers provided earlier reward deeper knowledge.

Quiz Bowl

Fortunately, there is a ready-made source of questions written with these properties from a competition known as Quiz Bowl. Thousands of questions are written every year for competitions that engage participants from middle schoolers to grizzled veterans on the “open circuit.” These questions represent decades of iterative refinement of how to best discriminate which humans are most knowledgeable (in contrast, *Jeopardy*’s format has not changed since its debut half a century ago; its television-oriented format is thus not considered as “pure” a competition among trivia enthusiasts).

Interpretability cannot be divorced from the task a machine learning algorithm is attempting to solve. Here, the existence of Quiz Bowl as a popular recreational activity is again a benefit: thousands of trivia enthusiasts form teams to compete in Quiz Bowl tournaments. Thus far, our algorithm has played only by itself. Can it be a good team player? And can it learn from its teammates? The answers to these questions can also reveal how useful it is at conveying its intentions.

Box 1 shows an example of a question written to reward deeper knowledge and the places in the text where our system (***) and Ken Jennings¹ (*) answered the question.

A moderator reads the question word by word and the first player who knows the answer uses a signaling device to “buzz in.” If the player has the correct answer, he earns points; if not, the moderator reads the rest of the question to the opponent. Because the question begins with obscure clues and moves to more well-known information, the player who can buzz first presumably has more knowledge.

BOX 1

Sample Quiz Bowl Question

The question begins with obscure information and incorporates more well-known clues as it progresses. In our exhibition match, Ken Jennings answered (*) this question before the computer could (**), showing he had deeper knowledge on this topic.

*Q: This man ordered Thomas Larkin to buy him 70 square miles of land, leading him to acquire his Mari-
posa gold mine. He married Jessie, the daughter of
Thomas Hart Benton, and, during the Civil War, he
controversially confiscated (*) slave-holder property
while acting as the leader of Missouri. Kit Carson
served as the guide for the first two of his expeditions
to survey the American West. For 10 points, name
this explorer known as “the Pathfinder” (***) who was
also the first presidential candidate of the Republican
Party.*

A: John C. Fremont

We have good evidence that Quiz Bowl serves as a good setting for conveying how computers think. Our trivia-playing robot (Boyd-Graber et al. 2012; Iyyer et al. 2014, 2015) faced off against four former *Jeopardy*

¹ Ken Jennings holds the record for longest winning streak—74 consecutive games in 2004—on the quiz show *Jeopardy*.



FIGURE 1 When opponents can see what a computer is thinking in a trivia game, they can more easily defeat it.

champions in front of 600 high school students.² The computer claimed an early lead, but we foolishly projected the computer's thought process for all to see (figure 1). The humans learned to read the algorithm's ranked dot products and schemed to answer just before the computer. In five years of teaching machine learning, I've never had students catch on so quickly to how linear classifiers work. The probing questions from high school students in the audience showed that they caught on too. (Later, when we played against Ken Jennings,³ he was not able to see the system's thought process and our system did much better.)

² <https://www.youtube.com/watch?v=LqsUaprYMOw>

³ <https://www.youtube.com/watch?v=kTXJCEvCDYk>

"Centaur Chess"

A growing trend in competitive chess is "centaur chess" (Thompson 2013). The best chess players are neither a human nor a computer but a computer and a human playing together. The language of chess is relatively simple; given a single board configuration, only a handful of moves are worthwhile. Unlike chess, Quiz Bowl is grounded in language, which makes the task of explaining hypotheses, features, and probabilities more complicated.

I propose a "Centaur Quiz Bowl" as a method of evaluating the interpretability of predictions from a machine learning system. The system could be part of a team with humans if it could communicate its hypotheses to its teammates.

Efforts to Explain Machine Learning Answers

At our exhibitions, we have shown ordered lists of predictions while the system is considering answers. This is effective for communicating *what* the system is “thinking,” but not *why* it provides an answer. Thus, a prerequisite for cooperative QA is the creation of interpretable explanations for the answers that machine learning systems provide.

Linear Approximations

Deep learning algorithms have earned a reputation for being uninterpretable and susceptible to tampering to produce the wrong answer (Szegedy et al. 2013). But, instead of making predictions based on explicit features, one of their strengths is that they embed features in a continuous space. These representations are central to deep learning, but how they translate into final results is often difficult—if not impossible—to determine. Ribeiro and colleagues (2016) propose local interpretable model-agnostic explanations (LIME): linear approximations of a complicated deep learning model around an example.

LIME can, for example, create a story of why a particular word caused an algorithm to provide a specific answer to a question. A logistic regression (a linear approximation of a more complicated predictor) can explain that seeing the words “poet” and “Leander” in a question would be a good explanation of why “John Keats” would be a reasonable answer. But individual words are often poor clues for why the algorithm suggests a particular answer. It would be even better to highlight the phrase “this poet of ‘On a Picture of Leander’” as its explanation.

Human-Computer Teamwork

I propose to extend LIME’s formula to capture a larger set of features as possible explanations for a model’s predictions. For example, “And no birds sing” is a well-known line from Keats’ poem “La Belle Dame sans Merci,” but explaining the prediction by providing a high weight for just the word “sing” would be a poor predictor. The algorithm should make itself clear by explaining that the whole phrase “no birds sing” is why it cites “La Belle Dame sans Merci” as the answer. While recurrent neural networks can discover these multiword patterns, they lack a clear mechanism to communicate this clue to a user.

Fortunately, Quiz Bowl provides the framework needed to measure the collaboration between com-

puters and humans. The goal of a Quiz Bowl team is to take a combination of players and produce a consensus answer. It is thus the ideal proxy for seeing how well computers can help humans answer questions—if it is possible to separately assess how well the computer aids its “teammates.”

Statistical Analyses and Visualizations

Just as baseball computes a “runs created” statistic (James 1985) for players to gauge how much they contribute to a team, Quiz Bowlers create statistical analyses to determine how effective a player is.⁴ A simple version of this analysis is a regression that predicts the number of points a team will win by (a negative number if it’s a loss) with a given set of players.

Individual words are often poor clues for why an algorithm suggests a particular answer.

There are two independent variables we want to understand: the effect of the algorithm and the effect of visualizations. We analyze the effect of a QA system and a visualization as two distinct “team members.” The better a visualization is doing, the better its individual statistics will be. This allows us to measure the contribution of a visualization to overall team performance and thus optimize how well a visualization is communicating what a machine learning algorithm is thinking.

Conclusion

Combined with the renaissance of reinforcement learning (Thrun and Littman 2000) in machine learning, having a clear metric based on interpretability allows algorithms to adapt their presentations to best aid human collaboration. In other words, the rise of machine learning in everyday life becomes a virtuous cycle: with a clear objective that captures human interpretability, machine learning algorithms become less opaque and more understandable every time they are used.

⁴ The Quiz Bowl Statistics Program (SQBS), <http://ai.stanford.edu/~csewell/sqbs/>

Despite the hyperbole about an impending robot apocalypse associated with artificial intelligence killing all humans, I think a bigger threat is automation disrupting human livelihood. In juxtaposition to the robot apocalypse is a utopia of human-computer cooperation, where machines and people work together using their complementary skills to be better than either could be on their own. This is the future that I would like to live in, and if we are to get there as engineers we need to be able to measure our progress toward that goal.

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Agile and fractal power system design and control methods are needed to realize the benefits of distributed generation and storage technologies.

Agile Fractal Systems: Reenvisioning Power System Architecture



Timothy D. Heidel



Craig Miller

Timothy D. Heidel and
Craig Miller

The methods used to plan and operate the grid since the dawn of electrification have worked well. Indeed, the US grid has set the absolute standard for scale and performance of engineered systems for more than a century, but new technologies, economics, social attitudes, and environmental sensibilities are calling this model into question.

Rapidly falling costs of distributed electricity generation methods such as solar photovoltaics and storage technologies coupled with the growing emphasis on improving electric power system resiliency have motivated the investigation of alternative architectures for planning and operating electric power systems.

In addition, recent advances in power electronics, computation, and communication technologies could provide the opportunity to optimize and control grid operations closer to the locations where power is consumed (Kassakian et al. 2011), offering significant efficiency, cost, reliability, and emissions benefits.

But the methods that have historically been relied on for designing and operating power systems will prevent the full realization of the potential benefits associated with the newer technologies. Power system design and

Timothy Heidel is deputy chief scientist and Craig Miller is chief scientist, both at the National Rural Electric Cooperative Association (NRECA).

control methods that are both agile and fractal are needed to fully realize the benefits offered by distributed generation and storage technologies.

Background

In a 2014 speech, then US Secretary of Energy Ernest Moniz defined the electrical grid of North America as “a continent-spanning machine of immense complexity that is at its best when it is invisible” (Moniz 2014). There has probably never been a more succinct and accurate definition of the grid that has grown from the first central power plant opened in 1882 in Manhattan.

*What constitutes a grid?
Is it the continent-spanning
totality, or one utility,
one feeder, or one building?
The answer is, increasingly,
all of these.*

For more than a century the electric power delivery system has evolved continuously as generations of engineers have identified improvements enabling greater reliability, resilience, and lower cost. Over time, every component and procedure has been refined and polished. Today, the grid operates with impressive reliability, often making it invisible.

The grid’s generally routine reliability is largely a consequence of the system’s scale, literally its angular momentum. Titanic power flows from the Hoover Dam and its kin, an immense fleet of large-scale central power generation stations throughout the country. Small generators and loads are effortlessly swept into synchronicity by the current flowing from these huge turbines. This has proven to be a very good way to design a system, especially given the economies of scale and increased efficiency of most electricity generation technologies.

Recent Changes Motivating New Adaptation

The recent rapid growth of distributed energy resources located at the far, thin edge of the grid is calling the existing model into question. As these resources con-

tinue to proliferate, individual homes, businesses, and factories will begin to have a far larger influence on the operation of the grid both locally and throughout the system (Kristov 2015).

Distributed and, particularly, customer-owned generation, thermal and electrical storage, and load control technology such as communicating thermostats and building management systems all raise the question of what constitutes a grid. Is the grid the continent-spanning totality, or is it one utility, one feeder, one portion of a feeder, or one building? The answer is, increasingly, all of these. A useful working definition of a grid is a collection of electrical assets (generation, load, storage, transport) that can be controlled by a single entity. By this definition, grids range from individual buildings to regional transmission organizations (RTOs) spanning multiple states.

A building energy management system may control rooftop photovoltaic or gas-powered combined heat and power technologies, loads, energy storage, and purchases from or sales to the grid. It is an electrical grid in every sense except scale and presents many of the same problems in optimal control. It must also act in harmony with all the other actors in the grid. This will become increasingly critical as the electric power system as a whole evolves to rely ever more heavily on distributed energy resources.

This is a unique time of challenges to adapt the grid for new and changing needs. The challenges present an opportunity to think beyond incremental improvement to a fundamental reimagining and reinvention, building on emergent technology in distributed generation and sensor technology and advances in communications and industrial controls.

Agile and Fractal Grids

The hierarchical model of the grid challenges the old simplifying dichotomy in which generation and transmission companies thought of the distribution system as an exogenous, slowly varying, uncontrollable load, and distribution companies treated the transmission systems as an infinite bus. With many systems and actors involved, the fundamental problem in operations moves from pure control to harmonization.

A conglomeration of today’s distinct and incompatible methods of operating buildings, campuses, feeders, distribution systems, generation and transmission systems, RTOs, and independent system operators (ISOs) will not enable high potential agility. Furthermore, it

will create a morass of interoperability standards and local, ad hoc, idiosyncratic methods of coordination.

Efforts to establish commonality in the problems of grid operations across many scales can move the system closer to a grid that continuously adapts, collaborates, and harmonizes to achieve greater reliability, resiliency, and efficiency. We believe that such a grid must be agile and fractal.

What Is an Agile Grid?

To be agile in this context, a grid must be capable of dynamically reconfiguring and optimizing based on rapidly changing local conditions.

Even under ideal conditions the grid is constantly changing—components are installed and retired every day, and load varies with weather, season, and the vagaries of human activity. Beyond these (literally) “blue sky” variations, storms, natural disasters, equipment failures, and other factors disrupt normal grid operations.

Variations have always been present, but they are poised to have more significant impacts as new weather-dependent generation sources (such as solar and wind) and new electricity uses (such as electric vehicles) become ubiquitous. Efforts to design and build the grid of the future must therefore be based not on a static approach but on a design process that is constantly evolving and that allows the routine and continuous adaptation of operations to account for changing conditions and circumstances.

As new technologies enable a more efficient grid, the fiction of a static grid—designed to a fixed point and then simply operated as designed—will be further undermined. A campus or individual building in an office park may sometimes operate autonomously, sometimes focus on local coordination, sometimes operate as part of a much larger whole. The future grid must be envisioned as a grid of grids of grids, dynamically adapting when challenged.

What Is a Fractal Grid?

Fractal design is an essential element to achieve desired grid agility. Taking inspiration from fractal geometric figures, fractal grids will exhibit the same control and operational characteristics at every scale.

In a fractal grid, any part of the overall power system will be capable of performing all of the functions of the full grid today. With fractal design, parts of the grid can safely isolate from the rest of the power system if and when it is optimal to do so (e.g., in response to local

weather conditions, changes in fuel costs) but return to the broader system when conditions change. Decisions on how and when to segment parts of the system will be based on economic, engineering, and business considerations.

Figure 1 illustrates the concept of an agile, fractal grid. Figure 1a illustrates the current operation of a distribution grid. Energy flows to customers from two substations and the system operates with a tree structure. A normally open switch isolates the green and blue portions of the distribution system. Individual customers with generation or storage can use power generated locally and may in some circumstances be able to feed that power back to the local grid.

Figure 1b illustrates how the grid might be reconfigured after an equipment or line failure. In this scenario, energy is still fed from two substations, but certain customers are now receiving power from Substation B instead of Substation A. This scenario is becoming increasingly common as utilities install automated switching technologies in distribution systems.

*What's needed is a grid
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Finally, figure 1c illustrates the potential for a portion of the grid, corresponding to a small group of customers, to further isolate from the rest of the system for business or economic reasons. That portion of the system would consume power, in this specific scenario, purely based on locally available generation resources. Eventually, one would generally expect the operation of the system to return to that shown in figure 1a.

Technical Challenges

Rearchitecting the control of electric power systems will not be achieved quickly or simply. Indeed, the study of grid architecture is emerging as an important new research domain (e.g., Taft and Becker-Dippmann

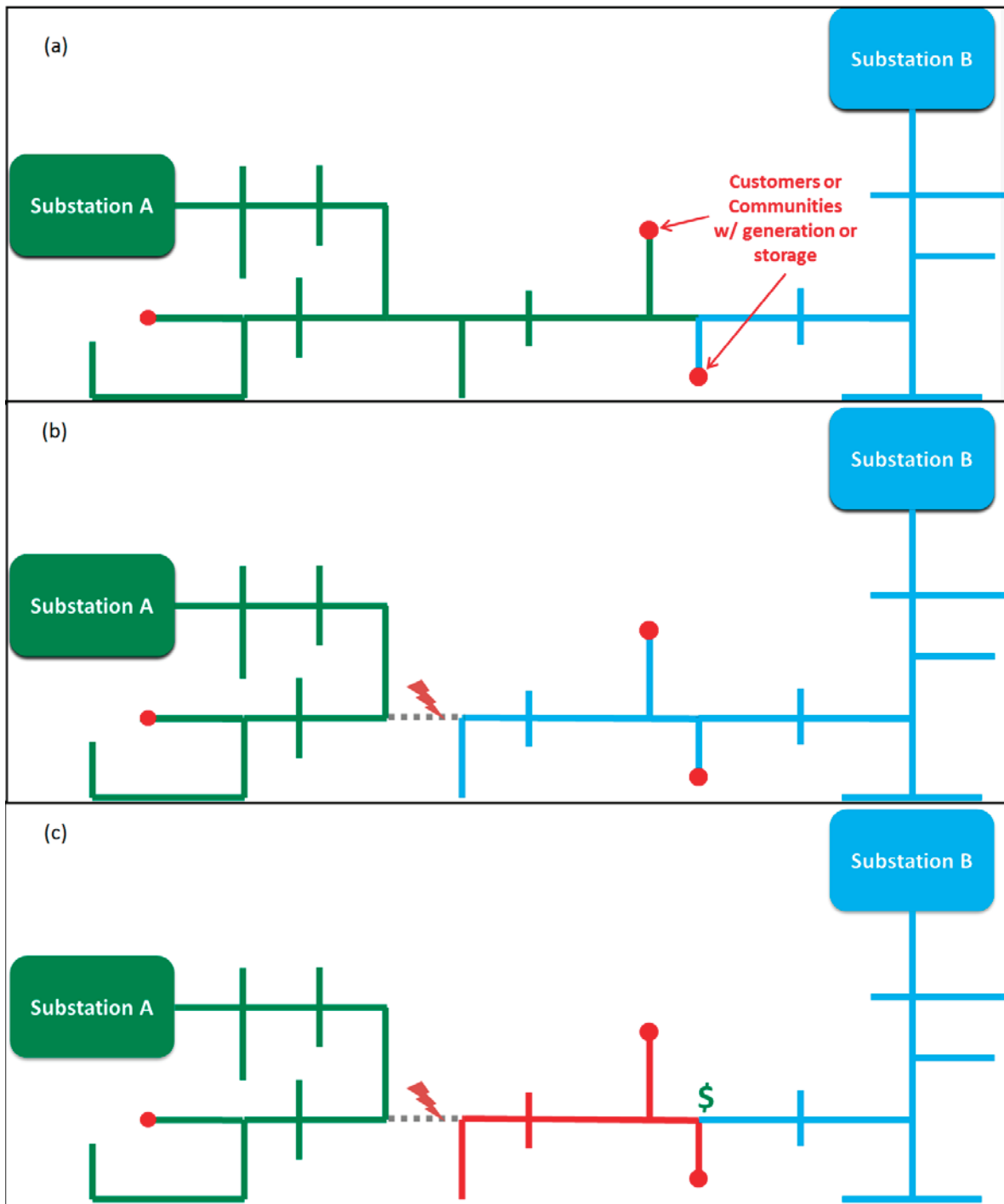


FIGURE 1 Agile, fractal grid scenarios. (a) Normal distribution system operations with power fed from two substations. The green and blue portions of the feeders are electrically isolated by a normally open switch. (b) Distribution system reconfiguration, widely used today, transfers some customers to a new substation feed in the case of an outage in a portion of the network to minimize the scale and duration of the outage. (c) Agile, fractal grid design enables portions of the system (shown in red) to operate independently in order to satisfy objectives for reliability and economics. Decisions on when and how to segment networks can be made centrally or in a distributed fashion.

2015). But the technology needed is there or nearly there.

Achieving the transition to an agile and fractal future grid will rely primarily on three classes of innovation:

- (1) precise state awareness,
- (2) precise controls, and
- (3) advanced analytics (including forecasting and optimization technologies).

Precise State Awareness

Successful grid operations in an agile, fractal environment will require precise knowledge of the state of the grid at all times and locations. Grid operators need to understand the operating state and the real-time capability of loads, generators, and storage devices. Ensuring the safety of utility personnel and customers will also require a precise understanding, at all times, of what parts of the system are connected to each other (and what reconfiguration options are permitted).

Fortunately, recent years have seen dramatic advances in sensor technologies that can contribute to state awareness, such as communicating digital consumption meters and distribution system phasor measurement units (von Meier et al. 2017). The rapidly falling costs of communication technologies also enable grid operators at all levels to communicate state-related information more often and on a more granular basis.

Precise Controls

Many companies are developing advanced switching and power electronics technologies that can enable more rapid and precise control (Bhattacharya 2017). More advanced protection system devices, reactive power controllers, networked switches, and disconnect-capable meters can enable more agile volt/voltage-ampere reactive (VAR) control throughout the system and a wider range of feasible system reconfiguration options.

Many of these technologies are already being adopted in the utility community to reduce system losses, enhance efficiency through conservation voltage reduction, or improve resiliency during and after storms. The power electronics-based inverters that interface with distributed energy resources such as photovoltaics or storage devices will play an increasingly important role in enabling more precise control of the system.

Advanced Analytics

A new generation of electricity system data analytics is needed (National Academies 2016), with more precise and accurate algorithms for forecasting the evolution of customer needs and generation resource capabilities. Scalable algorithms will also need to be developed to optimize large, diverse fleets of controllable resources (Panciatici et al. 2014). These algorithms will help translate improved state awareness into decisions on how best to deploy distributed energy resources and other controllable devices.

Many of the components required to realize agile, fractal grid operations are either already available or in advanced development.

Effectively and securely managing the transport, storage, and analysis of data among a large number of diverse stakeholders will be a key architectural design challenge. Advances in the analysis of corrupted or incomplete data will also be critically important. Many of these advances will rely on techniques for making decisions in the face of significant uncertainty.

Conclusion

Analytically driven and agile control of the grid is being made technologically possible by declining costs of renewable and distributed generation technologies, higher-performance computing, and high-bandwidth communications, coupled with advances in power electronics and related control technologies. Indeed, many of the individual components required to realize agile, fractal grid operations are either already available or in advanced development.

But significant research and development are still needed to determine how to optimally integrate all the required component technologies. A particular challenge will be harmonization of this vision for future grid operation with the reality of continuous incremental change, which is necessary to the engineering of all critical infrastructure technologies. Control systems that are consistent with agile, fractal operation will have to

coexist for some time with the control approaches that are used widely today.

As this new architecture for the control of electricity delivery infrastructure becomes widely used, we expect it will be possible to achieve greater reliability, resiliency, and efficiency while also easing the challenge of adapting to future changes. Finally, we believe insights gained throughout this transformation could have important implications for the design of other highly distributed engineered systems.

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Improvements in performance, cost, and safety can help realize the benefits of wirelessly powered electric vehicles.

Wireless Charging of Electric Vehicles



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Khurram Afridi

Road transportation, which accounts for 23 percent of US total energy consumption, 59 percent of petroleum consumption, and 22 percent of greenhouse gas emissions (Davis et al. 2016), is undergoing a major transformation with the advent of ridesharing, autonomous driving, and vehicle electrification. Collectively these technologies, in conjunction with renewable sources of electricity, have the potential to dramatically reduce the negative impact of road transportation on the health of the planet.

The successful convergence of these technologies will require electric vehicles (EVs) that are low cost and fully autonomous. These attributes can be realized through wireless charging.

Introduction

Consider a future in which a driverless ridesharing EV pulls over as you exit a building, takes you to your destination, and proceeds to drive passenger after passenger without ever needing to stop to recharge its battery. Instead, power generated by nearby wind and solar resources is delivered wirelessly from the roadway to the vehicle while it is in motion.

Not having to stop for recharging will make electric vehicles truly autonomous, and, because the vehicles can thus remain in service for more hours, fewer vehicles will be needed to meet passenger demand. Furthermore, EVs with in-motion (dynamic) wireless charging can have much smaller

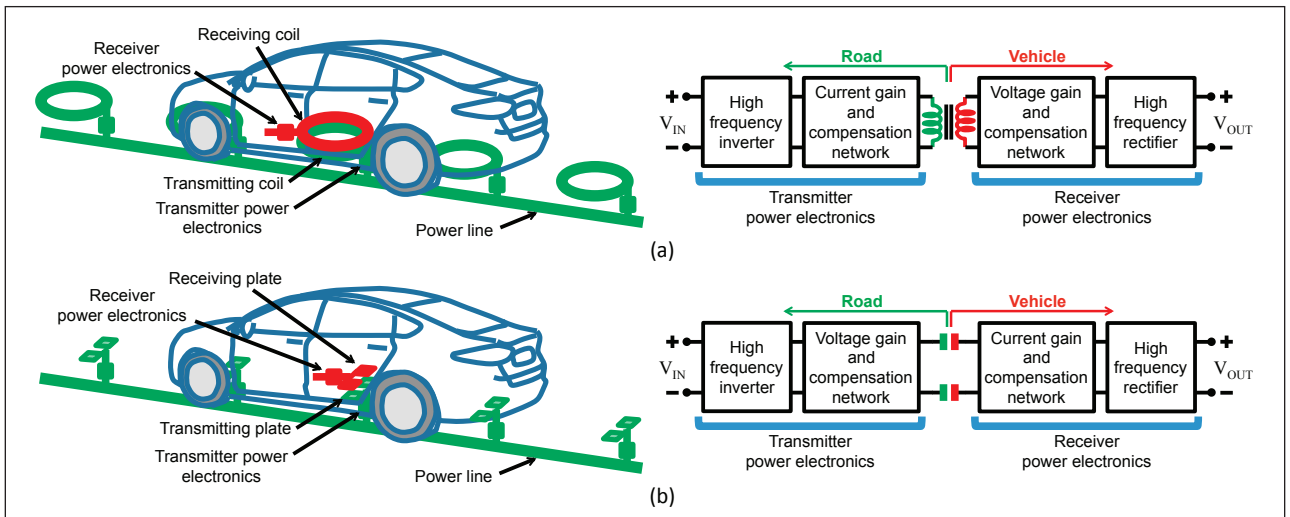


FIGURE 1 Physical implementation (left) and block diagram representation (right) of two approaches to deliver energy wirelessly to electric vehicles from an electrified roadway: (a) inductive wireless power transfer (WPT) using coils (embedded in the roadway and in the vehicle) that are coupled through magnetic fields, and (b) capacitive WPT using plates coupled through electric fields. In both cases, power electronics (comprising a high-frequency inverter and rectifier with semiconductor devices, and gain and compensation networks with inductors, capacitors, and/or transformers) is the enabling technology.

batteries, an option that can reduce their cost and accelerate adoption.

While the concept of medium-range wireless power transfer (WPT), achieved using near-field (nonradiative) electromagnetic coupling, has existed since the pioneering work of Nikola Tesla (1891) more than a century ago, the technology to enable effective dynamic WPT for EVs is still in its nascent stage. Numerous challenges related to performance, cost, and safety need to be overcome before the vision of wirelessly powered EVs can be realized.

Near-Field Wireless Power Transfer

Near-field WPT systems are of two types: inductive, which use magnetic field coupling between conducting coils, and capacitive, which use electric field coupling between conducting plates to transfer energy (see figure 1). For medium-range applications (in which the distance between the transmitter and the receiver couplers is comparable to the size of the couplers, as in EV charging), inductive WPT systems have traditionally been preferred.

Inductive WPT Systems

Building on work done for material handling applications during the 1990s (Green and Boys 1994), the past decade has seen tremendous progress in inductive WPT

technology for stationary charging of EVs (Bosshard and Kolar 2016). Aftermarket stationary chargers are already available, and some EV manufacturers have announced plans to introduce built-in stationary inductive WPT systems as early as 2018.

However, for magnetic flux guidance and shielding, inductive WPT systems require ferrite cores, making them expensive and bulky. Also, to limit losses in the ferrites, the operating frequencies of these systems are kept under 100 kHz, resulting in large coils and low power transfer densities. The high cost and low power transfer density are particularly problematic for dynamic WPT, as these systems need to have very high power capability to deliver sufficient energy to the vehicle during its very brief time passing over a charging coil.

For these reasons dynamic inductive WPT is yet to become commercially viable, although a few experimental systems have been demonstrated (Choi et al. 2015; Onar et al. 2013).

Capacitive WPT Systems

Capacitive WPT systems have potential advantages over the inductive systems because of the relatively directed nature of electric fields, which reduces the need for electromagnetic field shielding. Also, because capacitive WPT systems do not use ferrites, they can be operated at higher frequencies, allowing them to be

smaller and less expensive. Capacitive WPT could thus make dynamic EV charging a reality.

But because of the very small capacitance between the road and vehicle plates, effective power transfer can occur only at very high frequencies, making the design of these systems extremely challenging. With the recent availability of wide-bandgap (gallium nitride [GaN] and silicon carbide [SiC]) power semiconductor devices that enable higher-frequency operation, high-power medium-range capacitive WPT systems are becoming viable (Regensburger et al. 2017; Zhang et al. 2016).

Two major challenges associated with capacitive WPT for EV charging are (1) achieving high-power transfer density at high efficiencies while meeting electromagnetic safety requirements, and (2) maintaining effective power transfer even as the couplers' relative position changes. These challenges have been a focus of my group's recent efforts.

Achieving Safe and Efficient High-Power Transfer

The size of the couplers in WPT systems can be reduced and the power transfer density increased by designing the systems to operate at higher frequencies. In inductive systems the increase in induced voltage with higher frequency compensates for the reduced mutual inductance of the smaller coils, and in capacitive systems the increase in displacement current with higher frequency compensates for the smaller plates' lower capacitance. Higher operating frequencies also enable smaller power electronics associated with WPT systems (see figure 1) thanks to a decrease in energy storage requirements.

But achieving high efficiencies at high switching frequencies is very challenging. And the fringing fields of WPT systems must be within safe levels (as defined by the International Commission on Non-Ionizing Radiation Protection; ICNIRP 1998) in areas occupied by people and animals (e.g., the vehicle cabin and outside the perimeter of the chassis). These requirements for capacitive WPT systems can be met through circuit stages that provide appropriate voltage and current gain (to reduce displacement currents) as well as reactive compensation (figure 1). An active area of research is the design of these circuit stages (Lu et al. 2015; Theodoridis 2012).

Multistage Matching Networks

Our work in this area has explored approaches utilizing multistage matching networks that can simultaneously provide gain and compensation (Sinha et al. 2016).

We have discovered that, depending on the ratio of the system input and output voltages, there is an optimal number of stages that maximizes efficiency, and we have identified the optimal distribution of gain and compensation among these stages.

To further reduce fringing fields in capacitive WPT systems, various coupler design approaches have been considered. Those that use dielectric materials for field guidance introduce additional losses and have limited success in medium-range applications.

Phased-Array Field Focusing

We have been exploring techniques traditionally used for beamforming in radars and other far-field applications (Hansen 2009). We have developed a near-field phased-array field-focusing approach that uses multiple phase-shifted capacitive WPT modules to achieve dramatic reductions in fringing fields (figure 2). We have shown that a 180°-outphased configuration yields a progressive reduction in fringing electric fields as the number of modules increases (Kumar et al. 2015).

*Our near-field
phased-array approach uses
multiple capacitive WPT
modules to dramatically
reduce fringing fields.*

Phased-array field focusing provides opportunities for innovation, for example in the exploration of methods that incorporate parasitic interactions between multiple coupling plates in the design of the matching networks. Such phased-array approaches could also be adapted for inductive WPT to help eliminate ferrites (Waters et al. 2015).

Achieving Variable Compensation

To achieve effective power transfer, WPT systems need to operate close to the resonant frequency of the resonant tank formed by the reactances (capacitive and inductive) of the coupler and compensating network. However, the coupler reactance depends on the vehicle's road clearance, and varies as the vehicle moves across the charger (figure 3). The drift between

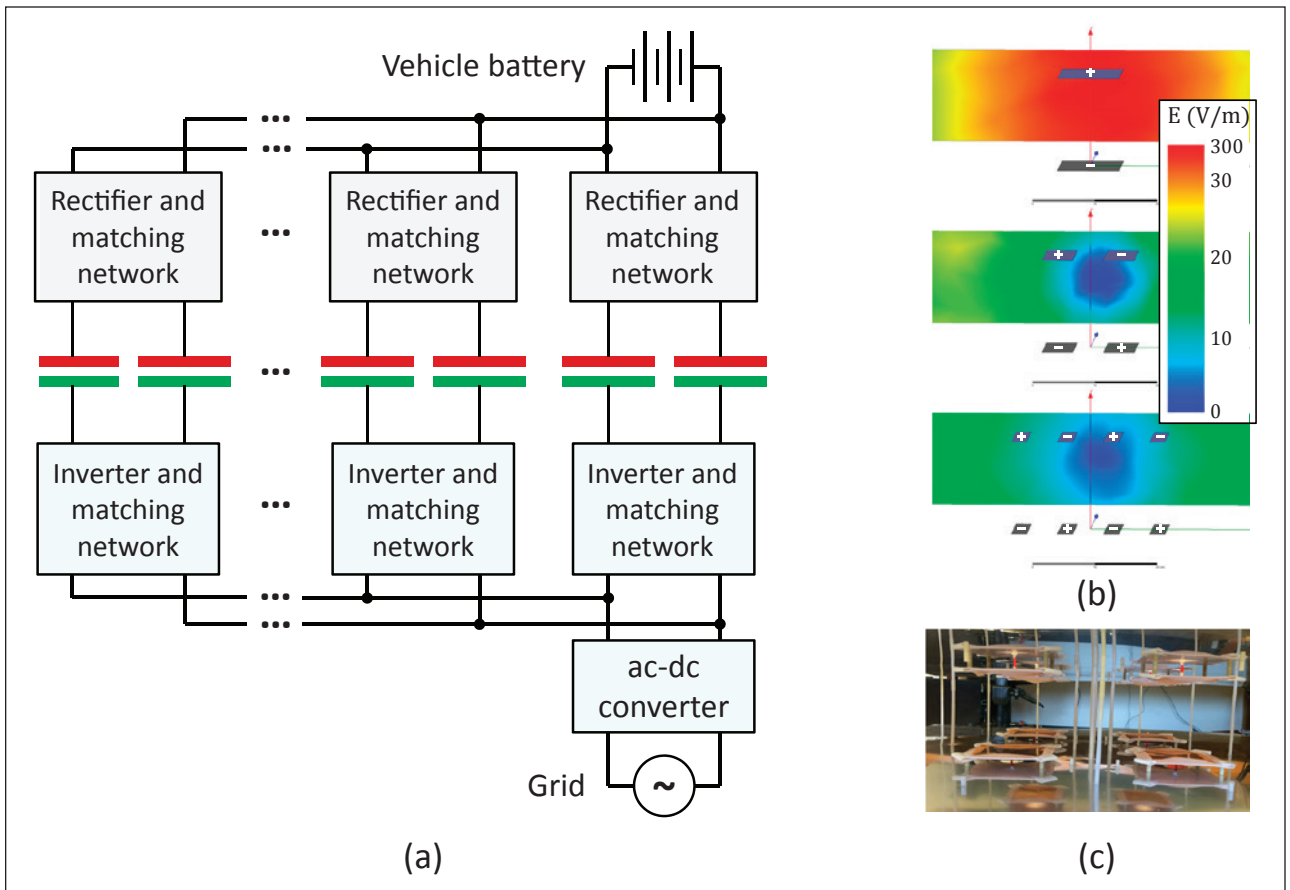


FIGURE 2 Multimodular near-field phased-array capacitive wireless power transfer (WPT) system: (a) block diagram representation, (b) simulated performance showing fringing field reduction with progressive increase in the number of modules, and (c) photograph of a prototype system. E = electric field strength; V/m = volt per meter.

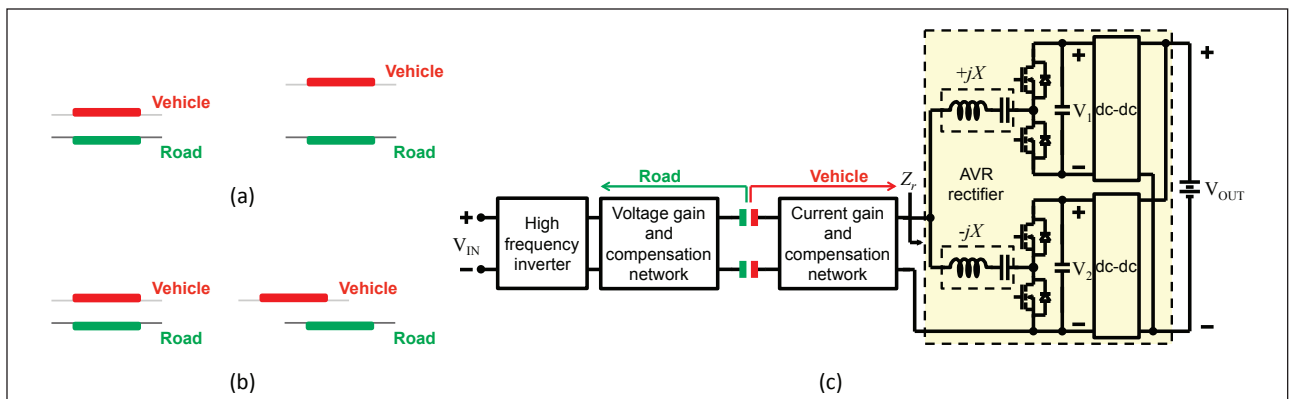


FIGURE 3 Coupling variations and an approach to compensate for these variations: (a) variation in coupling due to different vehicle road clearances, (b) variation in coupling due to change in vehicle position as it drives over the charger, and (c) a capacitive wireless power transfer (WPT) system with an active variable reactance (AVR) rectifier that can provide continuously variable compensation by controlling the voltages V_1 and V_2 . jX = tank reactance; Z_r = rectifier input impedance.

resonant and operating frequency causes a reduction in power transfer and WPT system efficiency.

In WPT systems that operate at frequencies below 100 kHz, where bandwidths are not restrictive, the traditional way to deal with variations in coupling is to change the operating frequency to track the resonant frequency (Covic and Boys 2013; Shekhar et al. 2013). But in high-frequency WPT systems the operating frequency must stay within one of the designated, very restrictive industrial, scientific, and medical (ISM) bands (e.g., 6.78 MHz, 13.56 MHz, and 27.12 MHz; FCC 2014).

One solution, employed in low-power inductive WPT systems, is to use a bank of capacitors that can be switched in and out of the compensating network, to keep the resonant frequency roughly unchanged as the transmitter and receiver move relative to each other (Lim et al. 2014). But this is not an effective approach for higher-power WPT systems as the switches have to be much bigger and more expensive to keep the system efficient. This approach is also less suited to capacitive WPT because it requires multiple switchable compensating inductors, which are bigger than capacitors.

Other adaptive impedance matching techniques include the use of saturable and variable inductors (James et al. 2005), but these techniques reduce system efficiency and do not scale well with power.

We have developed new high-frequency rectifier and inverter architectures that compensate for coupling variations while operating at fixed frequency and maintaining high efficiency. An example is the active variable reactance (AVR) rectifier shown in figure 3 (Sinha et al. 2017). By appropriately controlling the output voltages of its two coupled rectifiers, the AVR can provide continuously variable compensation while maintaining optimum soft switching to ensure high efficiency. This compensation architecture ensures that the output power of the WPT system is maintained at a fixed level across wide variations in coupling and is applicable to both capacitive and inductive WPT systems.

Conclusions and Future Directions

High-performance, safe, and cost-effective dynamic electric vehicle charging has the potential to revolutionize road transportation. What combination of capacitive and inductive WPT will enable this revolution is an open question. Both systems offer tremendous opportunities for research, especially in high-fre-

quency power electronics and near-field coupler design. Research is also needed on

- health effects of long-term exposure to weak electric and magnetic fields,
- mechanisms to detect living and foreign objects in the proximity of WPT systems,
- methods to determine optimal charger power levels and spacing for cost effectiveness,
- techniques to embed WPT technology in roadways, and
- approaches to analyze impacts of large-scale WPT system deployment on the electric grid.

We have developed new high-frequency rectifier and inverter architectures that compensate for coupling variations while operating at fixed frequency and maintaining high efficiency.

The technologies developed for dynamic EV charging are foundational—they can also enable wirelessly powered biomedical implants, humanoid robots, and supersonic hyperloop transport. The technological challenges are exciting and the possibilities endless.

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Machine learning can describe data better than biomedical models, providing engineering solutions, essential benchmarks, and enhanced understanding.

The Roles of Machine Learning in Biomedical Science

Konrad Paul Kording, Ari S. Benjamin, Roozbeh Farhoodi, and Joshua I. Glaser



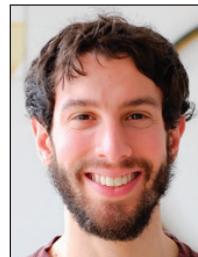
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Joshua I. Glaser

While the direct goal of biological modeling is to describe data, it ultimately aims to find ways of fixing systems and enhancing understanding of system objectives, algorithms, and mechanisms. Thanks to engineering applications, machine learning is making it possible to model data extremely well, without using strong assumptions about the modeled system. Machine learning can usually better describe data than biomedical models and thus provides both engineering solutions and an essential benchmark. It can also be a tool to advance understanding.

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Using examples from neuroscience, we highlight the contributions, both realized and potential, of machine learning, which is becoming easy to use and should be adopted as a critical tool across the full spectrum of biomedical questions.

Introduction

The goal of nearly all of computational biology is to numerically describe a system, which is often quantified as the explained variance. In some cases, only the explained variance is of interest—for example, to make predictions. But in most cases, just describing the data successfully is not sufficient. There has been much discussion of objectives in the neuroscience community (e.g., Dayan and Abbott 2001; Marr 1982).

Uses of Models

The typical model is designed not only to numerically describe data but also to meet other objectives of the researcher. In some cases it is used to inform how to fix things—to predict what would happen based on certain interventions. In others, the goal is to determine whether the system optimizes some objective; for example, whether the intricate folds of the brain minimize wiring length (Van Essen 1997). Or the aim may be to understand the system as an algorithm—for example, which algorithms the brain uses to learn (Marblestone et al. 2016). Probably most commonly, a model is used to understand underlying mechanisms—for example, how action potentials are enabled by interactions between voltage-dependent ion channels (Hodgkin and Huxley 1952).

Modeling is often based mostly on human insights, but these are bound to be incomplete in systems with many nonlinearly interacting pieces.

So far, progress in the modeling field comes mostly from human insights into systems. People think about the involved components, conceptualize the system's behavior, and then build a model based on their intuitive

insights. This has been done for neurons (Dayan and Abbott 2001), molecules (Leszczynski 1999), and the immune system (Petrovsky and Brusica 2002).

Biomedical researchers are starting to use computational models both to describe data and to specify the underlying principles. However, understanding such complex systems is extremely difficult, and human intuition is bound to be incomplete in systems with many nonlinearly interacting pieces (Jonas and Kording 2017).

What Is Machine Learning?

The vast field of machine learning is a radically different way of approaching modeling that relies on minimal human insight (Bishop 2006). We focus here on the most popular subdiscipline, supervised learning, which assumes that the relationship between the measured variables and those to be predicted is in some sense simple (Wolpert 2012), with characteristics such as smoothness, sparseness, or invariance.

Supervised algorithms receive vectors of features as inputs and produce predictions as outputs. Machine learning (ML) techniques mostly differ by the nature of the function they use for predicting (Schölkopf and Smola 2002). Rather than assuming an explicit model about the relationship of variables, ML techniques assume a generic notion of simplicity.

The field of machine learning is undergoing a revolution. It has moved from a niche discipline to a major driver of economic activity over the last couple of decades as progress revolutionizes web searching, speech to text, and countless other areas of economic importance. The influx of talent into this field has led to massive improvements in algorithm performance, allowing computers to outperform humans at tasks such as image recognition (He et al. 2015) and playing Go (Silver et al. 2016). These developments in machine learning promise to make it an important tool in biomedical research. Indeed, the number of ML-related papers and patents in biomedical research has grown exponentially (figure 1).

Uses of Machine Learning for Biomedical Research

Many kinds of questions can be answered using machine learning techniques. In some cases they are useful for predictions, such as whether a drug will cure a particular cancer. In others they set a benchmark—for example, what are the shortcomings of the human-thought-out model relative to what may be possible? In yet other

cases machine learning may enhance understanding of a system by revealing which variables are shared between components of a system.

Description and Prediction

The standard use for machine learning is to make a prediction based on something that can be measured. For example, in psychiatric medicine, studies have used smartphone recordings of everyday behaviors (e.g., when patients wake up or how much they exercise) to predict mood using machine learning (Wang et al. 2014).

A typical problem in neuroscience is the decoding of neural activity (Velliste et al. 2008) to infer intentions from brain measurements. This application is useful for developing interactive prosthetic devices, in which one uses measurements from the brain of a paralyzed subject to enable a robot to execute the movement. Many algorithms have been developed to solve such problems (Corbett et al. 2012; Yu et al. 2007); for this application, general purpose machine learning tends to do extremely well (Glaser et al. 2017).

Computationally similar problems exist throughout biomedical research, in areas such as cancer (Kourou et al. 2015), preventive medicine (Albert et al. 2012), and medical diagnostics (Foster et al. 2014). In these areas only the quality of the predictions is of interest. Similarly, many engineering problems are mainly concerned with the error size of predictions. When the main goal is to obtain accurate predictions, it is best to first try machine learning methods.

Benchmarking

Often the goal is not just to describe and predict data but to produce models that can be readily understood and taught. Machine learning can be extremely useful by providing a benchmark.

One problem when evaluating a model is that it is hard to know how much its errors are due to noise versus the insufficiency of the model. Because machine learning is a useful tool for making predictions, it may provide close to an upper bound for human-produced models. If a human-generated model produces results that are very different from the ML benchmark, it may be because important principles are missing or because the modeling is misguided. If, on the other hand, a model based on human intuition is very close to the ML benchmark, it is more likely that the posited concepts are, indeed, meaningful.

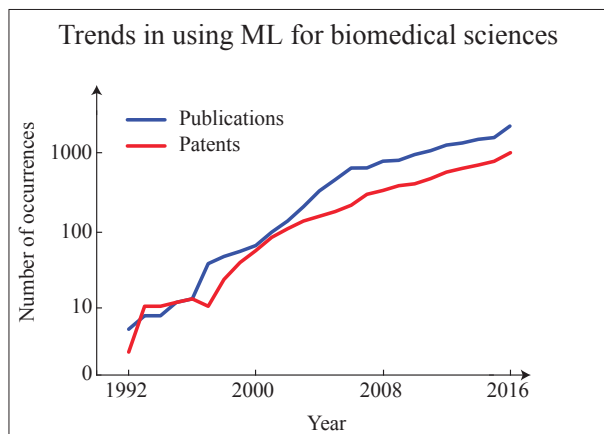


FIGURE 1 Trends in use of machine learning (ML) for biomedical sciences, 1992–2016. Publication data (blue) were collected from the Semantic Scholar website using the keywords “biomedical” and “machine learning.” Patent data (red) were collected from Google Patents using the same keywords.

But how is it possible to know whether a model is missing important aspects? We argue that ML benchmarking can help answer those questions (Benjamin et al. 2017).

Understanding

Machine learning can also directly help understanding. One important question is whether a system carries information about some variables (for example, whether neural activity contains information about an external stimulus), but it may not be clear whether the relation between the variables is linear or nonlinear. With machine learning it is possible to determine whether information is contained in a signal without having to specify the exact nature of the relationship.

Another important question concerns the information shared between two parts of a system. For example, which aspects of the world (high dimensional) are shared with which aspects of the brain (also high dimensional)? Machine learning makes it possible to ask such questions in a well-defined way (Andrew et al. 2013; Hardoon et al. 2004).

For many questions in biology, machine learning promises to enable new approaches to enhance understanding.

Machine Learning: A Necessity for Ever-Growing Datasets

Datasets are rapidly growing and becoming more and more complex as they become multimodal and multi-

faceted (Glaser and Kording 2016). In neuroscience, the number of simultaneously recorded neurons is increasing exponentially (Stevenson and Kording 2011), as is the amount of electronic health record data (Shortliffe 1998).

Challenges in Modeling for Complex Datasets

There are several ways in which these changes in datasets will create new problems for modeling. First, we humans are not very good at thinking about complex datasets. We can only consider a small hypothesis space. But in biology, as opposed to physics, there are good reasons to assume that truly meaningful models must be fairly complex (O’Leary et al. 2015). While humans will correctly see some structure in the data, they will miss much of the actual structure. It could be argued that it is nearly impossible for humans to intuit models of complex biological systems.

Second, nonlinearity and recurrence make it much more difficult to model complex systems (O’Leary et al. 2015), which require complex models. It can be hard to falsify models that are very expressive or have many free parameters. One needs to both explain complexity and ensure that the model will fail if the causal structure is dissimilar to the model. For full-cell interactions or full-brain modeling, the design of models that strike this delicate balance seems implausible.

*With machine learning,
using many variables
improves predictions,
even if it is not clear
which variables contribute.*

Finally, in the case of the large complex systems that are characteristic of biology, a major problem is the lack of understanding of how many different models could in principle describe the data. Models can explain some portion of the variance, but not necessarily the mechanism (Lazebnik 2002). Comparing models is pointless if they are not good at describing the relevant mechanisms.

Given all these arguments, it may be that physics-based non-ML-based approaches can only partially succeed. Any reasonably small number of principles

can describe only part of the overall variance (and potentially a relatively small part). It is unclear how far the typical approach in biomedical research, drawing on concepts of necessity and sufficiency, can help to enhance understanding of the bulk of activity in complex interacting systems (Gomez-Marin 2017). Machine learning has the potential to describe a very large part of the variance.

A Note about Model Simplicity and Complexity

Machine learning also changes the objectives of data collection. In traditional approaches, measuring many variables is unattractive as, through multiple comparison testing corrections, it is not possible to say much about each of them. But with machine learning, using many variables improves predictions—even if it is not clear which variables contribute—making it attractive to record many variables.

This is not just a vacuous statement about information processing. It reflects the fact that the brain and other biological systems are not simple, with few interactions, but highly recurrent and nonlinear. The assumption of simplicity in biology is largely a fanciful, if highly convenient, illusion. And if the systems subject to machine learning are not simple, then biases toward simple models will not do much good.

Based on their intuitions, researchers are starting to fit rather complex models to biological data, and those models usually fit the data better than simpler models. However, a complex model based on a wrong idea may fit the data extremely well and thus negate the advantage of an interpretable model.

A good fit does not mean that the model is right. For example, Lamarckian evolution explains a lot of data about species, but it was based on a fundamentally misleading concept of causal transmission of traits. The problem of apparent fit affects human intuition-based models, but not ML models, which, by design, do not produce a meaningful causal interpretation.

Specialist Knowledge Not Necessary for Machine Learning

There are countless approaches in machine learning, certainly more than most biomedical researchers have time to learn. Kernel-based systems such as support vector machines are built on the idea of regulating model complexity (Schölkopf and Smola 2002). Neural networks are built on the idea of hierarchical representations (Goodfellow et al. 2016). Random forests are built

on the idea of having many weak learners (Breiman 2001). One could easily fill books with all the knowledge about machine learning techniques.

Yet the use of ML techniques has actually become very simple. At application time, one requires a matrix of training features and a vector of the known labels. And given the availability of the right software packages (Pedregosa et al. 2011), generally only a few lines of code are needed to train any ML system.

Moreover, ensemble methods obviate the need to choose a single machine learning technique (Dietterich 2000). The idea is that a system can run all techniques and then combine their predictions using yet another ML technique. Such approaches often win ML competitions (e.g., kaggle.com).

Furthermore, a new trend has developed rapidly in the past few years: automatic machine learning (Guyon et al. 2015). The idea is that most ML experts do similar things: they choose one of a number of methods (or all of them if they use ensembling) and then optimize the hyperparameters of those techniques. They may also optimize the feature representation. Although this can take a significant amount of time via trial and error, the process is relatively standard and several new packages allow automation of some or all of it.¹

These developments are likely to pick up speed in the next year or two, making it less necessary for biomedical scientists to know the details of the individual methods and freeing them to focus on the scientific questions that machine learning can answer.

Examples of State-of-the-Art Machine Learning in Neuroscience

With examples from neuroscience we illustrate two uses of ML approaches, predictions and benchmarking.

Neural Decoding

In neural decoding the aim is to estimate subjects' intentions based on brain activity—for example, to predict intended movements so that they can move an exoskeleton with their thoughts. A standard approach in the field is still the use of simple linear techniques such as those used in the Wiener filter, in which all previous signals during a given time period are linearly combined to predict the output.

¹ Examples of these packages are available at <https://github.com/automl/auto-sklearn>, www.cs.ubc.ca/labs/beta/Projects/autoweka/, <https://github.com/KordingLab/spykesML>, and https://github.com/KordingLab/Neural_Decoding.

There has recently been a lot of interest in improving this and similar approaches using modern machine learning. For many applications the goal is simply good performance. To analyze the advantages of using standard machine learning, we implemented many approaches: the linear Wiener filter, the nonlinear extension called the Wiener cascade, the Kalman filter, nonlinear support vector machines, extreme gradient-boosted trees, and various neural networks (figure 2).

To solve biomedical and other engineering problems, use of standard machine learning should be the starting point.

The modern neural network-based techniques did very well (Glaser et al. 2017), and a combination of all the techniques, using ensemble methods, performed even better. The same phenomenon was seen when decoding from different brain regions. Thus we conclude that, to solve biomedical engineering problems, use of standard machine learning should be the starting point.

In this sense, machine learning also sets a benchmark for other decoding approaches. When neuroscientists write decoding algorithms they are often based on their insights into the way the brain works (Corbett et al. 2012). However, without a comparison to modern machine learning, it is not possible to know whether or to what extent these insights are appropriate.

As machine learning becomes automatic and easy to use, we argue that it should always be used as a benchmark for engineering applications.

Neural Encoding

Neural encoding, or tuning curve analysis, involves the study of signals from a neuron or a brain region to understand how they relate to external variables. Such a characterization can yield insights into the role of a neuron in computation (Jonas and Kording 2017).

Typically, the neuroscientist chooses a model (often implicitly) and the average signal is plotted as a function of external variables such as visual stimuli or move-

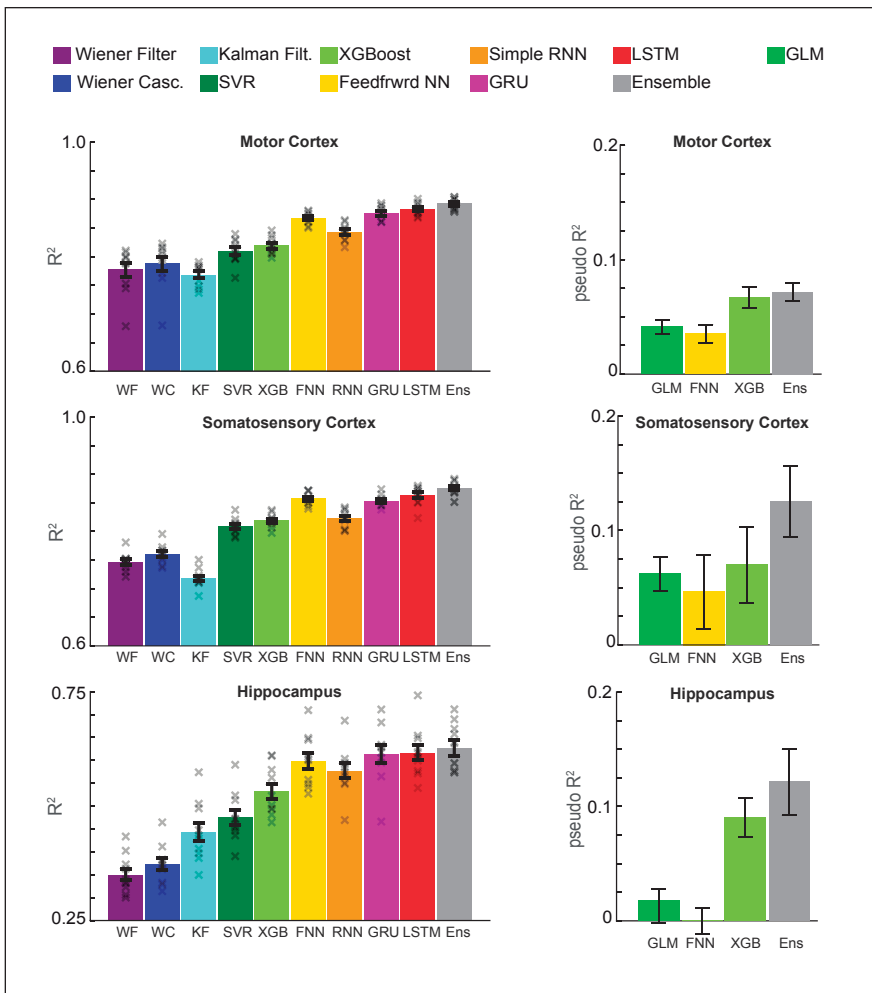


FIGURE 2 State-of-the-art machine learning decoding (left) and encoding (right). Left: Predicting state based on signals from three brain areas using various machine learning techniques and then ensemble analysis. Right: Predicting spikes using signals from three brain areas. Motor cortex data are from a study of macaques; somatosensory cortex and hippocampus data are those of humans. Data replotted with permission from Glaser et al. (2017), Benjamin et al. (2017). Casc. = cascade; GLM = generalized linear model; GRU = gated recurrent unit; LSTM = long short-term memory; NN = neural network; RNN = recurrent neural network; SVR = support vector; XG = extreme gradient.

ments. This approach generally assumes a simple model. Would machine learning give better results?

For such applications it is impossible to know whether poor model performance is due to external variables unrelated to neural activity or to the choice of model form. In principle, input variables may affect the neuron's activity in highly nonlinear ways. This hypothesis can be tested with machine learning.

When we compared the generalized linear model (GLM; Pillow et al. 2008), it performed considerably

worse than neural networks or extreme gradient–boosted trees (figure 2). And again, the combination of all the methods using ensemble techniques yielded the best results. It can be difficult to guess features that relate to neural activity in exactly the form specified by the GLM.

Interestingly, despite the fact that the space was rather low dimensional, GLMs performed poorly relative to modern machine learning. This may suggest that the tuning curves measured by neuroscientists are rather poor at describing neurons in real-world settings.

In this context, machine learning can conceptually contribute in the following ways:

1. It can detect that a variable is represented, even if there is no linear correlation.
2. It can set a benchmark that humans can strive for.
3. It offers a possibility of replacing the common cartoon model of neural computation with a complex (although admittedly hard to interpret) alternative.

Conclusion

The incorporation of machine learning has profound implications for neuroscience and biomedical science.

For biomedical modeling, traditional modeling and machine learning cover opposite corners. Traditional modeling leads to models that can be compactly communicated and taught, while explaining only a limited amount of variance. Machine learning modeling explains a lot of variance, but is difficult to communicate. The two types of modeling can inform one another and both should be used to their maximal possibility.

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Using a simple decision tree model, we introduce efficient hardware architectures to predict abnormal neurological states in various disorders.

Efficient Feature Extraction and Classification Methods in Neural Interfaces

Mahsa Shoaran, Benyamin A. Haghi, Masoud Farivar, and Azita Emami



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Brain disorders such as dementia, epilepsy, migraine, and autism remain largely undertreated, but neural devices are increasingly being used for their treatment. Such devices are designed to interface with the brain, monitor and detect neurological abnormalities, and trigger an appropriate type of therapy such as neuromodulation to restore normal function.

A key challenge to these new treatments is to integrate state-of-the-art signal acquisition techniques, as well as efficient biomarker extraction and

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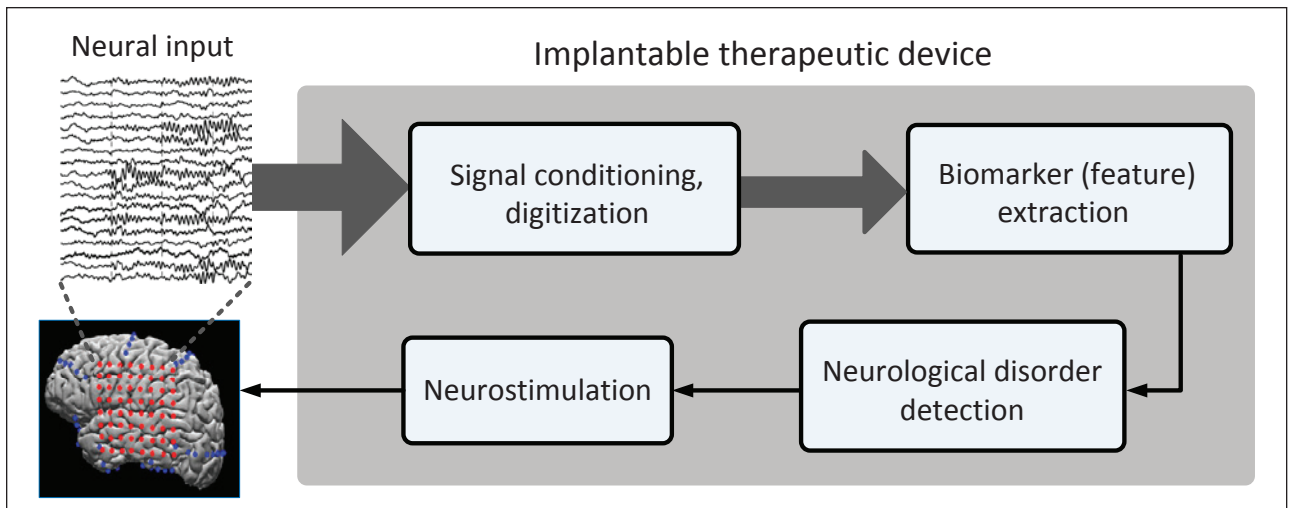


FIGURE 1 General block diagram of a closed-loop therapeutic system for detection and suppression of disabling neurological symptoms.

classification methods to accurately identify symptoms, using low-cost, highly integrated, wireless, and miniaturized devices.

Therapeutic Neural Devices

A general block diagram of a closed-loop neural interface system is shown in figure 1. The neural signals recorded by an array of electrodes (intracranial, scalp, or other types) are initially amplified, filtered, and digitized. A feature extraction processor is then activated to extract the disease-associated biomarkers. Upon abnormality detection, a programmable neural stimulator is triggered to suppress the symptoms of disease (e.g., a seizure, migraine attack, Parkinson's tremor, memory dysfunction) through periodic charge delivery to the tissue.

The abnormality detector device must demonstrate high sensitivity (true positive rate), sufficient specificity (true negative rate), and low latency. It also has to satisfy the safety, portability, and biocompatibility requirements of the human body.

An Example of Neuroengineering Treatment: Epilepsy

The emerging field of neuroengineering uses engineering technologies to investigate and treat neurological diseases. Epilepsy has been one of the primary targets, along with movement disorders, stroke, chronic pain, affective disorders, and paralysis (Stacey and Litt 2008).

Approximately one third of epileptic patients exhibit seizures that are not controlled by medications. Neuro-modulation offers a new avenue of treatment for intractable epilepsy.

Over decades, research on epilepsy has led to fundamental understandings of brain function, with strong implications for other neurological disorders. In addition, because of the severity of refractory epilepsy and the need for surgery, human tissue and epileptic EEG datasets are largely available. Most therapeutic neural interfaces reported in the literature have therefore focused on extracting epileptic biomarkers for automated seizure detection (Shoaran et al. 2015; Shoeb et al. 2004; Verma et al. 2010).

The spectral energy of neural channels in multiple frequency bands as well as various time and frequency domain features have been used as potential seizure biomarkers. To improve the power and area efficiency in multichannel systems, a spatial filtering technique was proposed to precede the seizure detection unit (Shoaran et al. 2016b). But in most devices the classification of neural features is performed either remotely or by means of moderately accurate thresholding techniques.

For one patient-specific support vector machine (SVM) classifier (implemented by Yoo et al. 2013), the classification processor contributes to a significant portion of chip area and power. To improve the accuracy of detection, resource-efficient on-chip learning is becoming an essential element of next-generation implantable and wearable diagnostic devices.

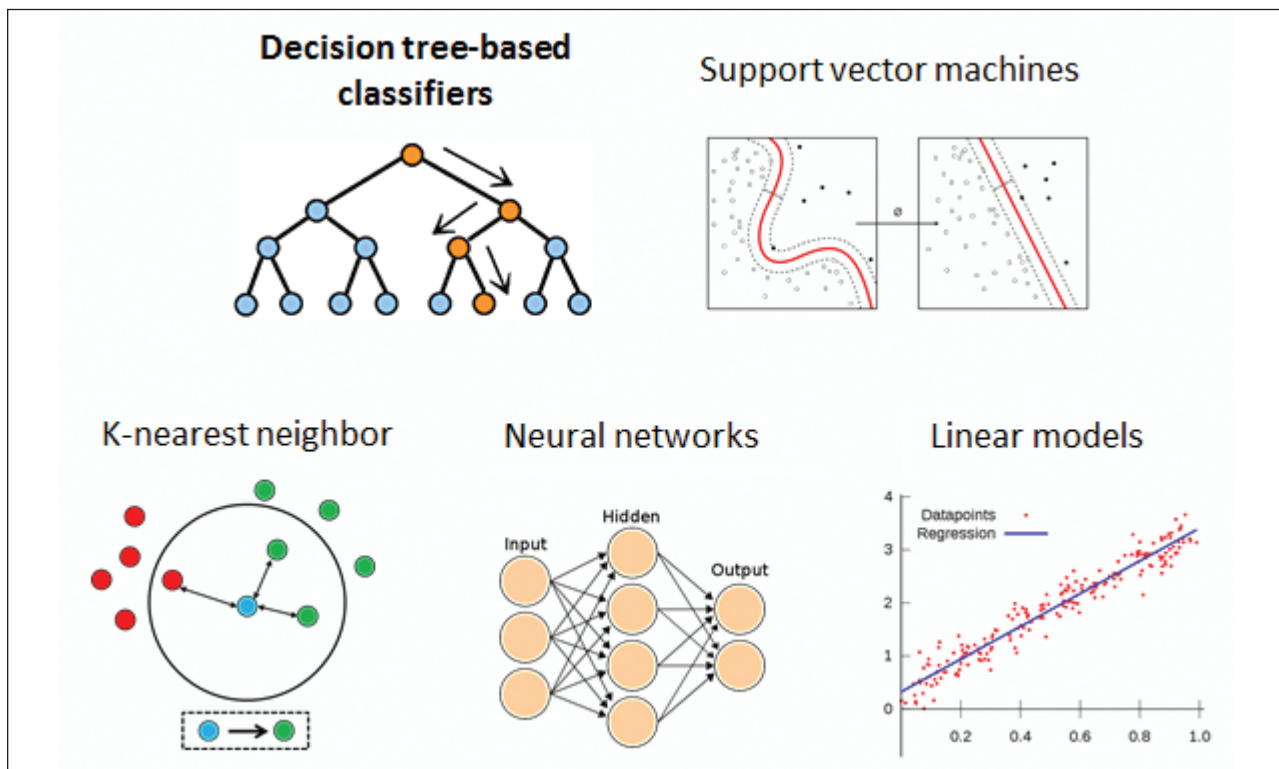


FIGURE 2 Schematic of common learning models as potential candidates for hardware implementation.

Machine Learning in Neural Devices: Scalability Challenges

Conventional classification techniques such as SVMs, k-nearest neighbors (KNNs), and neural networks (illustrated in figure 2) are hardware intensive and require high processing power and large memory units to perform complex computations on chip.

Numerous studies show that a large number of acquisition channels are required to obtain an accurate representation of brain activity, and that the therapeutic potential of neural devices is limited at low spatio-temporal resolution. It is expected that future interfaces will integrate thousands of channels at relatively high sampling rates, making it crucial to operate at extremely low power. The device must also be very small to minimize implantation challenges.

Despite a substantial literature on machine learning, hardware-friendly implementation of such techniques is not sufficiently addressed. Indeed, even the simple arithmetic operations performed in conventional classification methods can become very costly with an increasing number of channels.

Finally, filter banks and, in general, feature extraction units can be hardware intensive, particularly at higher frequencies associated with intracranial EEG. Extensive system-level design improvement is needed to meet the requirements of an implantable device while preserving high-resolution recording capability.

Decision Tree-Based Classifiers

We present and evaluate a seizure detection algorithm using an ensemble of decision tree (DT) classifiers. The general schematic of a single decision tree is shown in figure 2.

With only simple comparators as their core building blocks, DT classifiers are a preferable solution to reduce hardware design complexity. Using a gradient-boosted ensemble of decision trees, we achieve a reasonable tradeoff between detection accuracy and implementation cost.

Gradient boosting (Friedman 2001), one of the most successful machine learning techniques, adaptively combines many simple models to get an improved predictive performance. Binary split decision trees are

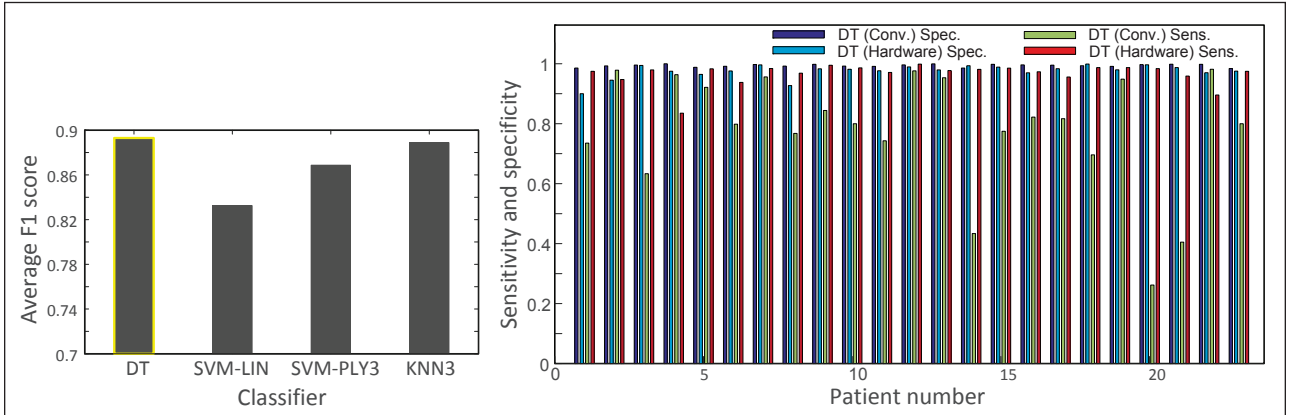


FIGURE 3 Comparison of predictive ability of different classification methods with an ensemble of 8 decision trees (DT) of depth 3 (left), and the classification performance of the asynchronous hardware model compared to a conventional (conv.) DT (right). KNN = K-nearest neighbor; LIN = linear; PLY3 = polynomial kernel of order 3; SVM = support vector machine.

commonly used as the “weak” learners. Boosted trees are at the core of state-of-the-art solutions in a variety of learning domains because of their accuracy and fast computation and operation.

Combined with an efficient feature extraction model, we show that, with only a small number of low-depth “shallow” trees, the boosted classifiers quickly become competitive with more complex learning models (Shoraran et al. 2016a). These ensembles of axis-parallel DT classifiers are excellent candidates for on-chip integration, eliminating the multiplication operation and offering significant reductions in power and chip area.

Performance Evaluation and Hardware Design

As a benchmark, we compare a boosted ensemble of 8 trees with a depth of 3 to linear SVM, cubic SVM, and KNN-3 models proposed for on-chip classification, using the following features: line length, time-domain variance, and multiple band powers. The proposed approach is tested on a large dataset of over 140 days of intracranial EEG data from 23 epileptic patients.

Figure 3 (left) shows the average F1 measure of classifiers. This benchmark is already competitive with its peers, and can outperform using larger ensemble sizes. It achieves an average seizure detection sensitivity of 98.3 percent.

Decision trees are very efficient, but also susceptible to overfitting in problems with high feature space dimensionality. To address this, we limit the number of nodes in each tree—that is, we design shallow trees with a small number of features. These shorter trees are also more efficient in hardware and, equally important,

incur less detection delay. In our simulations, the detection accuracy is not significantly improved (<0.5 percent) with DT depth values of 4 or more.

Proposed Decision Tree Architecture

We propose the architecture shown in figure 4 (left) to implement ensembles of decision trees. At each comparison step, only the features appearing in the active nodes of trees are needed; the rest of the recording array can be switched off to save power.

Because the final decision is made upon completing decisions at prior levels, a single feature extraction unit can be sequentially used per tree. This results in a significant hardware saving, in contrast to SVM, which requires all features from the entire array.

For example, the memory required to classify 32-channel neural data with 8 trees (a maximum depth of 3 and threshold resolution of 8 bits) is as low as 100 bytes, while SVM and KNN-based arrays would need over 500 kB of memory. Depending on the specific patient and the difficulty of the detection task, additional “supportive” trees can be used to further boost the classification accuracy.

The proposed architecture faces a practical challenge of designing decision trees under application-specific delay constraints. Given any DT ensemble $\tau = \{\tau_1, \dots, \tau_k\}$ obtained from our original method, we need to ensure that each tree τ_i satisfies the delay constraint: $\sum_{i \in \pi(h)} d_i \leq \Delta T$, where d_i is the time required to compute feature f_i , ΔT is the maximum tolerable detection delay, and $\pi(h)$ is the set of all predecessors of node h . We propose a “greedy” algorithm to solve this

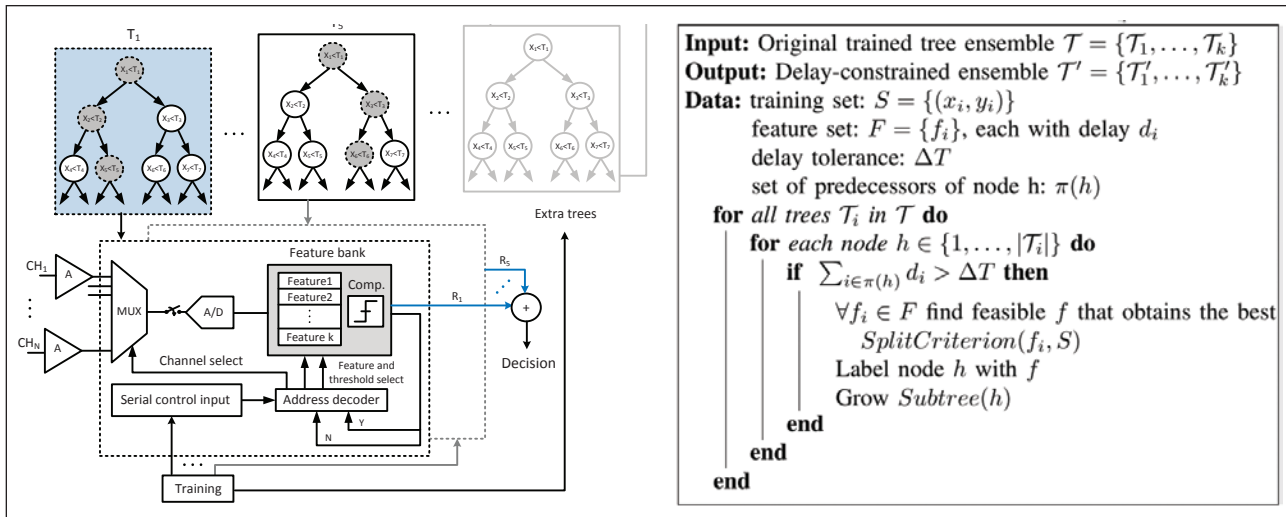


FIGURE 4 Hardware-level architecture for an ensemble of decision tree classifier with primary and supportive trees (left) and a greedy training algorithm to meet the delay constraints (right). A = amplifier; A/D = analog to digital converter; CH = channel; Comp. = comparator; k, N = number of features and channels; MUX = multiplexer; R = result.

practical constraint by building trees that satisfy the delay requirement, as illustrated in figure 4 (right).

However, this algorithm may result in a suboptimal solution. We therefore investigate a novel asynchronous model to learn from neural data streams, the results of which are shown in figure 3 (right). In this model, the trees are built with features that maximize accuracy regardless of their computational delay. Based on averaged results of completed trees and previous results of incomplete trees, decisions are frequently updated (over 0.5-sec intervals) to avoid long latencies and maximize sensitivity. Once completed, longer trees contribute to decisions at future time steps.

Conclusions

Based on a simple yet sufficiently accurate (98.3 percent) decision tree model, we introduce efficient hardware architectures and related training algorithms to predict the abnormal neurological states in various disorders, such as epilepsy, Parkinson’s disease, and migraine. Such classifiers may allow the full integration of processing circuitry with the sensor array in various resource-constrained biomedical applications.

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Vertical transportation systems in megatall buildings must minimize anxiety, increase convenience, and improve efficiency while maintaining safety and reliability.

The Evolution of Elevators: Physical-Human Interface, Digital Interaction, and Megatall Buildings



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Stephen R. Nichols

For more than 160 years advances in vertical transportation and elevator technology have been key enablers of the increasingly high-rise buildings that define cities around the world. Improvements in elevator safety, robustness, quality, space efficiency, and performance have allowed buildings and cities to grow megatall.¹ The design and construction of such buildings and their vertical transportation systems need to be balanced with improvements that reduce passengers' anxiety while increasing convenience and efficiency.

This article reviews the history of elevators and their technologies. It then examines specific considerations for megatall buildings, such as building traffic, lobbies and layout, and evacuation. The discussion considers the incorporation of new technologies and user-centered design to improve passenger experience.

Brief History of Elevators

The functional “job to be done” (Christensen 2011) of an elevator is simple: transport passengers and cargo safely and quickly from one altitude to another.

¹ Megatall buildings are 600 meters or more. For reference, the original 110-floor World Trade Towers in New York were just over 540 meters. The world's tallest building, Burj Khalifa in Dubai, is 828 meters.

Early Methods

Elevators have been part of human history as far back as the pyramids of ancient Egypt (Gavois 1983), when the construction of large structures required the capacity to raise materials to greater heights than humans could lift without mechanical advantage. The Egyptians, Romans, Babylonians, and others devised increasingly sophisticated rope and pulley systems, capstans, and other hoists for construction purposes—and there is evidence of an elevator hoistway in the Roman Colosseum completed in the year 80.

The first counterweight, used to balance and counteract the effects of gravity, did not appear before 1670 and hoists were not widely applied to industry until 1830 (Goodwin 2001). Elevators were generally not successful because of their unreliability and lack of safety. Fraying rope and other mechanical failures due to wear and excessive weight were common causes of dangerous accidents that made factory owners reluctant to use elevators for cargo. Passenger use was all but unthinkable.

Invention of the Elevator Safety Brake

The use of levers, ropes and pulleys, and other lifting means persisted without many significant improvements until the invention in 1852 of the elevator safety brake by Elisha G. Otis (1811–61). He demonstrated it at the New York World's Fair (figure 1²) in 1854 (Goodwin 2001), and it was patented in 1861.

Otis's invention took a simple flat-leaf spring from a cart and applied it to the roof of an elevated hoist such



FIGURE 1 Elisha Graves Otis performs his safety elevator demonstration in the dome of the Crystal Palace at the World's Fair in New York City (May 1854). Hired by showman PT Barnum to perform the feat, Otis rode up on the platform, had the rope cut, and, when the car did not fall in front of the stunned crowd, proclaimed: "All safe, ladies and gentlemen! All safe!" Courtesy Otis Elevator Company.

that, in the event of the hoist rope's failure, the tension in the spring would cause shoes on either end of the spring to engage with notches in the guide rails at either side of the hoist. As dramatically demonstrated at the World's Fair, when the rope was cut, the safety brake activated and brought the hoist to an abrupt halt with no harm to the cargo or passengers.

The safety brake quickly transformed an unreliable, little-used industrial tool into a viable means of transporting not only cargo but also people. The first-ever safe commercial passenger elevator was installed in 1857 in a Manhattan department store owned by E.V. Haughwout and Co.

² All figures and images are provided from the Otis Historical Archive: Historical Photographs, Illustrations and Ads; Digital Image Collection.

With the commercial success of safe passenger elevators, architects and builders started constructing taller buildings. Prime real estate in buildings and cities quickly moved from the first few floors that were conveniently close to the building entry to the top floors and penthouses away from the dust and clamor of the city street.

The breakthrough in elevator safety prompted the evolution toward taller and taller cities and, eventually, today's megatall buildings.

Elevator Technology Drivers

The competing benefits and disadvantages of gravity and friction, coupled with continuous improvements in power management, building materials, and other factors, transformed elevators from purely functional devices to a central component of urban buildings and city life.

Harnessing Gravity

The art of elevating—moving people vertically through buildings—is fundamentally about controlling gravity, which is both the elevator's enemy and friend. It must be overcome to move people safely and smoothly, and harnessed (through counterweights and other means) for control and energy savings.

Early advances focused on propulsion technology.

With the commercial success of safe passenger elevators, architects and builders started constructing taller buildings.

Steam engines in the 1850s and 1860s, hydraulic systems in the 1870s, and electric motors in the 1890s (installed at either the top of the elevator hoistway or the bottom of the elevator pit) powered elevators through a variety of arrangements and layouts to enable higher rises, different building configurations, and efficient vertical motion. Rotating machinery and ropes, hydraulic pistons, or the combination thereof created the upward force to pull or push the passenger and cargo compartment up and to stop it safely, smoothly, and accurately at a desired destination.

Improvements in propulsion technology enabled the control of gravity, fostered public confidence in elevators, and led to widespread success. Advertisements initially showed the elevator's industrial roots with a focus on machinery (figure 2), but soon luxurious elevator interiors shifted the focus to passengers and elevators became part of the architectural intention of a building.

Controlling Friction

The safe, controlled, smooth deceleration and stopping of an elevator are of paramount importance.

Traction elevators balance friction and the interface between the rope (or belt) and the drive sheave, whether the "rope" is a hemp rope, steel cable, polyurethane-coated steel belt, or carbon-fiber suspension member. Innovations in roping (with one-to-one and two-to-one roping, under- and overslung, and roped hydraulic arrangements) and other technological advances yielded a series of inventions from the latter half of the 19th century into the 20th (see figures 3, 4). These improvements in elevator machinery and propulsion benefited both passengers and architects as elevators became faster and larger.

Systems in which propulsion did not rely on frictional interfaces were introduced in the 1990s: the first linear motor elevator system was commercially offered by Otis in Japan (Janovský 1999). This system, with the motor mounted on the counterweight, reduces the complexities of controlling friction for propulsion while retaining the counterweight for the advantages of working with gravity. Advances in linear motors will eventually make it possible for multiple elevator cars to travel simultaneously in individual hoistways.

Managing Power

Rotating machinery, whether powered by steam or electricity, and linear motors all require power. Careful management of that power is required for both the elevator system and the building system as a whole.

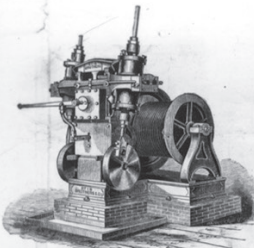
Innovations like the counterweight and two-to-one roping are advantageous because they require lower power. Reduced power consumption allows propulsion components to be smaller and more efficient, benefiting both the building owner and the architect in the long-term operational cost of the elevator and the building's overall energy footprint. Linear motors may offer some benefits, but they require significantly higher amounts of power than traditional means (Janovský 1999).

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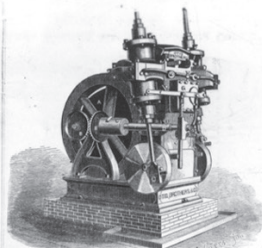
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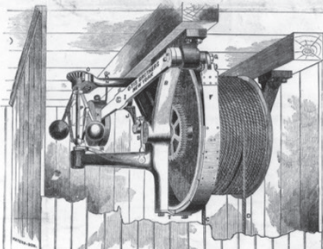
Union Hoisting Engine. Cut A.
Otis' Patent Double Gear Hoisting Engine, adapted for use in connection with Safety Platform for Storage Warehouses, Packing Houses, Shipping, Docks, Mines, &c. Motion of Platform at will of attendant, up to 100 feet per minute.



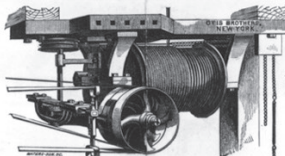
Union Hoisting Engine. Cut B.
Otis' Patent Double Gear Hoisting Engine, showing application of Patent Automatic Stop Mechanism, by which the engine is automatically stopped after making any desired number of revolutions. Motion of Platform at will of attendant, up to 100 feet per minute.

DEALERS in all kinds of Machinery required in the application of Steam for Hoisting Purposes.
STEAM BOILERS, STEAM PUMPS, STEAM & WATER GAUGES, STEAM & WATER PIPES, DAMPER REGULATORS, SHAFING, IRON CASTINGS, PULLIES, &c.

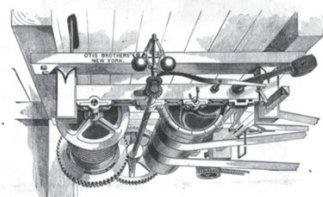
WIRE ROPE
Of the best quality, manufactured expressly for Hoisting, constantly on hand and supplied to Order.



Automatic Safety Drum. Cut C.
Otis' New Patent Safety Mechanism for stores and high buildings where the excessive weight of the Wire Lifting Rope tends to prevent the Safety Spring from acting at the critical moment, thereby rendering a safety device intermediate between the Hoisting Engine and Safety Platform necessary. This "Safety Drum" is secured directly over the hatchway, and acts as a monitor to the entire machine, instantly stopping the Platform upon any approach to an unsafe motion.

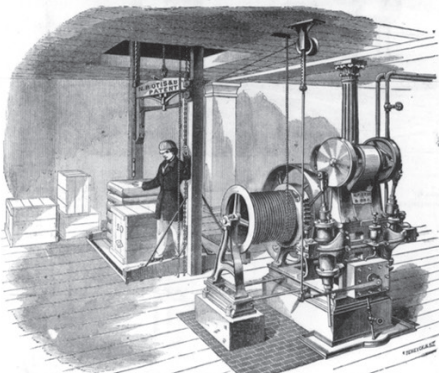


Lifting Power—screw combination. Cut D.
For Manufactories and all general purposes of hoisting by belts. A strong, compact machine, simple in construction, and readily attached to work with or without Safety Platform.

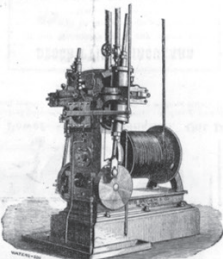


Lifting Power—gear combination. Cut E.
For Universal Hoisting Machine, as illustrated below, showing "The Belt Attachments," by which the machine is instantly stopped in case the gearing reaches an unsafe motion from any cause, as in the breaking of a belt while the machine is in motion.

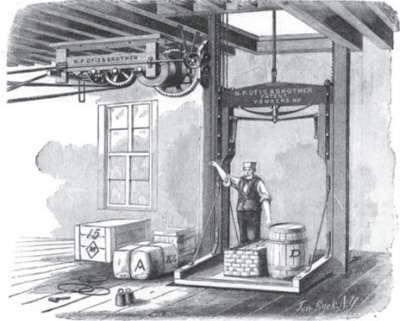
DESCRIPTIVE CIRCULARS
Of our Machinery, with any information required, will be furnished on application by Mail or in person.



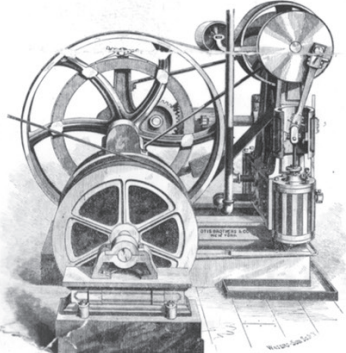
Metropolitan Hoisting Engine. Cut F.
Otis' Patent Noiseless Belt and Gear Hoisting Engine, Safety Platform and connections, for Hotels, Mercantile Houses, &c. Platform or Car moves any speed, at will of attendant, up to 200 feet per minute.



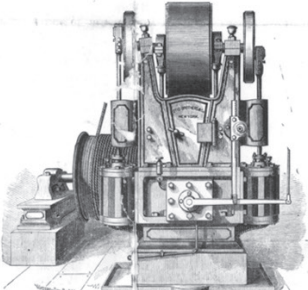
Relief Hoisting Engine. Cut G.
Otis' Patent Noiseless Screw Hoisting Engine, adapted for use in connection with Safety Platform, also especially fitted and readily attached for working the ordinary sidewalk Hoisting Machine, giving 60 feet per minute motion of Platform.



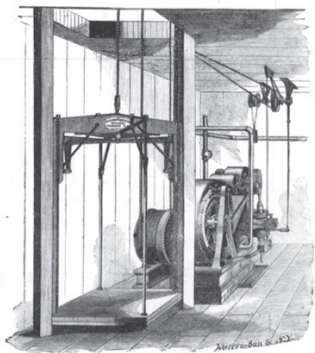
Universal Hoisting Machine. Cut H.
Otis' Patent Lifting Power, Safety Platform and connections, for Factories, Mills, Shops, Bakeries, and all general business purposes where steam, water or other power is in constant use. Motion of Platform 50 feet per minute.



Cut I.
Otis' National Stationary Cylinder Hoisting Engine.
Side View. See Cut J.



National Hoisting Engine, Front View. Cut J.
In this Hoisting Engine are combined many novel and useful features, which will commend it to such as prefer stationary cylinders. It is very strong, and compactly built, presents a neat and tasteful appearance, and runs without noise. The valve-gear is constructed upon an entirely new principle, by which a direct-acting and very simple motion is obtained with less loss by friction than in any other mechanism for the purpose in use.



Metropolitan Hoisting Machine, showing Corner Platform. Cut K.
This "Corner Platform" is adapted to buildings where it is necessary to handle goods to and from the platform on all sides or on any two sides at right angles at any of the different floors.

Printed by HOLT, RINEHART & WOOD, 104 William St., N. Y.

FIGURE 2 This 1869 Otis Brothers ad illustrates advances in steam engines and belt-driven hoist machinery for early elevator propulsion. Hydraulic piston-powered elevators were adopted in the 1870s and electric elevator motors in 1889. Courtesy Otis Elevator Company.

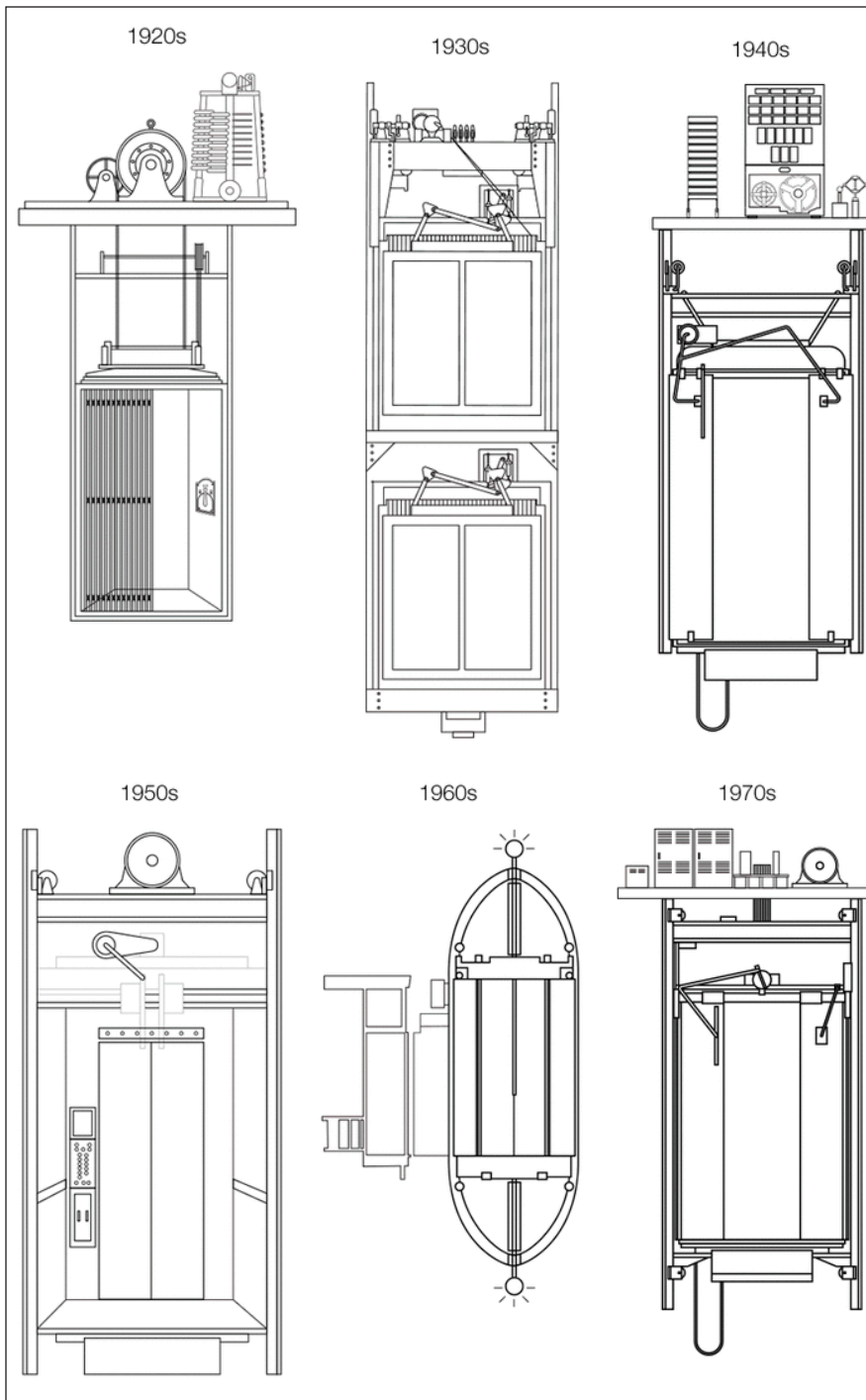


FIGURE 3 Elevator innovations in the mid-20th century looked beyond propulsion and hoisting technology. In the 1920s signal control and push buttons start to pave the way for automated control that, with the introduction of automatic doors, is realized in the 1950s (car operating panel shown to the left of the doors). In the 1970s the first integrated circuit, electronic, controlled elevator is introduced by Otis as the technology continues to shrink. Courtesy Otis Elevator Company.

An elevator system's power use, environmental impact, and sustainability must be considered in the context of the building system and the city itself. Recent innovations in battery-, solar-, and even hydrogen-powered elevators (Auditeau 2007) are intended to help elevator systems coexist in the environment where they operate.³

Building Construction, Materials, and Use of Core Space

An elevator system must adapt to a building's construction methods and materials (e.g., concrete, steel, timber). Steel construction in North America may yield different optimal configurations than concrete or prefabricated buildings in Asia. Advances in timber construction for sustainability or seismic advantage will require elevators to innovate along with the building material.

In addition, architects must consider a building's core space (allocated to elevators, machine and utility rooms, ventilation shafts, and the like) and the percentage of rentable space consumed by an elevator system. Developments such as the ability to use multiple cars in a hoistway can optimize both core space use and traffic flow through a building, as explained below in the discussion of double-deck elevators.

³ Also see "Gen2 Switch" brochure and information from the Otis Elevator Company (www.otis.com/site/lb/Pages/Gen2-Switch.aspx).

The Passenger Experience and Human Behavior

Passenger experience is the art and science of matching the elevator experience to the expectations of the people riding the elevator. It is a true human-machine interface that requires enhanced technology, an understanding of human behavior, and the smooth interaction between the two. A user-centered design approach helps to adapt beyond the functional “job to be done” in order to meet new social and emotional requirements.

Personal Expectations

One important dimension of this experience is ride quality. The quality of an elevator ride—the noise and vibration experienced by passengers—is another area where technology has progressed steadily to provide smoother and quieter rides.

Social, circumstantial, and ethnographic differences, however, are associated with different expectations of what constitutes a “good ride.” Residential passengers may think of the elevator as an extension of their living space. Hospitality passengers may want their visit to be better than their home. Commercial passengers may simply expect an efficient and secure journey that doesn’t impinge on their valuable time. Passengers in New York City may want to feel the rush of moving quickly up the building. Passengers in Tokyo may look for the experience of leaving one space, entering the elevator, and a moment later having the doors open in an entirely new space with little physical feeling of movement.

Technological Enhancements

For much of the early history of elevators, the experience was simple and very personal. Passengers would communicate directly with elevator operators who guided traffic, opened and closed doors, and directed the movement of the elevator car.

Elevator buttons were introduced in 1892, electronic signal control in 1924, automatic doors in 1948, and

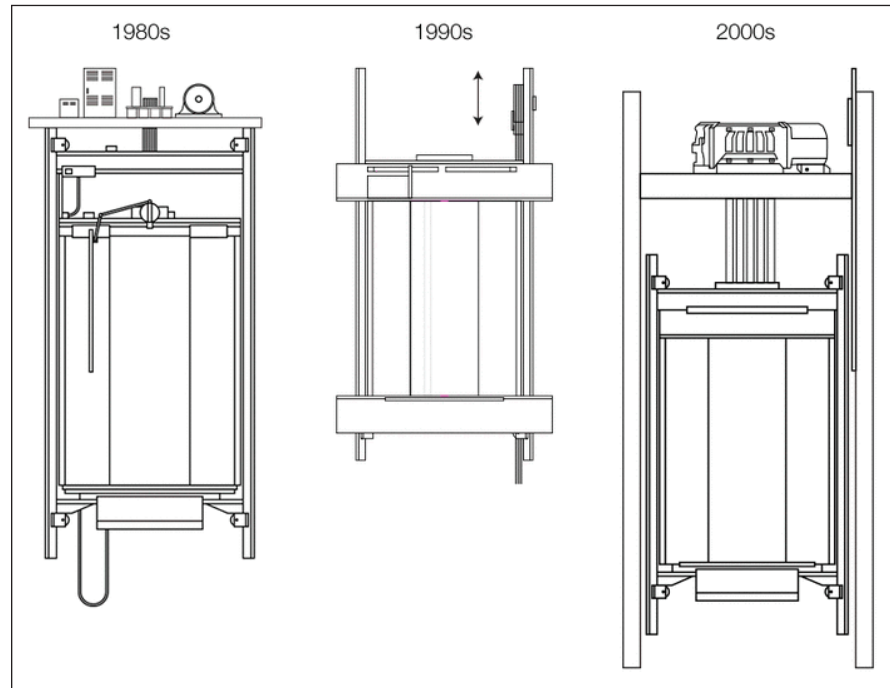


FIGURE 4 Elevator innovations in the late 20th century. Looking beyond the elevator shaft, remote service was introduced in the 1980s. In the 1990s space-saving linear magnetic motors (shown to the right along the counterweight rail) remove the need for an elevator machine room. The turn of the century ushers in machine-roomless (MRL) elevators with flat coated steel belts and other more sustainable technologies. Courtesy Otis Elevator Company.

in 1950 the first operatorless elevator was installed at the Atlantic Refining Building in Dallas. Full automatic control and autotronic supervision and operation followed in 1962, and elevator efficiency has steadily increased in other ways.

Yet questions associated with personal interaction remain. Where is the passenger in relation to the elevator? Is the passenger ready to ride or leave the elevator? Is the passenger allowed to go to his desired destination? How does the machine interact with the passenger to communicate valuable information?

Integration of the Two

Many of the challenges in modern passenger experience involve providing intuitive interactions and behavior solutions, and these can largely be achieved through new technologies and the application of connected and Internet of Things (IoT) technologies from other industries (Gulan et al. 2016). Digital interaction technology such as smartphones, wearables, video analytics, and other sensors, as well as advances in physical-human interfaces (e.g., touchscreens instead of buttons), will greatly improve intuitive behavior.

Technologies can be combined and introduced to lower anxiety and increase convenience and efficiency. Ensuring that passengers feel safe, trust equipment reliability, reduce or eliminate their wait time, get to their destination faster, and travel in a secure, comfortable, personalized space is of paramount importance to elevator technology well beyond the early physics-based problems.

Challenges of Megatall Buildings

The growing height of buildings and the desire for people to live and work at higher altitudes amplify all the challenges discussed.

- Propulsion systems must be devised to carry increasing duty loads of passengers and cargos, yet fairly quickly in high-rise buildings the combined weight of the ropes and suspension components outweighs the desired movable mass.
- Safety and braking technology that works well at low speeds must combat increasingly high forces, thermal loads, and more demanding friction environments.
- Physically moving larger and larger elevator machinery to the top of the building during construction and providing power to those machines throughout the life of the building are monumental challenges for both the elevator and the building itself.

Challenges to the passenger experience increase dramatically with taller buildings.

All the challenges in elevator design, from ride quality to seismic concerns, must be considered and optimized, in addition to new, unique challenges such as building sway due to wind. Challenges to the passenger experience (e.g., comfort, convenience, dispatching, traffic flow) also increase dramatically with taller buildings.

Automated Destination Dispatching

Tall buildings and their operators must accommodate the need to efficiently move large numbers of people. With megatall buildings, passengers' experience must be considered from the moment they enter the building, traverse the lobby, and approach the elevator system.

The potentially competing experiences of seamless elevator use and robust security must be balanced via access control. Effective integration of these aspects is demonstrated at 7 World Trade Center, where the presentation of credentials at lobby turnstiles automatically calls the elevator within milliseconds as passengers walk the 45 meters to board the elevator.

Elevator travel in very tall buildings can be enhanced by faster, smoother rides, but the demands on the propulsion system require that the journey be broken into two or more partial trips. Thus a passenger wishing to go to the 100th floor might board an elevator in the lobby, exit into a "sky lobby" at the 50th floor, and board a different elevator to complete the trip to the 100th floor. One or more of these momentary pauses can delay arrival at the destination floor and increase confusion for the passenger.

Destination dispatching systems were introduced at the turn of the 21st century largely to increase building efficiency and improve traffic flow. They have mathematical advantages over traditional up/down dispatching in taller buildings. Because the passenger enters the final destination ("floor 72") on the building landing, rather than entering first an "up" call and then "floor 72" in the elevator cab, the dispatching algorithms can intelligently group passengers, route them to the appropriate car and improve the building's dispatching efficiency.

In addition, the elevator of the not-too-distant future will be able to automatically recognize individuals, call the elevator, and adapt to where they are going in the building from day to day and hour by hour.

Double-Deck and Multiple Elevators

Megatall building lobbies and their layout must accommodate both the natural flow of people and the desired outcomes of the architects and elevator designers. Double-deck elevators⁴ appeared in 1931, enabling the transport of significantly more people in a single elevator shaft (figure 5). Double-deck and super-double-deck elevators (where two cars travel together but can move up to 2 meters independently to accommodate floor height differences) may be used to move larger populations throughout buildings, but they can also be used to segment populations and ferry people to different locations in the building.

⁴ Two elevator cars attached to the same frame move together, the bottom car serving odd-numbered floors and the upper car even-numbered floors.

The introduction of multiple cars in elevator hoistways provides a dramatic change to the experience of riding an elevator, mandating changes to how elevators communicate with individuals who become more like the passengers of vertical trains.

Evacuation

Evacuation and egress of megatall buildings is of special concern. Historical practice for evacuating any building mandates the use of stairwells for safe evacuation. With increasingly tall buildings and the need to move larger numbers of people, the use of elevators for evacuation is preferable to stairs or refuge spaces. Newer versions of the International Building Code (IBC) provide incentives for using elevators in an occupant evacuation operation for any building over 420 feet tall (128 meters or roughly 38 floors; NEII 2016).

Conclusion

The Internet of Things, advances in connectivity, ubiquitous smartphones, and other new digital technologies offer enormous opportunities for interpersonal communication and improvements in myriad dimensions of urban life, including people's vertical movement in increasingly towering structures for living and working.

Megatall buildings amplify the challenges in all aspects of elevator design for both technology and passenger experience. The goal of vertical transportation systems in megatall buildings should be to provide a natural interaction with the building ecosystem for a safe, efficient, convenient, and personalized passenger experience, balancing advances in elevator and building performance to provide a delightful ride every time.

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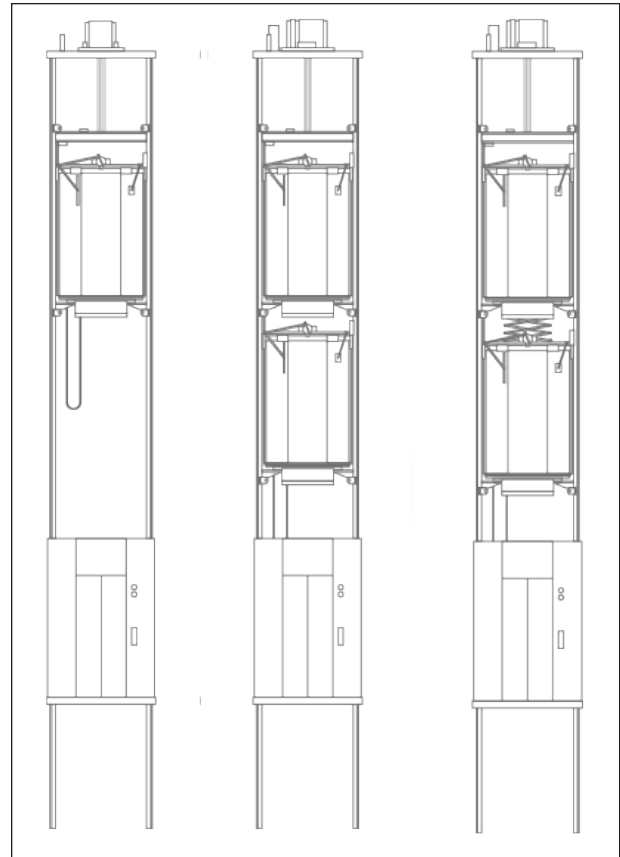


FIGURE 5 (Left) Most elevators are a single-deck configuration: one car serves all the floors for a given hoistway. (Center) High-rise buildings that require efficient flow of large numbers of people may use a double-deck car: two linked elevator cars move together, the top one stopping at the even-numbered floors and the lower one at the odd-numbered floors. (Right) Super-double-deck cars accommodate buildings with different floor heights (e.g., an entrance lobby with a higher ceiling) and heavy passenger traffic: the two cars travel together but can move up to 2 meters independently via a pantograph scissor-like device between them. Courtesy Otis Elevator Company.

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How might architecture address issues of ecology and sustainability so that buildings behave more like organisms in their built environments?

Applications of Insights from Biology and Mathematics to the Design of Material Structures



Jenny Sabin is the Arthur L. and Isabel B. Wiesenberger Associate Professor and director of the Sabin Lab in the College of Architecture, Art, and Planning at Cornell University.

Jenny E. Sabin

For the past 12 years, Jenny Sabin Studio and the Sabin Lab (based at Cornell University's College of Architecture, Art, and Planning) have engaged in work at the forefront of a new direction for 21st century architectural research practice—one that investigates the intersections of architecture and science, and applies insights and theories from biology and computation to the design of material structures that are adaptive, interactive, and resilient.¹

This paper describes multidirectional and multidisciplinary investigations shaping the future trajectories of these material innovations and technologies for architecture. The work aims to advance materials research and digital fabrication across disciplines to effect pragmatic change in the economical, ecological, and cultural production of contemporary architecture.

Background

Buildings account for nearly 40 percent of CO₂ emissions in the United States, with the remainder primarily from the industrial and transportation

Portions of this paper have been adapted from Sabin (2015).

¹ See Sabin and Jones (2017), a book on design research across disciplines through the lens of LabStudio, cofounded by Sabin, an architectural designer, and Jones, a molecular and cell biologist.

sectors.² Most contemporary sustainable approaches to reduce these emissions offer technological solutions through sanctioned rating systems such as LEED, a rating system launched by the US Green Building Council for both new construction and renovations of existing buildings. While these measures adequately address resource consumption in buildings, they do not address the systemic ecology of the built environment over the long term.

What are ways to rethink conceptual approaches to sustainability in architecture? What design research models are available to address these questions and thus shape future innovations and applications in architecture?

Recent Pioneering Research

Forward-thinking research in building materials includes that of Matthias Kohler's group at ETH Zürich.³ In the group's work with industrial robots Kohler coined the term *digital materiality*, which enables real-time feedback with material constraints through robotic digital fabrication processes. His more recently coined term, *computational contextualism*, refers to how sensors operate to integrate environmental feedback in a robust design process for the built environment.

Ronald Rael and Virginia San Fratello of Emerging Objects (www.emergingobjects.com) claim that all materials start as powder or end in dust. Their 3D-printed work integrates bits of data and particles of light to transform this dust into nonstandard objects and products for future building blocks, challenging the status quo of rapid prototyping by designing the material itself.

Researchers such as Rob Shepherd and Maria Paz Gutierrez explore architecture applications in programmable matter and materials science. Shepherd's work on actuators, sensors, displays, and additive manufacturing protocols for soft wearable robots underscores the importance of iterative complex feedback between material and mechanical design in the development of these techniques and wearables.

In parallel, the work of the BIOMS group (Bio Input onto Material Systems), directed by Gutierrez at the University of California, Berkeley, takes direct inspiration from skins found in nature. Repurposing the tex-

tile as an important architectural element, the BIOMS multifunctional membrane features an integrative sensor and actuator system that not only is designed to answer to many functions through what Gutierrez calls the "synergistic optimization of heat, light, and humidity transfer" but also is a closed loop system.⁴ It therefore does not require energy input through mechanical actuators, sensors, and a mainframe.

Biology and computation can inform the design of material structures that are adaptive, interactive, and resilient.

And through select research projects at the Institute for Computational Design and Construction at the University of Stuttgart, Achim Menges argues that technological innovation across multiple disciplines suggests that design computation is no longer limited to the binary world of the digital, but is now interfacing with the complex realm of the physical. How is this innovative and forward-thinking work leveraged and funded?

Federal Support for Innovation

In 2010 the National Science Foundation (NSF), under the Emerging Frontiers for Research Innovation (EFRI) Science in Energy and Environmental Design (SEED) umbrella, solicited proposals for transdisciplinary research teams to engage the problem of sustainability in terms of building energy use and its impacts on the built environment.

In an unprecedented occurrence, applicant teams were to include architects and, importantly, AIA licensure was not required. This opened up opportunities for both licensed architects and architectural designers engaged in practice and core academic design research to apply with collaborative teams across academia, practice, and industry. Successful project proposals required a radical departure from traditional research and design models in architecture and science, with a move toward

² See "Benefits of Green Building," <https://www.usgbc.org/articles/green-building-facts>.

³ As discussed at the Matter Design Computation Symposium: The Art of Building from Nano to Macro, Cornell AAP Preston Thomas Memorial Lecture Series, March 10–11, 2017.

⁴ As stated in an unpublished text, "Multifunctional Building Membrane: Self-Active Cells, Not Blocks," M.P. Gutierrez (BIOMS director/lead) with L.P. Lee (BioPoets director), the UC Berkeley BIOMS team (C. Irby, K. Sobolski, P. Hernandez, D. Campbell, P. Suen), and B. Kim (BioPoets team).

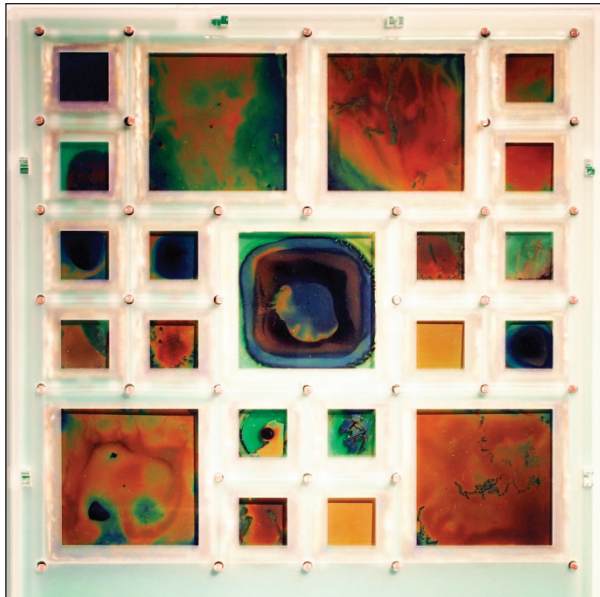


FIGURE 1 eSkin interactive prototype. Indium tin oxide (ITO)-treated glass cells with voltage-controlled nanoparticle solution, housed on a custom-built PCB substrate and controlled locally via ambient sensing nodes. © Sabin Design Lab, Cornell University; Shu Yang Group, University of Pennsylvania; Jan Van der Spiegel and Nader Engheta, University of Pennsylvania.

hybrid, transdisciplinary concepts and new models for collaboration.

Drawing on Nature to Inform Architecture

In the Sabin Lab we ask: How might architecture address issues of ecology and sustainability so that buildings behave more like organisms in their built environments? We are interested in studying the human body for design models that give rise to new ways of thinking about adaptation, change, and performance in architecture.

Our expertise and interests focus on the study of natural and artificial ecology and design, especially in the realm of nonlinear biological systems and programmable materials that use minimum energy with maximum effect. Seminal points of reference for the work include matrix biology, materials science, bioengineering, and mathematics through the filter of crafts-based media such as textiles and ceramics, with advanced digital fabrication protocols including robotic fabrication and 3D printing.

Our collaborative work looks to nature, specifically cellular biology, for an analogous deep organicity of interrelated parts, material components, and building

ecology. Generative design techniques emerge with direct references to natural systems such as cellular networking behavior and models of structural color found in the wings of the blue *Morpho* butterfly or the feathers of hummingbirds. We do not simply mimic these exquisite systems and structures, but instead focus on modeling and simulating behavior and processes through custom tools and methods that translate flexibility, adaptation, growth, and complexity into applied architectural prototypes and adaptive materials systems. Our work offers novel possibilities for redefining architecture in terms of ecological design and digital fabrication.

Research to Create Adaptive Building Skins

Since the start in fall 2010 of our NSF SEED project, Energy Minimization via Multi-Scalar Architectures: From Cell Contractility to Sensing Materials to Adaptive Building Skins, my colleague Andrew Lucia and I (as co-PI) have led a team of architects, graduate architecture students, and researchers in the investigation of biologically informed design. We use the visualization of complex datasets, digital fabrication, and the production of experimental material systems for prototype speculations of adaptive building skins, designated eSkin, at the macrobuilding scale (figure 1). The full team, led by principal investigator Shu Yang, is engaged in rigorous scientific research at the core of ecological building materials and design.

The work described here is a subset of ongoing transdisciplinary research spanning cell biology, materials science, electrical and systems engineering, and architecture. The eSkin project applies these disciplines to the design and engineering of responsive materials and sensors (Sabin et al. 2014), operating on a multiyear research plan in three phases:

1. production of catalogues of visualization and simulation tools to discover new behaviors in geometry and matter;
2. exploration of the material and ecological potentials of these tools using experimental structures and material systems created through digital fabrication; and
3. generation of scientifically based, design-oriented applications in contemporary architecture practice for adaptive building skins and material assemblies.

The goal of the eSkin project is to explore materiality from nano to macro scales based on an understanding of nonlinear, dynamic human cell behaviors

on geometrically defined substrates. To achieve this, human smooth muscle cells are plated on polymer substrates at a micro scale. Sensors and imagers are being designed and engineered to capture material and environmental changes based on manipulations by the cells, such as changes in color, transparency, polarity, and pattern (Lee et al. 2014; Li et al. 2012).

In recent eSkin prototypes, the team is exploring dynamic switching between opaque, transparent, and highly colorful components assembled in a single full-scale prototypical building façade unit (figure 1). Specifically, the team is working with structural color, where physical structures in the form of particles interact with light to produce a particular color.

Silica colloidal nanoparticles dispersed in an organic medium (solvent) are sandwiched between two transparent conductively treated indium tin oxide (ITO) pieces of glass, housed in an assembly of 3 laser-cut plexiglass frames. The light reflected from the ordered structure (depending on the particle size, distance, and reflective index contrast between the silica nanoparticles and the organic medium) is of a specific wavelength.

When a voltage is applied to the particulate solution, the surface charge of the particles is altered, changing both the distance between the particles and the color. At each intersection between the color cells, a sensor based on shifts in light intensity levels actuates voltage change between the adjacent color cells. Thus when a finger, hand, or figure passes by a sensor, a detected shift in light intensity triggers a small voltage shift across the ITO component, reorganizing the distribution of particles in the solution, ultimately affecting the reflected appearance of color from the nanoparticle solution (Sabin et al. 2014; Sabin and Jones 2017).

The relevance of this particular prototype and the eSkin project to megatall buildings is primarily in building façade design. For example, in many glass-clad megatall buildings, a glazing treatment known as ceramic frit patterning is used to minimize solar heat gain and energy loss without obstructing the occupants' view. These treatments are effective but permanently static.

We envision and have demonstrated a strategy for dynamic and adaptive building skin treatments that behave similarly to a standard frit pattern, but change throughout the day and night and in response to extreme shifts in climate and local environment. We propose to integrate eSkin in either existing building façade construction to enhance energy saving or in new megatall building façade design.

Conclusion

Through the eSkin project, insights into how cells can modify their immediate extracellular microenvironment are investigated and applied to the design and engineering of highly aesthetic passive materials, sensors, and imagers that will be integrated in responsive building skins. Such skins will enable buildings to adapt to external changes in temperature and internal solar heat gains to better regulate energy consumption and loss.

Our project addresses energy minimization at multiple scales of architecture by working toward challenging goals such as those put forward by the US DOE.⁵ We hope that our interdisciplinary work will not only redefine research and design through collaboration but also address social, environmental, and technological dimensions that ultimately enhance building design and the built environment.

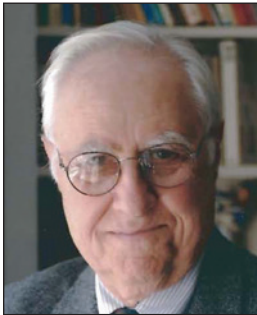
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⁵ See <https://www.energy.gov/eere/buildings/commercial-buildings-integration-0>.

Op-ed

The H-1B Visa



Samuel C. Florman (NAE) is chair (ret.) of Kreisler Borg Florman General Construction and author of books about the relationship of engineering to the general culture.

One Sunday evening this past August I turned on the TV and idly flipped from one station to the next. I landed on the start of an old favorite, *60 Minutes*, and decided to see what this CBS stalwart was up to. I knew from experience that in summer the program often revisits topics reviewed earlier in the year, and sure enough that is what I encountered.

I found myself watching a reprise of an outrageous, infuriating story that had been featured in March. Headlined “You’re Fired,” it tells the tale of American tech workers who find themselves arbitrarily replaced by foreign personnel who have been brought to the United States on special visas and who work for substantially reduced wages. Adding to the anguish of the situation, the replaced workers—in order to receive termination pay—are forced to teach the basics of their jobs to the people who will replace them. How is it possible that, six months after the original telling, this deplorable situation—the misuse of the H-1B visa—persisted?

Two years ago there was an outburst of news stories when workers at Walt Disney World sued after losing their jobs to holders of H-1B visas. Following that scandal, *The New York Times* published a scathing editorial on June 15, 2015: “Workers Betrayed by Visa Loopholes.”

More recently, in March 2017, the past, present, and newly elected presidents of IEEE-USA, an organization that represents almost 200,000 American professional engineers, posted a letter online that tells “the real

story of the H-1B visa”: “It is a tool used by companies to avoid hiring American workers, and avoid paying American wages.”¹

It also happens that Donald Trump, while running for president, announced that he would “end forever the use of the H-1B as a cheap labor program.” However, President Trump has taken no such action to improve the situation for American workers. An additional year’s worth of the specially arranged permits were issued, adding a president’s broken promise to the distasteful story.

Like many other people I’ve been shocked each time the headlines appear. Yet, frankly, like many other people I lose track of the situation, assuming each time that the evil will be overcome.

After all, the H-1B visa program was enacted in 1990 with the best of intentions: Foreign workers with special technological talents were to be admitted to the United States for designated periods of time, providing help where high-level help was needed. There was no intent to undercut the market with cheap labor from abroad, but rather to provide additional talent where talent was in short supply. Unfortunately, as time went by, adept entrepreneurs with shadowy political connections managed to bring in groups of foreigners not to fill needs and make for a flourishing multinational enterprise, but rather to sneak in crews who agreed to work for below-market salaries, thus making money for unprincipled corporations and creating unanticipated hardship for American technical workers.

Yes, I had lost track of what was happening in the scandal department, yet I was conscious of growing concerns in the US engineering community about *globalization*, competition linked to increased technical competence in other nations.

In fact, I wrote an article titled “My Profession and My Nation: A Worrisome Confrontation,” which appeared in the summer 2005 issue of *The Bent of Tau Beta Pi*. The

¹ “Commentary: The H-1B Visa Problem as IEEE-USA Sees It,” IEEE Spectrum, March 6, 2017.

thrust of the article was that, although the acceleration of technological change had added elements of uncertainty to the career path of American engineers, these hardworking and resourceful folks were doing their best to adapt to the changing world as we moved into the new millennium. However, with the rapid increase of competition from foreign nations, the climate had turned ominously inhospitable. In 2003, for example, unemployment for electrical engineers rose precipitously to 7 percent. This, plus abundant anecdotal evidence, created widespread anxiety. I recognized in my article that certain responsible members of the NAE community were reluctant to take “a protectionist approach” in dealing with foreign competition. But my instinct was “to support the American engineering societies which seek, by legitimate political means, to protect their members.”

I suppose that this article was responsible for my being one of the ten NAE members selected to serve on an ad hoc committee appointed in 2006 to organize and conduct a public workshop on engineering offshoring and to prepare a summary report of the event. The workshop was held in 2007, and the proceedings, *The Offshoring of Engineering*, issued in early 2008.

The terminology surrounding the word “offshoring” can be confusing. When Boeing has its 787 airplanes manufactured in foreign lands, that is offshoring, sometimes called outsourcing. Bringing foreign workers to the United States under special visas is not the same thing. Yet both activities present American engineers with potential competition.

The NAE committee in which I participated looked at the H-1B visas only briefly and incidentally, noting pro and con sympathies on the issue. Actually, “pro and con” would have been an appropriate subtitle for the entire report, as it presents facts and statistics and arguments from all points of view. To wit: “Plausible scenarios have been developed showing that offshoring either helps, is neutral, or hurts engineering in the United States. Only continued discussions and further studies will lead to a thorough understanding of the potential benefits and costs of offshoring” (p. 3). Jeepers. How diplomatic is it possible to be?

I’ve often heard it said that NAE members represent an elite cadre, not adequately concerned about guarding their professional associates from foreign competition. Yet I found my fellow members of the Committee on Offshore Engineering—and the all-important project staff—able, committed, congenial, and fair-minded. And surely all members of the NAE seek “to provide nonpartisan, objective guidance for decision makers on pressing issues” (to quote one recent statement of purpose).

But that August evening when I saw the *60 Minutes* reprise of an outrageous, infuriating story, I was reminded anew of the H-1B visa scandal, and surprised and very disappointed to find that the matter was still wide open and unresolved. What I’m trying to say, respectfully and earnestly, is that I’m similarly surprised and disappointed not to have found a serious discussion of the matter in the considered, expert, objective work of the National Academy of Engineering and its sister academies.

An Interview with . . .

Holly Morris, Television Reporter and News Anchor



RON LATANISION (RML): Thank you so much for taking the time to speak with us today.

HOLLY MORRIS: My pleasure. Thank you for the interest.

RML: We were absolutely delighted to learn we could talk with a television journalist who has a civil engineering degree.

MS. MORRIS: Well, it's one of my favorite things to talk about, so I'm glad you asked.

RML: How did a civil engineer become a television journalist?

MS. MORRIS: I was always really math and science oriented, and when I was going off to college and trying to decide what I wanted to major in, what I wanted to do, I had a conversation with my dad. He said, "Holly, go to college and get an education, and then be anything you want to be. You want to get an education

that's really going to teach you something but that's going to be applicable in many ways and at the same time provide you with a real profession if you want it."

So I looked at different things. I was applying to Duke and really loved chemistry so I originally thought I might go into chemical engineering. But at that time Duke had only four disciplines in its engineering school: biomedical, electrical, mechanical, and civil and environmental. When I read about the disciplines, civil and environmental engineering piqued my interest the most—that's what I thought I would enjoy working in if I chose to go the engineering route.

But I always had an interest in television news. I had talked with a news director in the Cincinnati area—that's where I'm originally from—and he said, "Holly, I can teach you how to do a newscast. You don't have to go to school for that. But what I can't teach you is how to think and how to solve problems. So you need to go to school." He basically said exactly what my dad said: get an education, learn about as much as you can because that will serve you better in a journalism career—knowing about a lot of things besides the nuts and bolts of how to do a newscast. Take courses in writing to learn how to be a good writer, and learn how to be a good thinker.

One of the things that drew me to Duke engineering specifically was that it was "philosophy" based. Their approach was, for example, 'NC State might have a 16-week course in surveying, but at Duke we want to teach you the importance of surveying, why you survey. What do you get out of it and how does that help you do your project? The technology of surveying is always going to change, so we don't need to teach you specifically how to use today's tools because by next year they'll be different. What you need to know is the philosophy behind surveying.'

That really appealed to me. I say all the time, the best thing I have is my engineering degree because it teaches me how to solve problems. I have used the process of solving a problem every day in my life since I graduated with my degree.

CAMERON FLETCHER (CHF): That's wonderful. What kinds of problems? More generally, how do you apply your engineering background in your current life, professional or otherwise?



Morris on set at Fox 5 in Washington, DC.

MS. MORRIS: Two ways. One, in engineering when you're going through your education you have to take in massive amounts of information and process it. And you have to process it quickly, to be able to pick out the things that are important, that apply and will help you find the right answer. In journalism, a lot of times you get a ton of background or other information and you have to be able to sift through it, often very quickly, and you have to be able to pick out the pieces of information that are important that you need to tell the viewer, that make the story, or that can help make your case if you're doing some kind of investigative journalism, for example. You're constantly sifting through information and picking out what's important.

The other thing I would say I use all the time, at work and on boards that I've served on and with nonprofits, is working in a group—doing group projects, determining what your strengths are, what other group members' strengths are, and how you can work together to come up with an answer to the problem. We did that a lot at Duke. With a city transportation planning project, for example, we learned that some people are better at some things than others—you have to be able to figure out your strengths and weaknesses and others' as well, and how to come up with the best group to get the best product. I use that all the time both at work and in my personal life.

RML: That's a very good description in a broad sense of what engineering is all about. It does involve team effort. Typically engineering problems involve more than one discipline—like mechanical and chemical—and there are often many facets to an issue. So learning how to work as a team is very important.

Your mentioning your professors at Duke reminds me that one of the people we have interviewed in this series is a Duke professor named Henry Petroski. Do you recognize that name?

MS. MORRIS: Yes, definitely. I didn't have a class with him, but a very good friend of mine did.

RML: Your philosophy sounds very much like his.

MS. MORRIS: I would say it was pretty much the philosophy of the school.

RML: Turning to another topic, you anchor a show called *Good Day DC*, is that right?

MS. MORRIS: Yes. I do two different shows. I anchor the regular early morning news, Fox 5 Morning News, from 4:25 to 6:00 a.m., and then I'm a cohost of a talk show, *Good Day DC*, from 9:00 to 11:00 a.m. So I work from 3:30 in the morning to about noon.

RML: I understand you won some Emmys for reporting and an Edward R. Murrow award for live reporting. Which do you prefer, live reporting or the role as an anchor? What's the distinction from your point of view and which do you prefer?

MS. MORRIS: If you're talking about doing only straight anchoring I would prefer the live reporting because I like being out in the mix. I like doing live interviews, talking with people, seeing things as they are happening, or helping to create good live TV out in the field. I really enjoy that. I also like the technical process of putting on live shows from the field, and the creative process of it too, having to try to tell a compelling story and make good TV from your surroundings. *Good Day DC* affords that.

The early morning newscast is your regular "crime and slime"—you sit and read the news that happened overnight. On *Good Day DC*, we have live guests, we get up and move around, we interact, so I get to try to create good live TV and do live interviews, to think on my toes. I like to interact with people and not just have a set format where they are telling you what to say. I did live reporting in the field for a long time before I moved into the studio, and *Good Day DC* kind of affords me

both the prestige I guess that comes with anchoring a show and the opportunity to use the skills that I really enjoy using.

CHF: Do you have some say in the topics that you comment or report on?

MS. MORRIS: Definitely. We have an editorial meeting every day, and everybody has a say, from the writers to the segment producers to the planners to the executive producer, news director, reporters, anchors, everybody. It's like a brainstorming session every morning (after our shows, obviously, because we go on so early). We reflect on what we did today and then we brainstorm about what do we want to do tomorrow? How do we want to cover it? Who do we want to talk to? That kind of thing. Everybody can be a part of that process, which is great.

If you have a thirst for knowledge and a curiosity about things, you're well suited to be an engineer.

CHF: What topics do you most like to cover?

MS. MORRIS: Everything. I always say I like to be a jack of all trades, master of none, to tell you the truth, because I think knowledge is power. I have intellectual curiosity—and my husband and I really love to see that in our son. I like to know about things—how they work, why something is happening the way it is—and I think that also naturally draws a person to engineering. Actually, it applies to everything. If you have a thirst for knowledge and a curiosity about things, you're well suited to be an engineer.

RML: Yes, I think curiosity is a major feature of science and engineering. Your background is in civil and environmental engineering, right?

MS. MORRIS: And with my knowledge of the environment has been very helpful when certain stories come along. If you've been educated in a field, you have the ability to ask informed questions. And having a scientific mind is helpful.

RML: Yes. I was thinking particularly about issues associated with the infrastructure. This is something you

understand probably better than most people in Congress do. I think there is some bipartisan agreement that our country's infrastructure needs attention, but the question is always how to pay for it. That's where things get hung up. Do you have any features or discussion of issues of that kind on *Good Day DC* or on the news that you anchor?

MS. MORRIS: Sometimes we do. The DC region is an interesting market because it's local yet at the same time national news is local news here. It's the only place in the country that's like that.

Whatever topic comes up, we always try to talk about the different angles and opinions and to get everyone represented. We may not come to any conclusion or an answer but we definitely try to have the discussion of what we think would work best with the people in the know so they can inform us.

I will say that there's been a huge shift in news reporting. It used to be the Walter Cronkites of the world just did straight reporting. Even Fox's slogan at one time was "We report, you decide." Don't get involved, just present the facts.

Now we're encouraged by our management to give our opinions and say what we think. So if someone were to ask my opinion, I would say, "Well, I agree with that" or "I don't agree with that, what about this?" This is a shift, but it does get discussion going and if people are watching maybe they have their own discussions as well.

RML: Do you have members of Congress on your show?

MS. MORRIS: Oh yes.

RML: When you talk with them about, for example, infrastructure, what is your sense of whether this Congress is likely to do anything on that, given the polarity we've seen over the past 8 or 9 years? Do you think there's any likelihood that something will move forward in terms of funding for infrastructure renewal?

MS. MORRIS: I sure hope so. I don't know if that will happen given the climate, which, unfortunately, is a bit obstructionist now. It doesn't matter what the topic is, it's just not going to happen. So I think that even though some members of Congress may believe that something needs to happen, if it doesn't fall on the side they want to be on, they're not going to go for it.

RML: Yes, that's an unfortunate characteristic that we've seen all too often for the past 10 years or so. Something has got to change though. There is a gen-

eral agreement that things like the infrastructure in this country really need attention.

I often think that a television journalist is not only reporting the news but shaping the news. I wonder whether from your perspective you see opportunities to shape the news in the following sense. Let's suppose you have taken a position that 'We need to do something about the infrastructure and I want to get members of Congress to think about this seriously.' Would you be in a position to actually try to shape the thought of members of Congress by making a very pointed argument about the infrastructure, or is that beyond what a television journalist should or could do?

MS. MORRIS: Well, I don't know if a television journalist should do that. I personally don't believe that journalists should shape the news. I don't think I should shape your opinion for you. I should give you all sides of an argument. Even if I interject my opinion, all sides should be represented and you should make your own decision.

But I think there are a lot of media that shape the news. If there's an hour-long newscast, there's only so much of a story you can tell, and newspeople make decisions every day about how they are going to tell a story, what information they're going to share, what information they're not going to share—and that very much shapes people's opinions.

I even find it frustrating as a journalist when I'm going to interview someone and I'm trying to research a topic—it can be hard to find articles that aren't slanted one way or another. I have to be on my toes to realize that this one is coming from this point of view or that one's coming from another point of view and how do I see it from all sides.

I also think we're in a bad place right now where it's 'everyone's entitled to their opinion unless you disagree with me, then I don't want to hear it.' That doesn't help anybody. And it doesn't intellectually stimulate any kind of productive discussion. That's what I was alluding to earlier—it seems our politicians have drawn lines in the sand more than ever. And the American people are hurting as a result, because things don't get done—even though both sides might agree that something needs to be addressed, just for the sake of saving face they won't. I think that's really unfortunate.

CHF: If you had the opportunity to speak with some members of Congress would you challenge them on exactly that?

MS. MORRIS: Sure, if I had the opportunity to speak with any member of Congress—or I would argue that same point with someone in the media in terms of shaping someone's opinion and that not being the whole story, being biased. I think bias comes from both sides, from the politicians and from the media.

For example, someone asked me 'If you're of a conservative nature and you feel like the media is being liberal, how do you fight that at work?' I think you have to realize the battles you can fight. You can't fight every battle.

The best thing I have is my engineering degree because it teaches me how to solve problems.

In our editorial meetings I think that's the best time to bring up another side. When we are shaping our coverage, when we say we want to talk about a topic and someone says, 'Okay, we need to have so-and-so on,' it's my responsibility to say, 'What about the other side? We also need to have this side on. Even though you guys may overwhelmingly feel this way, don't you think it's fair that this side is represented as well?' I feel like that's how I can make a difference.

RML: You are one of probably very few television journalists with a technical background to be able to respond in real time to discussions like the one you're talking about. Are you aware of other television journalists who have a technical background?

MS. MORRIS: I can't think of anyone off the top of my head but I'm sure they're out there. I do have a pretty funny story. When I was trying to get the permission to do this interview with you, my news director said to me, "Why are they asking you to do this interview? Are you an engineer?" Now, on my desk at work I have a Duke Engineering placard and other things about engineering. I said, "Yes, I graduated with a civil and environmental engineering degree from Duke." He said, "I did not know that."

CHF: You mentioned a moment ago having to do research. How much research do you do to prepare for each show or for a particular topic?



Morris boards a US Air Force Thunderbird F-16 Fighting Falcon.

MS. MORRIS: It depends. I do as much as I can. There's not always much advance notice but I always try to do as much as I can to be well informed. Our live interviews last about 4–5 minutes, not very long; I would do more research, obviously, if I was going to do a taped interview where we'd sit down and talk for 20 minutes. But I do a lot of research on whatever the topic is or whoever the person is that I'm talking to. Sometimes I want to ask questions that are thought provoking or challenging, but generally speaking I do research so that I don't ask a question that I don't already know the answer to.

RML: Who has been your most interesting interviewee? Who have you spoken to that you most enjoyed or thought was the most provocative?

MS. MORRIS: Wow. I've been doing this for a long time. I have talked with so many people that it's hard to narrow down. It's been people across the board. People get caught up on the famous people that you talk to,

but I find that the more fascinating person might be the one who has the keys to the gems at the Smithsonian, where you have to go two levels back to even get into the vault to see the gems that they don't put out, like a tiara worn by the queen of Spain in the 19th century. I think people with those kinds of jobs are fascinating.

I also remember one time sitting on the floor of the Kennedy Center, on the big red carpet with stages at either end, and chatting with pianist Marvin Hamlisch. He was such a delight and told amazing stories. He was so unpretentious and would play a little something on the piano and then talk some more. He was very down to earth. It was great.

We did an interview with Patrick O'Connell, the proprietor and chef at the Inn at Little Washington. Off camera he told fascinating stories about things that happened at the restaurant. I really enjoyed talking with him.

Once I had the honor of flying with the US Air Force Thunderbirds. I walked out onto the tarmac at Joint Base Andrews and there was my name on the side of the plane! The pilot and I flew for about an hour. That was a joy!

I also did a series for about a year and a half called *Pay It Forward*. We did stories on people who were doing just that—making a difference in this world, they're just selfless people. I felt honored to meet and spend time with every one of them.

One woman started a business giving birthday parties to kids in homeless shelters, mostly with single moms. She does custom birthday parties and makes it seem like the mom in the homeless shelter is throwing the party for the child, so the child thinks their own mom is doing it. She's providing this service for moms who can't, making a difference in these people's lives.

I felt so blessed to meet people like that. If I were a practicing engineer sitting behind a desk designing dams or bridges, I wouldn't meet those types of people day in and day out. That's one of the things I love most about my job: I meet people I would never otherwise meet. I go places I wouldn't otherwise go. That's what I liked about working live in the field: I went someplace different every day. I feel like that has been such an amazing opportunity that I have been blessed with.

CHF: But the *Pay It Forward* series has been discontinued?

MS. MORRIS: Well, I got promoted to the anchor job and, because I work from 3:30 to 12:30, I don't have time to go out and shoot stories as much as I used to.

The station still does some *Pay It Forward* stories, just not regularly.

CHF: You talked about some of the perks of being an anchor here in Washington and certainly your conversation with Marvin Hamlisch at the Kennedy Center sounds quintessentially Washingtonian. I want to know, Holly, was that you on stage with Steve Martin and Martin Short at Wolf Trap National Park for the Performing Arts on September 15?

MS. MORRIS: It was! Oh my gosh. I get to do a lot of things but this was definitely a highlight—going out on stage and giving champagne to Martin Short and Steve Martin. My husband and I got to meet them and they were delightful and funny.

It's funny because I don't really get nervous—I've been doing this for so long—but before I walked out there I was thinking, 'I cannot trip. I cannot spill this champagne.' I didn't have to even say anything, I literally just walked out and gave them two glasses of champagne. But I was a little nervous. They're comedy legends!

One day I got an email from the PR person at Wolf Trap. Over the years I've done many, many live shots at Wolf Trap and helped promote them. I was so honored that they thought of me to do this. I asked them, "Do you want me to share this with somebody—I could do one night and someone else the other night?" They said, "Nope, we want you to do both nights." That was a real treat. It was a great show. My husband and I laughed for two hours straight.

CHF: My friends and I did too. It was just wonderful.

MS. MORRIS: They said they travel for five days doing shows and then take a couple of weeks off. I asked how long they're planning on doing this show, and they said at least another five years. I'm going to tell everybody I know to go see this show because it is great.

CHF: Did you mention it on your broadcast?

MS. MORRIS: Oh yes. I mentioned it before I went to do the appearances, and they took pictures while I was there, and then of me with them, and I talked about it on the show afterward. It was definitely super fun.

RML: I understand you also like sports.

MS. MORRIS: I do love sports, especially basketball. You can't go to Duke and not like at least college basketball.



Morris as a cheerleader for the Duke University Blue Devils (1992).

RML: You've been to some pretty important games. A feature about you from the Duke School of Engineering, in August 2011, mentions that you were at that great game, the Eastern regional game that everybody remembers if they watch basketball –

MS. MORRIS: Yes. I was at the game because I was a cheerleader. I was there in a short skirt, with a big bow in my hair and pompoms. I was the only cheerleader who was an engineer. My fellow cheerleaders made fun of me because we'd be traveling for basketball and there I was sitting on the sidelines doing my problem sets. They would have papers to write but they could always get extensions. None of my professors said, "Oh yes, Holly, you can have an extension." It was more like, "No no no, your stuff is due when it's due." So I always had my homework with me when I traveled at games and I was always the only one doing it, although I would try to talk to my professors. I wrote a paper called "All Blondes Aren't Dizzy."

When the engineering school was trying to get donors or get people to come, they would have me come in and talk, or if they had young people, especially girls, that were thinking about the school, because 25 years ago not a lot of girls went into engineering and there was a push to get girls interested. There still is today, but even more so back then. So they would have me talk with kids and try to recruit girls to come to the engineering school.

*I was a cheerleader,
with a big bow in my hair
and pompoms.
I was the only cheerleader
who was an engineer.*

Truth be told, I probably would not have even gotten into Duke if I hadn't applied to the engineering school because Duke's Trinity College of Arts and Sciences is so much more competitive, at least it was back then, and I was coming from a public high school in Fairfield, Ohio.

RML: Were you born and raised in Ohio?

MS. MORRIS: Yes, a suburb of Cincinnati.

RML: And you're not a Buckeye –

MS. MORRIS: No. Two things. One, all my family (except me) went to the University of Cincinnati, and Cincinnati and Ohio State don't like each other. And two, I wanted to go away to school. Half the kids in my high school went to local schools. I was valedictorian and I wanted to go someplace where I accomplished something by getting in. I wanted them to choose me. I was very fortunate, my mom and dad said I could apply anywhere and we did the whole college tour thing and I fell in love with Duke, where, as I said earlier, I studied civil and environmental engineering.

CHF: Did you ever do any kind of engineering work, maybe in a summer job?

MS. MORRIS: No. I did internships. My dad is an architect and one summer I did an internship at his company and did some project-based work, but my

other summers I interned in television. In fact, the summer before my senior year I interned at CBS network in New York City. It was very competitive to get an internship there but one day a lady there called me and said, "I just have to talk to you. I have a stack of resumes here but I pulled yours because I want to know why in the hell an engineer wants to come work at CBS News!" I told her and she said, "You're hired."

RML: Holly, it's my observation that of all the engineering majors, the folks who choose civil engineering usually have a much broader perspective on, let's say, social needs. I guess it's because in a way you're dealing with items like the infrastructure, which obviously serves a great social purpose, or transportation or communication systems. It strikes me that there must be something in your thinking as well as in the thinking of other civil engineers that focuses more on the broader public good. So it doesn't surprise me, given all the things you've told us today, that civil engineering might have been your choice.

I also want to mention our first interview, with a poet named Richard Blanco. He's a civil engineer as well, so he's both a poet and a professional engineer—he has a PE license. He told us that he puts PE after his name as most professional engineers would do. Then he explained that when he speaks to a group of civil engineers, "I'm Richard Blanco, PE, Professional Engineer. And when I speak to a lay audience about poetry, I'm also Richard Blanco, PE—Poet Engineer."

MS. MORRIS: Oh, that's funny.

RML: I thought that was a hilarious comment. Actually, we seem to keep running into civil engineers who have a great social awareness and concern. That's the connection I'm trying to make.

MS. MORRIS: I like that. I will gladly be in that group.

CHF: It seems like your career has been evolving. Where do you see it evolving to in about 5 years?

MS. MORRIS: That's a great question. I often think about that. I'm an "old" mom; I have one son who is 5 years old and I had him when I was 40—I established my career and then had my family. So I'm very happy where I am right now and with the life that it affords me with my family. Yet, at the same time, I often think, "What more can I do? What's my next thing?" I've been at this particular station 19 years, which is a long time.

CHF: Is that unusual in that field? Is there a lot of bouncing around?

MS. MORRIS: There is, but once you get to a top 10 market a lot of people stay. I used to think I might like to go to the network but I just don't know. It would have to be the right opportunity because right now my focus is my family and being able to be very engaged and involved with my son, which my husband and I both love because we both were comparatively old when we had him. My husband went to Duke too, he's a year younger than me. We did what we wanted to do so now we never look back and think, 'Oh, gosh, I wish we had done this.'

So we're in a good place right now, but at the same time I don't want to get complacent. Of course, the thing about the news is it's always changing. Who would have ever dreamt the news cycle we had with the presidential election? The news is always new and different and that keeps it fun and interesting.

So it's a great question, but I don't know where I will be 5 years from now. I would be totally content staying right where I am. I really love my job. It's intellectually engaging, it's good for my family, and I love living in Washington, DC. I love what this area affords.

RML: It would certainly seem that you're on the pulse of the nation's news and policymaking so I can't imagine a much better place to be.

Do you ever speak to young women about engineering and your choices and the direction of your career?

MS. MORRIS: Yes, I love to talk about it. Whenever people ask, I go out and speak to schools and colleges and even professional groups. Or if someone says, "My daughter is interested in that, will you call her?," sure, absolutely.

So many people gave me great advice and helped me along the way that I think it's important to do the same. I wouldn't be where I am if someone didn't stop and take the time to have a conversation with me. And you always hope the next generation is even better, right? Isn't that the hope?

CHF: So that might be an area for further exploration and development for you.

MS. MORRIS: Yes, that's true. Actually, a friend of mine asked on behalf of a girl who was going to do a live interview. My friend said this girl's dad was willing to pay for her to have a media consultant, who cost about \$3,000. I said, "For heaven's sake, tell him not to spend his money, I'll do it for free," and I went and talked with this girl. She's in high school and has started

a nonprofit, and she was going to be interviewed on the news. I went in with the idea, 'Let me just work with you for about an hour and we'll be good.' My friend said, "You know, you just gave away this money." But I don't really need it and I would rather give the advice for free.

CHF: That's your own way of paying it forward.

MS. MORRIS: Yes, exactly.

RML: It's been interesting to me to watch the changes in the enrollment of young women at American universities, especially in engineering and science fields. It's changed dramatically. I taught at MIT for about 30 years and when I joined the faculty maybe 5 percent—or less—of our undergraduates were women. Today in both the science and engineering schools it's nearly parity—nearly half of the population of undergraduates are women. And they have a multiplicity of interests. I'm sure they would feel inspired by your story because it's a unique one, and it's been such a pleasure to have this conversation and to get an idea of how you've gotten so involved with television journalism.

Significant problems like aging infrastructure and global warming need to be addressed with answers that, realistically, only engineers can come up with.

MS. MORRIS: Thank you. I really appreciate your interest. Like I said, I love talking about it. And I've enjoyed my time with you.

RML: We do have a final question. We always ask the folks we speak with in these interviews if they have a message they would like to deliver to the members of the National Academy of Engineering and the other readers of *The Bridge*, which is circulated to members of Congress, schools of engineering throughout the country, libraries, professional organizations, and others.

MS. MORRIS: I think we are a very polarized nation right now and it's up to all of us to learn how to come

together for the greater good. And while this may seem like a leap, I think the Academy can lead the way by example. We have some significant problems that need to be solved—aging infrastructure, global warming, the list is long. These are issues that need to be addressed with answers that, realistically, only engineers can come up with. Thus we need the most brilliant minds coming together and not fighting over data that can be skewed to support certain answers but rather objectively look-

ing at all data and then brainstorming to find the best answer. If that happens, I believe real discoveries will be made and then, perhaps, others can see that selfless teamwork is truly the only winning formula.

RML: Holly, thank you so much.

CHF: Yes, thank you. It was a pleasure talking with you.

MS. MORRIS: Thank you all and have a great rest of your day.

NAE News and Notes

NAE Newsmakers

Frances H. Arnold, Dick and Barbara Dickinson Professor of Chemical Engineering and Biochemistry, California Institute of Technology, has been chosen to receive the American Institute of Chemical Engineers' inaugural **Margaret Hutchinson Rousseau Pioneer Award for Lifetime Achievement by a Woman Chemical Engineer**. The new award is presented to a woman member of AIChE who has made significant contributions to chemical engineering research or practice over the course of her career and who has helped pave the way for other women to have a greater impact in chemical engineering. Dr. Arnold received the award October 29 at AIChE's annual meeting in Minneapolis.

Zdenek P. Bazant, McCormick Institute Professor and W.P. Murphy Professor, Northwestern University, received the **ASME Medal** at the society's 2017 International Mechanical Engineering Congress and Exposition November 3–9 in Tampa. He was recognized "for developing a statistical theory of the strength and lifetime of quasi-brittle materials of random material properties, as well as verifying it with experimental evidence and demonstrating its relevance to structural safety." ASME further cited him "for formulating a kinetic energy release theory for material comminution into particles or random sizes under extreme strain rates."

Arup K. Chakraborty, Robert T. Haslam Professor of Chemical Engineering and director, Institute for

Medical Engineering and Science, Massachusetts Institute of Technology, was **elected to the National Academy of Medicine** on October 16, 2017.

The Hagler Institute for Advanced Study at Texas A&M University announced that **Vijay K. Dhir**, Distinguished Professor of Mechanical and Aerospace Engineering, University of California, Los Angeles, and **James E. Hubbard Jr.**, Glenn L. Martin Institute Professor and director, Morpheus Laboratory, University of Maryland, and director, Center for Adaptive Aerospace Vehicle Technology, National Institute of Aerospace, are among the seven members of its **2017–18 class of Faculty Fellows**. Each fellow is renowned for significantly advancing research in biology, computing, engineering, physics, physiology, or law. Dr. Dhir was acknowledged as a pioneer in fundamental and applied sciences that involve boiling as an efficient process of heat removal. Dr. Hubbard was recognized as a key pioneer in developing piezo film sensors and piezoelectric actuation systems for smart structures and materials applications.

Elazer R. Edelman, Thomas D. and Virginia W. Cabot Professor of Health Sciences and Technology, MIT/Harvard Medical School, received the **TCT Career Achievement Award** from the Cardiovascular Research Foundation at TCT 2017 in Denver on October 30. He has transformed patient care by bringing together experts from various disciplines to create

highly effective and clinically relevant solutions to medical problems, and his research has contributed to generations of life-changing devices such as bare-metal and drug-eluting stents.

Naomi J. Halas, Stanley C. Moore Professor, Rice University, has been awarded the **2018 Julius Edgar Lilienfeld Prize**, which recognizes an outstanding contribution to physics. Halas is being honored for her "pioneering research at the intersection of optics and nanoscience, and groundbreaking applications of those findings in the field of plasmonics, and for her exceptional impact communicating the excitement of scientific discoveries and their vital role in improving people's lives."

James O. Jirsa, Janet S. Cockrell Centennial Chair in Engineering, University of Texas at Austin, has been named to the **2017 class of ASCE Distinguished Members** for his contributions to the development of reinforced concrete construction through research, mentoring, and professional activities, and in particular to the fundamental understanding of bond and anchorage in concrete and their impact on seismic design.

Thomas Kailath, Hitachi America Professor of Engineering Emeritus, Stanford University, will receive the **Lifetime Achievement Award from the Marconi Society**, which is dedicated to furthering scientific achievements in communications and the Internet. This is only the sixth time in the society's

43-year history that the award has been given. Dr. Kailath was recognized for his many transformative contributions to information and system science over six decades as well as his sustained mentoring and development of new generations of scientists. The award acknowledges the wide range of his contributions to information theory, communications, filtering theory, linear systems and control, signal processing, semiconductor manufacturing, probability and statistics, linear algebra, and matrix and operator theory, which have directly or indirectly advanced modern communications technology.

Michael R. Ladisch, Distinguished Professor and director, LORRE, Purdue University, and **James R. Swartz**, professor, Departments of Chemical Engineering and Bioengineering, Stanford University, were elected **Fellows of the American Institute of Chemical Engineers**. Candidates, nominated by their peers, must have significant chemical engineering practice (generally 25 years), have demonstrated significant service to the profession, and have been a member of AIChE for at least 10 years.

Robert S. Langer, David H. Koch Institute Professor, Massachusetts Institute of Technology, is the recipient of the \$250,000 **Kabiller Prize in Nanoscience and Nanomedicine for 2017**. The prize is the largest monetary award in the world for outstanding achievement in the field of nanotechnology and its application to medicine and biology. Dr. Langer was honored for the extraordinary impact of his interdisciplinary work in the design and development of novel nanocarriers for improved small molecule drug delivery, as well as his work

on controlled delivery systems for genetically engineered therapeutic proteins, DNA, and RNA and his strong leadership.

Frances S. Ligler, Lampe Distinguished Professor of Biomedical Engineering, North Carolina State University, was honored by the university on October 9 with the **Innovator of the Year Award** for her work in biosensors and fluid control technology. Dr. Ligler has patent applications pending for two inventions: a diagnostic test that could reduce the duration of surgery for people with hyperparathyroidism and a miniature, disposable pump nicknamed the “hydraulic battery.”

Kuo-Nan Liou, Distinguished Professor of Atmospheric Sciences, University of California, Los Angeles, has been selected for the **2018 Carl-Gustaf Rossby Research Medal** for intellectual leadership and seminal contributions to improving the theory and application of atmospheric radiative transfer and its interactions with clouds and aerosols. The award, which is the highest honor bestowed by the American Meteorological Society, recognizes outstanding individuals and organizations of the weather, water, and climate community. Among his achievements, Liou discovered the depolarization principle to differentiate ice crystals from water droplets and, along with graduate students, developed a unified theory for light scattering by ice crystals and aerosols for application to remote sensing and climate research. Dr. Liou will be honored in January at the 98th annual meeting of the American Meteorological Society.

Steven B. Lipner, executive director, SAFECODE, was named a **Fellow of (ISC)²** at its 2017 Secu-

rity Congress in Austin. (ISC²) is a leading cybersecurity and IT security professional organization. The (ISC²) Fellow Award was established to honor and distinguish a select number of elite information security professionals who have made outstanding contributions throughout their careers to the information security profession.

The Institute of Electrical and Electronics Engineers' honor society is recognizing **Asad M. Madni**, independent consultant and retired president, COO, and CTO of BEI Technologies Inc., with the **Vladimir Karapetoff Outstanding Technical Achievement Award**. The award honors career accomplishments in the field of electrical and computer engineering.

Antonios G. Mikos, Louis Calder Professor of Bioengineering and Chemical and Biomolecular Engineering, Rice University, received the **James Bailey Award for 2017**. The award, sponsored by Cytos Biotechnology and named in honor of biotechnology pioneer Jay Bailey, was presented at the 2017 AIChE Annual Meeting in Minneapolis, where Mikos delivered the Bailey Award Lecture on October 31.

Leonard Pinchuk, Distinguished Research Professor of Biomedical Engineering, University of Miami, received the **2017 BioMed SA Award for Innovation in Health Care and Bioscience**. Dr. Pinchuk is the inventor or coinventor of numerous biotechnologies that have benefitted hundreds of millions of lives around the world. The award honors individuals who have put novel ideas into action with tangible, transformational results. BioMed SA is a nonprofit corporation founded in 2005 to help promote and grow San Antonio's

leading industry, health care and bioscience. The presentation was made during the annual award dinner September 13 in San Antonio.

Gintaras V. Reklaitis, Burton and Kathryn Gedge Distinguished Professor of Chemical Engineering, Purdue University, presented the **Prausnitz Lecture** November 1 at AIChE's annual meeting in Minneapolis. In his lecture, "Process Systems Engineering Contributions to Pharmaceuticals," he discussed the important role of process systems engineering in the drug component of health care—from traditional product-focused contributions to manufacturing innovations to emerging opportunities in personalized medicine.

William S. Saric, University Distinguished Professor and George Eppright '26 Chair in Engineering, Texas A&M University—College

Station, was awarded the **Takayama Medal** at the 14th International Conference on Fluid Control, Measurements, and Visualization (FLUCOME) at the University of Notre Dame. He received the medal for giving the keynote talk "Flight Experiments on Discrete Roughness Element Technology for Laminar Flow Control."

Raymond S. Stata, chair, Analog Devices Inc., was selected for the Global Semiconductor Alliance's **2017 Dr. Morris Chang Exemplary Leadership Award**, presented December 7 in Santa Clara, California. Mr. Stata is a pioneer of the semiconductor industry who is widely regarded as a visionary and is highly respected for his entrepreneurial investments. He was recognized for his longtime vision and focus on innovation at Analog Devices, as well as his abil-

ity to identify emerging technologies that could change the world and to inspire thousands of talented innovators.

John H. Sununu, president, JHS Associates Ltd., was honored with the **Lifetime Achievement Award** from the Business and Industry Association. The award was presented October 18 at the association's annual dinner in Manchester, New Hampshire.

Peter J. Winzer, research director, Nokia Bell Labs, is the recipient of the **2018 John Tyndall Award** presented by the Optical Society and the IEEE Photonics Society. Dr. Winzer is recognized for "contributions to understanding and advancing the capacity of coherent optical communication systems including advanced modulation formats and spatial multiplexing."

2017 Annual Meeting

NAE members, foreign members, and guests gathered in Washington, DC, in October for the NAE annual meeting. It began on Saturday afternoon, October 7, with an orientation session for new members in the National Academy of Sciences (NAS) Building on Constitution Avenue. That evening a dinner with the NAE Council in the NAS Building Great Hall honored the 84 new members and 22 new foreign members.

NAE chair **Gordon R. England** opened the public session on Sunday, October 8, with brief remarks encouraging the new members to be actively engaged in NAE programs and activities. President **C. D. Mote, Jr.** then delivered his annual address,

"Realizing the Vision of the Grand Challenges for Engineering Depends on the Grand Challenges Scholars Program." He noted that the theme for this year's meeting is autonomous systems, which are highly multidisciplinary, multicultural, and global, relying on communications, artificial intelligence, sensors, virtual and enhanced reality, big data, information technology, and security. The text of his address is reproduced on pages 65–69.

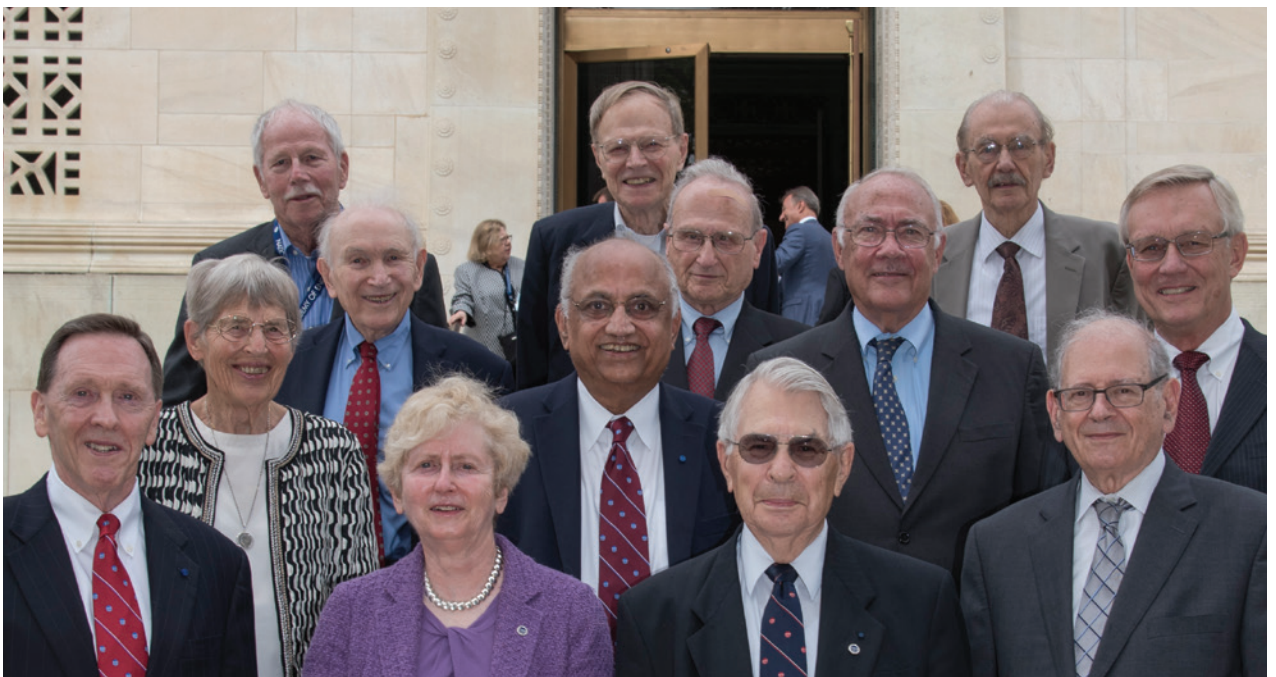
The induction of the NAE Class of 2017 followed President Mote's address, with introductions by NAE executive officer **Alton D. Romig, Jr.**

The program continued with the presentation of the 2017 Ramo

Founders and Bueche Awards. The 2017 **Simon Ramo Founders Award** was presented to **John E. Hopcroft**, professor, Computer Science Department, Cornell University, "for contributions to the advancement of computer science through pioneering publications, educational leadership, public service, and outstanding research." **Louis J. Lanzerotti**, retired Distinguished Member of the Technical Staff at Bell Laboratories, Alcatel Lucent, and Distinguished Research Professor, Department of Physics, New Jersey Institute of Technology, received the **Arthur M. Bueche Award** "for leadership in understanding the Earth's radiation environment and its effects on



Class of 2017.



Anniversary members: first row, l to r: Lance A. Davis (1992), Maxine L. Savitz (1992), William B. Morgan (1992), Byron D. Tapley (1987); second row: Johanna M.H. Levelt Sengers (1992), Venkatesh Narayanamurti (1992), E. Linn Draper, Jr. (1992), John L. Anderson (1992); third row: Henry J. Hatch (1992), Shlomo P. Neuman (1992); fourth row: Robert Liebeck (1992), William R. Schowalter (1982), Jan D. Achenbach (1982).



2017 new women members: front row, l to r: Chieko Asakawa, Dianne Chong, Darlene J. Solomon, Deb A. Niemeier; middle row: Cleopatra Cabuz, Selda Gonsel, Paula T. Hammond, Suzanne M. Vautrinot, Julia Hirschberg; back row: Ruby Leung, Kathleen C. Howell, Jennifer R. Holmgren, Ellen M. Arruda, Tsu-Jae K. Liu, Megan J. Smith.

communications and space hardware, and for contributions to public policy on space-based research.”

The **Bernard M. Gordon Prize for Innovation in Engineering and Technology Education Lecture** was delivered by **Julio M. Ottino**, dean of the McCormick School of Engineering and Applied Science at Northwestern University, where he is also Distinguished Robert R. McCormick Institute Professor, Walter P. Murphy Professor of Chemical and Biological Engineering, and professor (by courtesy) of mechanical engineering. Dr. Ottino described the underpinning of the whole-brain engineering philosophy that he has developed at Northwestern. Looking at history, he noted that the dividing lines between art, technology, and science are fairly new. Although the fields have diverged over time, he predicts that they could (and should) merge in the future and that there is much to be gained by understanding the thinking skills of each discipline.



At the forum: MiMi Aung, Clair Tomlin, Ali Velshi, C. D. Mote, Jr., James Bellingham, and Raj Rajkumar.

The whole-brain engineering approach combines the analytical, logical elements of “left-brain” thinking with the creativity, entrepreneurship, and divergent thinking

that typify “right brain” skills. Key to this strategy is combining learning and doing throughout the curriculum, rather than just in capstone courses. Using design as a founda-

tion, Northwestern has developed a number of initiatives that connect engineering with nearly all parts of the university.

After a break, Dr. Mote introduced the plenary speakers in a session on autonomy. The first speaker, Joichi Ito, a creator of diverse autonomous systems who is professor and director of the MIT Media Lab, talked about “Extended Intelligence—A System of Humans and Machines.” Patrick Lin, professor and director of the Ethics and Emerging Sciences Group at California Polytechnic State University, San Luis Obispo, brought societal and ethical perspectives to the theme, setting the stage for the next day’s forum. The day ended with a reception for members and their guests.

Monday began with the annual business session for members, during which Dr. Mote spoke about the NAE and answered questions. Next was the forum, “Autonomy on Land and Sea and in the Air and Space,” with a panel of experts discussing the value and imperative of advances in autonomous technologies. Raj Rajkumar, George Westinghouse Professor at Carnegie Mellon University, spoke about autonomy on the land; James Bellingham, director, Center for Marine Robotics, Woods Hole Oceanographic Institution, discussed autonomy at sea; Claire Tomlin, Charles A. Desoer Chair, College of Engineering, University of California, Berkeley, focused on autonomy in the air; and MiMi Aung, deputy division manager, Autonomous Systems, NASA Jet

Propulsion Laboratory, talked about autonomy in space. Ali Velshi, chief business correspondent and anchor, *NBC News* and *MSNBC Live*, moderated the discussion exploring the many questions surrounding the problems and possibilities of autonomous systems now and in the future. The videos of the forum are available on the NAE website (www.nae.edu).

On Monday afternoon, members and foreign members participated in NAE section meetings at the NAS Building and Keck Center. The meeting concluded with a reception and dinner dance at the JW Marriott. After dinner, dance music was provided by the Odyssey Band.

The next annual meeting is scheduled for September 30–October 1, 2018, in Washington, DC—*mark your calendars!*

Remarks by NAE Chair Gordon R. England



Gordon R. England

Good afternoon. It is my great honor and pleasure to welcome each of you to the 2017 NAE annual meeting. For all of our returning members it is a delight to have you with us once again, and I offer a very warm

welcome to our newly elected members. I am thankful for the opportunity to chair this most prestigious gathering and I am most grateful for President **Dan Mote**’s exemplary leadership, for the dedication and support of the officers and councilors, and for the hard work of the staff. Thanks to all!

For our new members, and as a reminder to all, the NAE’s core mission is to advise the government on engineering and technology matters. Therefore, while it is an honor to be a member, this is not an honor society. Rather, membership in the NAE carries with it a personal responsibility for members to serve, to make a difference to the nation and in the world.

To carry out this core mission the Academy largely relies on philan-

thropy. Having no base revenue and a modest endowment, philanthropy is the essential revenue source supporting fulfillment of the NAE mission. I extend my most sincere thanks to the seven members who accepted my \$100K challenge from last year’s annual meeting:

Section 2: **Fran and George Ligler**—their section challenge predates mine; in addition, they’ve lined up another member to fund a new challenge for Section 2, details to be announced soon.

Section 4: **Paul Boulous**

Section 5: **Gordon Bell, Tom Leighton, and Bob Sproull**

Section 7: **Jim Truchard**

Section 8 (NEW): **Chad Holliday** just established a challenge at the end of August.

Section 12 (NEW): **Chip Blankenship** just established a challenge in September.

As matching dollars are still coming in we'll announce the results when we have the final dollar amounts. The challenges for sections 8 and 12 will extend until the 2018 annual meeting. My thanks to everyone who participated this past year for your generous gifts of time and money to support the Academy.

This added funding is definitely helpful, but it still falls far short of the NAE's necessary resources to carry out its mission. The distinctive responsibilities of the NAE as an expert, objective, and independent advisor and as a catalyst and convener have been expanding steadily, along with the complexity and urgency of issues facing our nation. Yet every year it is a struggle to obtain critical funding to merely maintain operations and to fund a minimum number of programs.

The NAE leadership has therefore decided to embark on a major fundraising campaign. It is in the planning and organizing phase, with the kickoff scheduled for next year. Our fundraising goal will be aggressive, commensurate with the Academy's mission and needs. The campaign specifics will be announced this coming year, but key priorities have been identified: (1) ensure a vital and vibrant NAE, (2) underpin a powerful engineering enterprise for the nation—and the world, (3) provide critical leadership on emerging societal issues, and (4) support talented engineers to tackle grand challenges.

You may ask why now, and why such lofty goals?

Engineering is involved in every facet of business, government, and

our personal lives. It is pervasive in communications, energy, medicine, education, research, agriculture, defense, aerospace, law enforcement, transportation, manufacturing, finance—literally everything. Some liken this period to the late 1700s, a golden era of invention, when engineering innovation literally changed the world. Engineering is changing the world again, at an ever quickening pace, and providing longer, safer, more productive and joyful lives.

But there is also angst among citizens and politicians about the future of jobs, individual privacy, and growing inequalities in opportunities and income. It is generally accepted that engineering has made the world more interconnected. Yet as each generation is exposed to the latest technology it causes a rift with earlier generations. Those disconnects are now so pronounced that each cultural generation is getting its own name, like millennials and boomers.

As the most respected engineering organization in the country, the NAE has the responsibility to address critical issues facing engineering and work toward solutions of large societal challenges. Key to this engagement is cultivating a citizenry that understands the importance of engineering to society. Citizens need to be active and effective participants with the engineering community in shaping the nation's technological choices and future. Engineering is changing society and the NAE needs the resources to lead that change.

A centerpiece of the NAE's leadership vision is the Grand Challenges for Engineering and the Grand Challenges Scholars Program. The challenges facing

engineering today are not those of isolated locales but of the planet as a whole and all its inhabitants. A world divided by wealth and poverty, health and sickness, food and hunger cannot long remain a stable place for civilization to thrive—or survive.

The NAE has identified 14 engineering challenges that together are essential to maintain life on Earth as we know it while dramatically improving life for everyone. Programs to make progress in these 14 challenges are not funded. Although some progress is being made, the challenges are still more aspirational goals than solution focused.

Implicit in the challenges is the necessity to improve engineering education throughout the United States—and the world—so that the challenges can be met. In the United States, ensuring a highly competitive engineering workforce for security, health, prosperity, and future economic vitality is mandatory. Engineering educators, employers, professional societies, and state and local governments all have critical roles to play in preparing and strengthening the nation's engineering talent base. The NAE must serve as a catalyst to action for these stakeholders and as a resource in efforts to engage, educate, and employ the nation's talent as practicing engineers.

Funding from the campaign will put the NAE on a new trajectory—a trajectory of engagement, outreach, influence, involvement, and leadership—and it can no longer be delayed. Critical global and national issues must be tackled before they become insurmountable. Every one of our members needs to be part of making this new future a reality. Details of the campaign, and infor-

mation about how you can assist, will be provided in the coming months.

Thank you for your kind attention today. I encourage you to enjoy the annual meeting and this time

together with your colleagues and friends.

Realizing the Vision of the Grand Challenges for Engineering Depends on the Grand Challenges Scholars Program

Remarks by NAE President C. D. Mote, Jr.



C. D. Mote, Jr.

Welcome

Welcome to this year's annual meeting of the National Academy of Engineering, and a special welcome to our new members and foreign members on your induction day. I hope last night's dinner in the Great Hall was one to remember for you. That dinner experience remains permanently etched in my memory, which is one reason we do our best to create the magic of the evening for you. I also welcome our anniversary members, who received a personal invitation to this meeting on the occasion of the 25th anniversary of their election and every five-year interval thereafter. Your registration fee is waived, and your new class picture will verify for your admirers that you still pass for the 25-year-old surfer you once were. Spouses, families, and guests,

you all are most welcome too and I do hope you enjoy the program and the opportunity to meet your friends from afar.

Each year this meeting provides an opportunity for us to talk about where we are going as an academy, to highlight an engineering theme that is quickly developing in the world, and to recognize distinguished NAE award winners. The winners of the Simon Ramo Founders Award, the Arthur M. Bueche Award, and the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education will be introduced later today, so I will suppress my natural inclination to gush over them now.

The theme for this meeting, Autonomous Systems, was chosen in part because autonomy is running away with us at the moment. This engineering system theme is highly multidisciplinary, multicultural, and global, relying on communications, artificial intelligence, sensors, virtual and enhanced reality, big data, information technology, security, and so forth. While our first thoughts on autonomy may turn to the transportation domain (cars, trucks, trains, drones, ships, aircraft, space, delivery services, traffic monitoring, bicycle rentals, Uber), this is just the beginning. The prominence of autonomy has leaped to the forefront because it

moved from its creators directly to the marketplace, abruptly and powerfully jumping past all issues in between. It's coming fast, coming big, and coming globally with unavoidably disruptive consequences. It is an exemplar of what we must come to expect from large-scale engineering systems in today's connected world.

Speaking to us on autonomy this afternoon are Mr. Joichi Ito, a creator of diverse autonomous systems who is professor and director of the MIT Media Lab, and Dr. Patrick Lin, professor and director of the ethics and emerging sciences group at California Polytechnic State University, San Luis Obispo, who will bring societal and ethical perspectives to the autonomy theme. Tomorrow morning's forum, Autonomy on Land and Sea and in the Air and Space, engages a panel on the autonomy movement, each with expertise in one of the four domains. The panel will present both an integrated view of autonomy opportunities and challenges and also views focused on each area. Mr. Ali Velshi, of *NBC News*, will moderate the panel and handle questions from the audience.

The Grand Challenges for Engineering – A Defining Idea

As a brief review for later discussion, solutions to the 14 Grand Chal-

lenges for Engineering¹ are necessary goals to realize the 21st century engineering vision:

“Continuation of life on the planet, making our world more sustainable, secure, healthy, and joyful”

The challenges are all global-scale engineering system challenges whose solutions will depend on the assembly of inputs from locales around the world. They are a movement that requires the participation of people from countries and cultures that are inspired by the vision. They are arguably the clearest and most compelling explanation of engineering for students and the public alike because they illustrate both the vast span of engineering and how engineering serves people and society. And they constitute the first global vision for engineering in history.

Since their publication in 2008, the Grand Challenges have spawned both a biannual series of Global Grand Challenges Summits and a Grand Challenges Scholars Program that is preparing students to address them (and engineering system problems like them) and is spreading like wildfire.

My Takeaway Point

I would now like to open with my principal conclusion so that you

¹ The 14 Grand Challenges for Engineering (<http://engineeringchallenges.org/>): Make solar energy economical; Provide energy from fusion; Develop carbon sequestration methods; Manage the nitrogen cycle; Provide access to clean water; Restore and improve urban infrastructure; Advance health informatics; Engineer better medicines; Reverse-engineer the brain; Prevent nuclear terror; Secure cyberspace; Enhance virtual reality; Advance personalized learning; Engineer the tools of scientific discovery.

can think about it during my comments. The principal conclusion of my remarks today is:

A necessary condition for achieving the vision of the Grand Challenges for Engineering is the successful global implementation of the Grand Challenges Scholars Program.

This conclusion is driven by the following observations:

1. Students in the Grand Challenges Scholars Program are highly committed to the Grand Challenges for Engineering.
2. Students have the capability to introduce the Grand Challenges for Engineering movement in their local communities.
3. Students have the potential for leadership on the Grand Challenges for Engineering as they become professionals and volunteers.
4. The solutions to the Grand Challenges for Engineering are mandated to serve all global communities and no viable alternative for fulfilling that mandate is apparent.

I will endeavor to illustrate why engaging global engineering youth is necessary to achieving the vision of the Grand Challenges for Engineering. First, the summit.

3rd Global Grand Challenges for Engineering Summit

The 3rd Global Grand Challenges for Engineering Summit (<http://ggcs2017.org/>) was hosted jointly by the NAE, the UK Royal Academy of Engineering, and the Chinese Academy of Engineering here in Washington in July. It was the larg-

est program in NAE history, with some 900 attendees, *more than half* of whom were university students from *nearly 150 universities* in the three countries. It required multiple venues here at the National Academy of Sciences Building, George Washington University, and the US Institute of Peace.

The summit series (the 1st was in London in 2013, the 2nd in Beijing in 2015) facilitates collaborations to address the Grand Challenges, maintains the focus on the Grand Challenges vision, and, importantly, is an opportunity to inspire students and next-generation engineers to engage with the Grand Challenges for Engineering. The thematic focus of this year’s summit was sustainability, health, security, and joy of living, as well as education and public engagement. Topics included virtual reality and artificial intelligence, engineering and health care, climate change, and reverse engineering of the brain.

The program was divided between expert presentations on progress toward addressing the Grand Challenges and dynamic ways to engage student interest and participation. For the students, there were poster and business plan competitions, a podcast competition on “How to Change the World,” and extended Q&A opportunities with the speakers and sponsors. Student presentations on their experiences in the Grand Challenges Scholars Program highlighted the transformational impacts of this program on their education and, the highest accolade of all, on their choice of engineering career. I encourage you to visit the summit website² where the presentations can be viewed,

² www.engineeringchallenges.org/14500/23671/2017GCSummitMedia.aspx#tabs

and to read about the very impressive student competition winners.³

In addition, in a collaborative arrangement with NAE member **Dean Kamen**, the inaugural *FIRST Global Challenge* robotics competition (FIRST stands for “For Inspiration and Recognition of Science and Technology”; <http://first.global/fgc/>) drew high school student teams representing 157 countries in an Olympic Games–style, national team competition. The contest asked participants to take on one of the Grand Challenges: providing access to clean water.

I sincerely appreciate the most generous sponsorship of the Lockheed Martin Corporation, Boeing Company, Northrop Grumman Corporation, and Shell Oil Company that made this summit possible. We also received substantial support from NAE members **G. Wayne Clough** and **Ming Hsieh**. I cannot thank them enough for making this unique global summit a transformational success.

Grand Challenges Scholars Program: Preparing the Workforce for 21st Century Global Engineering Initiatives

Because the vision for the Grand Challenges for Engineering and their solutions are global, fulfilling that vision requires engaging people all over the world. Given the interest young engineers have expressed in the challenges, including their participation in our three summits, engaging them in the Grand Challenges Scholars Program has the best potential for galvanizing them to work on the challenges globally. This is a principal goal of the Grand Challenges Scholars Program as well

as the key to achieving the vision of the Grand Challenges for Engineering. A second, broader goal is to prepare students for the multicultural, multidisciplinary, socially conscious global engagement needed for 21st century engineering, through an educational supplement that is adaptable to any university engineering education program.

In creating a Grand Challenges Scholars Program, two questions are of primary importance, one for the students and one for the universities. For the students, what supplement to a traditional engineering program would stimulate their interest in and preparation for the vision and goals of the Grand Challenges for Engineering and problems like them? For the universities, to prepare students for global engineering initiatives, what could universities everywhere implement *easily* that concentrates on highly valued program outcomes (student competencies) while leaving the program details to each university? In this way each participating university determines which students it will admit to its program, how it will nurture each student competency, whether student achievement merits certification as a Grand Challenges Scholar, and how it will recognize its students who merit certification. Beyond agreeing to and certifying student achievement in the competencies, each university controls its own program. The National Academy of Engineering also recognizes those students who merit certification.

The Grand Challenges Scholars Program was introduced in 2009, just one year after the Grand Challenges for Engineering report, to answer brilliantly these two questions. It enhances students’ com-

petencies in five areas that are not usual elements of an engineering curriculum. The competencies are:

- **Research/creativity**—Mentored research or creative experience on a Grand Challenge-like topic; *talent competency*
- **Multicultural understanding**—Understanding of cultures, preferably through a multicultural experience, to ensure cultural acceptance of proposed solutions; *cultural competency*
- **Multidisciplinary**—Understanding of multidisciplinary engineering system solutions, developed through engagement; *multidisciplinary competency*
- **Viable business/entrepreneurship**—Understanding, preferably developed through experience, of the necessity of a viable business model for solution implementation; *business competency*
- **Social consciousness**—Understanding that solutions should serve primarily people and society, reflecting social consciousness; service learning promotes social consciousness; *social consciousness competency*

Comments on the Value of the Five Competencies

Engineering talent is the coin of the global realm. Every country, company, university, and organization I encounter seeks engineering talent, especially engineering talent needed in high-demand initiatives. Some countries recruit talent using incentives, and some take opportunities to the talent by creating centers at home and abroad, and some do both. Even China, which graduates more bachelor-degreed engineers

³ <https://www.nae.edu/MediaRoom/20095.aspx>

than the United States, European Union, and Japan combined, assertively recruits talent in engineering to meet its projected needs.

Engineering is the empowering discipline of our time, creating unprecedented advances for sustainability, health, security, and quality of life in our rapidly advancing technological environment. And this role for engineering can only increase because of advancing technological tools, opportunities for making advancements, scientific progress, societal needs, and increasing numbers of engineering systems. Engineering education today must prepare the talent needed for 21st century engineering.

Engineering education today should also be preparing engineering students for opportunities beyond those in their homeland. It should be preparing them to engage in engineering globally through foreign engineering experiences in multicultural, multidisciplinary, socially conscious initiatives. I feel strongly that in this century, all engineers from every country must be prepared for serious global engagement, even if the idea may seem remote at the moment. Change is accelerating, globalization continues to expand, and preparation for this reality will be invaluable today and inevitable subsequently.

Spread of the Grand Challenges Scholars Programs

In 2015 more than 100 US engineering deans signed a letter to President Obama committing to launch Grand Challenges Scholars Programs and prepare at least 20,000 Grand Challenges Scholars over the next decade. Last year 29 US programs were operational and 6 were under review. Now 56 US universi-

ties have operational programs or programs under review, and another 33 are exploring programs—that total increase is almost a factor of 3. Based on this strong interest, about 200 domestic programs—more than half of the engineering colleges in this country—would be a reasonable US target.

In addition, Grand Challenges Scholars Programs are operational or being formed at 19 foreign universities, where one year ago the number was just 2. The number of foreign university programs should actually exceed the US number to extend the vision of the Grand Challenges for Engineering globally.

Interest in the program among students is high, so continued growth, often driven by the students themselves, is realistic. Participation in the program by students from fields outside engineering is expected and determined by each university.

The program has also been incorporated in K–12 curriculums and in after-school programs in a dozen school districts.

Points to Note about the Grand Challenges Scholars Program

1. The Grand Challenges Scholars Program is a bridge from a national program to a global one that prepares students to undertake multicultural, multidisciplinary engineering system issues to serve people and society. The *talent competency* can link the program to areas beyond the Grand Challenges for Engineering.
2. The program's expansion has been driven largely by student interest and leadership. In a number of instances, students have created the program and then recruited a faculty mentor.

3. Participating students are the link to the young engineering communities around the world who will carry the vision of the Grand Challenges for Engineering forward globally.
4. The Grand Challenges for Engineering inspire engineering careers among students from diverse backgrounds, especially women and underrepresented minorities, who constitute *more than half* of the students in the program, although they account for *about a quarter* of the US engineering student population.

Closing Remarks: The Time of the Young Engineer

While there have been indications of this for some time, this past year has shown clearly that we are experiencing *the time of the young engineer*. As I mentioned, more than half the attendees at this year's summit were university students and the event inspired their interest in the Grand Challenges for Engineering. One sophomore, Mr. Benjamin Secino from Worcester Polytechnic Institute, wrote to me afterward and said: "the message I took from the lectures was one of fascinating progress and ongoing opportunity. Thank you for framing the Grand Challenges in a light that inspires the hundreds of students at the summit to work on long-term solutions. The [summit] is exactly what we need to inspire the current generation of engineering students to solve the problems of the world they will be graduating into." His understanding of the summits' vision and goals, and his excitement about them, are truly inspiring for this old professor.

From the beginning, the challenge of the Grand Challenges for Engineering has been fulfilling their

vision for the planet, requiring solutions that serve all people and societies. The solutions depend on the locale of their implementation—some, like access to clean water, can vary significantly within short distances. The vision of the Grand Challenges can therefore be met only by an assembly of solutions—each serving a particular locale or set of locales—that together serve all people. Each locale needs access to engineering talent to ensure

effective realization of the vision of the Grand Challenges.

As the Grand Challenges Scholars Program continues to expand nationally and globally, the bridges for solutions to grand challenges for particular locales will be built by the young engineers who participate in the program. Scholars Programs will share information, implement solutions to the Grand Challenges communicated by others, and collaborate with others to reach out around the

world. Some scholars will start companies. Many will have grand ideas. And so the assembly of talent and leadership, and the reach of assembled local solutions will piece-by-piece span more of the globe as the Grand Challenges Scholars Program continues its expansion. That is why this program is the key to fulfilling the vision of the Grand Challenges for Engineering in this century.

Stay tuned.

2017 Simon Ramo Founders Award Acceptance Remarks by John E. Hopcroft



2017 NAE Awards Committee chair Andrei C. Broder, NAE president C. D. Mote, Jr., Simon Ramo Founders Award recipient John E. Hopcroft, and NAE chair Gordon R. England.

The 2017 Simon Ramo Founders Award was presented to John E. Hopcroft, IBM Professor of Engineering and Applied Mathematics in Computer Science, Cornell University, “for contributions to the advancement of computer science through pioneering publications, educational leadership, public service, and outstanding research.”

I wish to thank all who have helped me in my career, especially my teachers in elementary school, high school, and college. Many had a profound impact on my life and that is why I became an academic. I wanted to have a similar impact on the next generation of talent. And I thank my PhD students who worked with me and helped build my career.

Also I wish to acknowledge and thank those individuals who created journals where we publish, funding agencies where we seek support, and the founders of the NAE. We often forget the work others have done to create the world we enjoy—many who do not get recognized with awards but whose work is vital.

I love teaching and research. I still teach full-time at Cornell, but also have become involved in other activities. In our lives our goals change. Early in our careers we are busy establishing a professional reputation. Later we seek other goals such as making the world a better place for many others.

Let me talk briefly about two activities that have captivated me lately.

The first involves early childhood development. When a child is born the neurons are present in the brain but not the wiring, most of which is formed in the first three years. Some is still formed in the first 20 years of a child’s life.

Imagine two children, one born in a stable upper-middle-class family

and another born in an inner city to a single mother who is on drugs. Surely the wiring will not be equivalent. If we provided free high-quality early childhood programs in inner cities, would we get our investment back 30 years later with fewer mental problems, less crime, and more productive citizens? Exploring the existing science on this issue and making it public could have a major impact on our society. The first

step was to discuss this with *Annual Reviews* and they are now working on publishing a review that will present some of the research needed to educate the public.

The second involves improving education in China. In the last 20 years the number of students in universities there grew from 6 million to 20 million and the government had to focus on increasing capacity. The number of faculty grew

from 300,000 to a million. Now they are focusing on quality. The opportunity to help them is an opportunity to improve the world for tens of millions of students.

Finally I would like to say that I appreciate this recognition but recognize that I have built on many people's contributions that allowed me to do things I wanted to do. Their important work enabled me to receive this award. Thank you.

2017 Arthur M. Bueche Award Winner Acceptance Remarks by Louis J. Lanzerotti

The 2017 Arthur M. Bueche Award was presented to Louis J. Lanzerotti, retired Distinguished Member, Technical Staff Bell Laboratories, Alcatel Lucent, and Distinguished Research Professor, New Jersey Institute of Technology, "for leadership in understanding the Earth's radiation environment and its effects on communications and space hardware, and for contributions to public policy on space-based research."

Thank you to the Awards Committee, its chair **Andrei Broder**, NAE chair **Gordon England**, and NAE president **Dan Mote**. The total surprise phone call from President Mote in early June informing me of my selection for the 2017 Arthur M. Bueche Award was exceeded only by my complete surprise in 1988 at my election to the NAE. I had absolutely no indication of my nomination in either case—demonstrating that the NAE has an amazing capacity for keeping confidentialities!

The Space Age was less than a decade old when I was offered the opportunity to join Bell Laborato-

ries after graduate school. Four Bell Labs alums are previous recipients of the Bueche Award; I am honored to be included among them.

Bell Labs fostered a collaborative technical culture whereby a vast array of practical telecommunications problems presented challenges whose solutions often led to new scientific understandings. I soon learned that the conventional linear model view of unfettered pure research leading to applications is not the only path to practical beneficial outcomes for society, or for a company. It may not even be the best path, as my Bell Labs experience taught. The necessity of finding and designing engineering solutions to problems arising in a business often fosters research that can lead to new fundamental understandings.

I was fortunate throughout my career at Bell Labs, and now at the New Jersey Institute of Technology, as well as the numerous organizations with which I have collaborated, to be surrounded and stimulated by exceptionally talented, committed, and congenial colleagues, friends, and students. I

thank them all for their friendships and collaborations.

In the mid-1840s William Henry Barlow, superintendent engineer of the Midland Railway company in England, measured "spontaneous" currents that disturbed the lines of the electrical telegraph that paralleled the rail tracks from Derby to Birmingham and Derby to Rugby. As a good engineer, and as he recorded in his publication,* he set up special measurements to understand the phenomena—and, as an engineer, to potentially effect design changes and/or mitigate around the currents. Barlow discovered that "in every case that came under [his] observation, the telegraph needles have been deflected whenever aurora has been visible." The complex processes that couple aurora to the telegraph lines were not by any measure unraveled by Barlow's engineering investigations, but the investigations led to fundamental research that continues today.

* Barlow WH. 1849. On the spontaneous electrical currents observed in the wires of the electric telegraph. *Transactions of the Royal Society* 139:61–72.



2017 NAE Awards Committee chair Andrei C. Broder, NAE president C. D. Mote, Jr., Arthur M. Bueche Award recipient Louis J. Lanzerotti, and NAE chair Gordon R. England.

I consider Barlow's investigations to be the inaugural study of space weather impacts on human technical systems.

In December 1901 Marconi's transatlantic radio feat opened a much wider bandwidth for telegraphic and later telephonic transmissions than long cables allowed. Marconi wrote that "times of bad fading [of radio signals] practically always coincide with the appearance of large sunspots and intense aurora-boreali...." He noted that these are "the same periods when cables and landlines experience difficulties or are thrown out of action."**

The lesson is that since the development of the electrical telegraph in the 1840s, space weather

** Marconi G. 1928. Communication. Proceedings of the IRE 16:40-69.

processes have affected the design, implementation, and operation of many engineered systems, at first on Earth and now in space.

As the complexities of such systems increase, as new technologies are invented, engineered, and employed, and as humans have ventured beyond Earth's surface, both human-built systems and humans themselves become more susceptible to the effects of Earth's space environment.

Arthur Clarke and John Pierce did not expect the space environment to be anything but benign when they proposed their Earth-circling communications satellites. Because of James Van Allen's discovery of intense trapped radiation around Earth, AT&T instrumented its Telstar 1 communications satellite with solid-state particle radiation

detectors to measure the environment Telstar traversed. The US Starfish Prime high-altitude nuclear test occurred on July 9, 1962, the day before Telstar's launch. Telstar's radiation detectors provided superb measurements of the artificial radiation belt produced by Starfish. And the detectors provided data for me to analyze when I arrived at Bell Labs and began work on building space weather particle detectors for NASA's geosynchronous test satellites ATS-1 and ATS-3 and two NASA satellites circling Earth in interplanetary space.

A huge solar event in August 1972 produced ground currents that overwhelmed an AT&T cable powering system in Illinois. This outage had critical implications for both civilian and national security interests, and I participated for a number of years in wide-ranging briefings. Analyses with colleagues of telecom and geophysical data from this event led to important engineering design changes in cable powering systems. These changes prevented further AT&T outages, including a near miss in the first transatlantic fiber system from a solar event in March 1989. This was an event that brought down the electrical grid in Quebec and fried a large electrical power transformer at a nuclear station in New Jersey. Bell Labs instituted a program for electrically monitoring at high precision key Atlantic and Pacific ocean cables in the context of solar and geophysical conditions.

I was asked in the mid-1970s to join the NASA Physical Sciences Committee, at the time the external advisory committee to the NASA associate administrator for science. At this time there were resource pressures on NASA science and the

opening of space research to a wider range of disciplines. The committee had many members who espoused the belief that studies of “particles and fields” in space around Earth should be finished—NASA research resources would best be spent on other scientific topics. As the principal committee person in this allegedly obsolete research field I was asked to make a presentation on the subject. My talk was equally devoted to frontier areas of space plasma physics research and the practical implications of NASA’s research in the field, past and future. A Senate staff person was in the public audience and was apparently very taken with the practical applications of this research in NASA’s program. As a consequence I was asked to testify at a Senate NASA hearing. The eventual result was the establishment of a division for this research area under the NASA associate administrator, an area encompassing both fundamental science and its applications. This unit continues today, currently named the NASA Heliophysics Division.

External advice from the National Academies since the earliest days of the civil space program had been incorporated in the Space Science Board (SSB) and Space Applications Board (SAB), as well as the Aeronautics and Space Engineering Board. When I was asked in 1988 to chair the SSB, the demarcation between applications and science was becoming somewhat fuzzy for several space research dis-

ciplines. With the SSB I embarked on nearly a yearlong examination of the roles of the SSB and SAB in the Academies. The result is the Space Studies Board of today, retaining the SSB acronym but now encompassing engineering and applications as well as science in those disciplines where such overlaps naturally occur, such as space weather.

The decision by the NASA administrator in January 2004 to forgo the final Hubble Space Telescope servicing and the installation of new instrumentation caused consternation in the wider public arena, to say nothing of uproar in the astronomy community. Under an urgent Congressional request, the National Academies formed a committee, which I was privileged to chair. The committee was to evaluate the scientific merits of continuing Hubble science should servicing and instrument upgrades occur, and to assess the engineering challenges and risks of human servicing (robotic servicing had been proposed as an alternative by the NASA administrator and was being pursued by the agency).

The committee’s intense work concluded that the fundamental science imperatives for maintenance servicing and instrument upgrades were unassailable. Hubble was not designed for robotic servicing; intensive engineering study of this option by the committee demonstrated its difficulty and complexity, if not near infeasibility. The committee concluded that human ser-

vic-ing, using the extensive NASA experience with human flight, was feasible and should be pursued.

I presented the committee’s results to the NASA administrator and several of his staff in a small NASA conference room on a quite cold, dark December 2004 evening. The administrator stopped listening after the third page, which presented the committee’s recommendations that included human servicing. Accompanying me out of the very difficult briefing where the administrator had not said more than a few words, the associate administrator for science said to me, “Lou, you have just killed Hubble.” Well, we all know now that Hubble, after human servicing and upgraded instruments, thrives today, continuing to produce astounding new scientific results.

In closing I must acknowledge that my technical and volunteer contributions in engineering and science have been possible only because of the support and love of my wife, Mary Yvonne DeWolf. For the 52-plus years of our marriage she has managed both to keep our family functioning and to pursue her parallel 40-year career as a PhD physical chemist. Her health problems in the past year have slowed her significantly, but her strong spirit and support continue.

Again, I am deeply grateful for being honored with the 2017 NAE Arthur M. Bueche Award. Thank you.

A TAX-WISE *giving* OPPORTUNITY

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If you are 70½ or older and own a traditional IRA, please consider making an IRA charitable rollover gift this year. A gift of up to \$100,000 from your IRA to the National Academy of Engineering will:

- not be included in your taxable income;
- satisfy your required minimum distribution (RMD) for the year;
- reduce your taxable income, even if you do not itemize deductions; and
- support our unparalleled, objective advice on engineering practice, education, and research.

Contact Jamie Killorin, Director of Gift Planning, at JKillorin@nas.edu or 202.236.8550 for more information about how to make your IRA rollover gift today.

Don't let end-of-year giving sneak up on you!

Time is running out to make a tax-deductible contribution in support of the NAE Independent Fund this year.

Your gift to the NAE ensures that the engineering students of today have the necessary skills to solve the Grand Challenges of the next century, while providing sustaining support for Academy programs.

If you would like to make a *simple* and *secure* gift to support the NAE, visit www.nae.edu/gift-form or call 202.334.2431 to make a gift today.

Thank you to all our members and friends who have already made a gift this year!

Highlights from the 2017 Golden Bridge Society Dinner

NAE president **C. D. Mote, Jr.** and his wife Patsy hosted an intimate dinner to celebrate the NAE's most generous members and friends at the National Museum of Women in the Arts (NMWA), the only major museum in the world dedicated solely to championing women in the arts. The museum was a fitting location for the dinner as the NAE pursues programs such as EngineerGirl and the Grand Challenges Scholars Program with the goal of preparing underrepresented groups to pursue careers in STEM-related fields and to tackle major challenges.

The Golden Bridge Society welcomed **Rob** ('14) and Lenore **Briskman**, Diana and **Michael** ('03) **King**, **Julia Phillips** ('04) and John Connor, and **Buddy Ratner** ('02)



Marci and Jim Truchard, NAE president C. D. Mote, Jr., and NAE chair Gordon England.

and Cheryl Cromer. New Einstein Society members **Jim** ('07) and Marci **Truchard** received a statuette as a token of the NAE's gratitude for their generous support. **David** ('00) and Susan **Daniel** were received as newly inducted Heritage Society members, and Dr. Mote recognized the following members of the Loyalty Society:

Tina Bueche, Virginia Bugliarello, **Bob Loewy** ('71), **Venky** ('92) and Jaya **Narayanamurti**, **Maxine Savitz** ('92), **Stan** ('91) and Evelyn **Settles**, and Mavis White. The Loyalty Society recognizes members and friends of the Academy who have given consistently for 20 years.

The night closed with Dr. Mote highlighting the tremendous suc-

cess of the third Global Grand Challenges Summit, held in July in Washington, DC, and the importance of philanthropy to the success of the NAE in addressing global challenges.

Thank you to all our members for your generous support, and thank you especially to those who are members of our giving societies.

2017 US Frontiers of Engineering Hosted by United Technologies

This year's US Frontiers of Engineering Symposium took place September 25–27 at United Technologies Research Center (UTRC) in East Hartford, Connecticut. NAE member **Robert D. Braun**, dean of engineering and applied sciences at the University of Colorado Boulder, chaired the organizing committee and the symposium. The sessions were Machines That Teach Themselves, Energy Strategies to Power Our Future, Unraveling the Complexity of the Brain, and Megatall Buildings and Other Future Places of Work. Dr. J. Michael McQuade, senior vice president for science and technology at United Technologies Corp., welcomed the group to the meeting. CEO Gregory J. Hayes provided additional remarks on the last morning of the meeting.

The first session concerned machines that, much like traditional computers, process information into useful output in a variety of applications—optimized by learning their own models. The first speaker discussed the application of interactive machine learning to self-optimizing tutoring systems in classrooms, work that advances the paradigm of reinforcement learning. This is an important foundation for

building machines that teach themselves. The next speaker focused on machine systems that use highly heterogeneous data—ranging from sensor streams and genomic data to unstructured data such as text—to make inferences that improve health care through predictive models and individualized treatment. The session concluded with a talk on machine learning qualities, such as question-answering AI, necessary for a future in which machines interact naturally with humans.

The next session addressed the question “How will we power our future?” The answer will be multifaceted and involve power generation and storage, new grid technologies, and transportation electrification. The first speaker set the stage by discussing “deep decarbonization” and what it will take to move from a carbon-rich energy system to one dominated by renewable energy. Because this will require substantial changes to how electric power systems are planned and operated, the speaker described emerging technologies that will improve real-time grid state awareness, achieve more robust control over power flows, and enable comprehensive approaches to power system optimization. This

was followed by a presentation on the merger of advanced physical models for wind energy with big data and analytics to enable the next generation of wind plants that will reduce the cost of energy. The third presenter talked about how imaging and machine learning will help design tomorrow's energy conversion devices. The final speaker described the state of the art for stationary and dynamic wireless charging of electric vehicles and the challenges in performance, cost, and safety that need to be overcome for widescale adoption of wireless power transfer systems.

The brain is a complex system consisting of micro- and macroscopic networks, and understanding it requires simultaneous measurements at multiple spatiotemporal scales. In the session Unraveling the Complexity of the Brain, speakers outlined the advances made by engineers to pave the way toward understanding the brain, treating its disorders, and enhancing its functions. The presentations described technologies to interface with the brain for recording and modulation, the neural basis of skill learning using brain-machine interfaces, new models for neuroscience, and effi-



US FOE participants.

cient feature extraction and classification methods in neural interfaces.

This decade saw the rise of a new breed of skyscrapers, megatall buildings, which are over 600 meters in height. In 2016 six megatall buildings were either completed or under way. The session on Megatall Buildings and Other Future Places of Work examined the impacts of advances in digital technologies, functional natural materials for structural innovation, and generative design and fabrication for high-rise buildings. The session began with an introduction of fundamental design transformations in the construction of megatall buildings and how their distinctive spatial characteristics influence the quality of life both in the building and in the surrounding urban environment. The next speaker addressed the role of digital interaction, physical-human interface, and intuitive behavior—spanning the disciplines of computer science and

electrical, mechanical, and systems engineering—in the transformation of vertical transportation. The third presentation centered on functional natural materials that challenge the status quo of structural systems in high-rise buildings. The final speaker described the applications of insights from biology and mathematics to the design of material structures in the form of adaptive building skins, material assemblies, and architectural interventions.

On the first afternoon of the meeting, attendees gathered in small groups for “meet and connect” sessions where they each presented a slide and then answered questions about their research or technical work. This event gave them an opportunity to get to know more about each other relatively early in the program. On the second afternoon, UTRC arranged tours of its new, state-of-the-art “innovation hub,” highlighting research in digital service for Otis Elevator, mea-

surement sciences and microscopy, human-machine interaction, machine learning, and additive and advanced manufacturing.

On the first evening Dr. David E. Parekh, corporate vice president and director of UTRC, gave the dinner speech, “Navigating Innovation’s Uncertain Course.” He compared the ability to know where innovation is heading to an autocross competition: one doesn’t know the race course, it is constantly changing, and there are others in fast pursuit. He cited the transitions from film to digital imaging and from taxis to shared transportation as examples of the difficulty of managing disruptive technological change. In addition to describing five keys to navigating innovation’s course, Dr. Parekh made the case that innovation needs to come from people with different perspectives and that great science is necessary but not sufficient for success.

Participants at this year’s meet-



Group discussion at the US FOE symposium.

ing will be eligible to apply for The Grainger Foundation Frontiers of Engineering Grants, which provide seed funding for US FOE participants at US-based institutions. The grants enable further pursuit of important new interdisciplinary research and projects stimulated by the US FOE symposia.

NAE member **Jennifer L. West**, Fitzpatrick Family University Professor of Engineering at Duke University, will take over as chair for the 2018 US FOE, which will be hosted by MIT Lincoln Laboratory in Lexington, Massachusetts, September 5–7. The 2018 topics are Quantum Computing, Resilient and Reliable Infrastructure, Theranostics: Diagnostics+Therapy,

and Technology for Humanitarian Assistance and Disaster Relief.

Funding for the 2017 US Frontiers of Engineering symposium was provided by United Technologies Corporation, The Grainger Foundation, National Science Foundation, Defense Advanced Research Projects Agency, Air Force Office of Scientific Research, DOD ASDR&E–Laboratories Office, Microsoft Research, Cummins Inc., and individual donors.

The NAE has been hosting an annual US Frontiers of Engineering meeting since 1995, and also has bilateral programs with Germany, Japan, India, China, and the European Union. The meetings bring together outstanding engineers from

industry, academia, and government at a relatively early point in their careers (participants are 30 to 45 years old), providing an opportunity for them to learn about developments, techniques, and approaches at the forefront of fields other than their own, which is increasingly important as engineering has become more interdisciplinary. The meeting also facilitates the establishment of contacts and collaboration among the next generation of engineering leaders.

For more information about the symposium series, visit www.naefrontiers.org or contact Janet Hunziker in the NAE Program Office at JHunziker@nae.edu.

New Program Office Staff



Shelley Latham

SHELLEY LATHAM is the new LinkEngineering Community Manager. She combines experience in communications and member engagement with over a dozen years as an enrichment specialist in K–12 schools. She has developed member communications strategies for the Blue Hill (ME) Public Library, several large community-supported agriculture (CSA) memberships,

and the Women's Business Brainstorm, a networking consortium of women in business and the arts. Shelley has extensive experience in print campaigns, web design, email marketing, social media outreach, press relations, development, video production, and event planning. She looks forward to working with the NAE to make LinkEngineering a trusted, go-to resource for K–12 educators that is fun, inspiring, and easy to use. She lives in Maine with her husband, three daughters, one dog, one cat, and six chickens.

DARUL WEST joined the NAE staff as senior program assistant to the NAE Awards Program, working with Deborah Young. He brings more than 10 years of experience in administrative and research work to his new position. He was previously



Darul West

a research analyst at CoStar Group, a commercial real estate research company providing research on commercial properties and transactions to its clients, and a specialist in small business banking at Chevy Chase Bank (now known as Capital One Bank). Darul can be reached at 202-334-1628 or by email at DWest@nae.edu.

In Memoriam

PETER BEARDMORE, retired director, Chemical and Physical Sciences Laboratory, Ford Motor Company, died September 17, 2017. Dr. Beardmore was elected to the NAE in 1992 for contributions to the science of engineered materials, and for outstanding leadership in the implementation of advanced automotive materials.

NICOLAAS BLOEMBERGEN, professor, University of Arizona, died September 5, 2017. Dr. Bloembergen was elected to the NAE in 1984 for outstanding contribution to quantum electronics including the level maser for communications

and the theoretical foundations for nonlinear optics.

ROBERT H. CANNON JR., Charles Lee Powell Professor and chair emeritus of Aeronautics and Astronautics, Stanford University, died August 15, 2017. Dr. Cannon was elected to the NAE in 1973 for contributions to automatic flight control, inertial guidance systems, engineering education, and organization of transportation research.

ROBERT P. CAREN, retired vice president science and engineering, Lockheed Corporation, died July 3, 2017. Dr. Caren was elected to the

NAE in 1989 for practical applications of space sciences in national security systems.

JACK V. CHRISTIANSEN, consulting engineer and independent consultant (retired), died August 16, 2017. Mr. Christiansen was elected to the NAE in 1985 for imaginative developments in design and construction of concrete shell structures of record span, particularly in areas of high seismicity.

DAVID A. DUKE, retired vice chair, Corning Incorporated, died October 9, 2017. Dr. Duke was

elected to the NAE in 1992 for outstanding contributions in research, development, and commercialization of innovative glass and ceramic products.

VON R. ESHLEMAN, professor emeritus of electrical engineering, Stanford University, died September 22, 2017. Dr. Eshleman was elected to the NAE in 1978 for contributions to the field of radar astronomy and radio science.

ABDEL-AZIZ A. FOUAD, Anson Marston Distinguished Professor of Engineering Emeritus, Iowa State University, died October 21, 2017. Dr. Fouad was elected to the NAE in 1996 for contributions to the analysis of the dynamics, stability, and control of electric power.

HARRY C. GATOS, professor emeritus of electronic materials and molecular engineering, Massachusetts Institute of Technology, died February 13, 2015. Dr. Gatos was elected to the NAE in 1983 for contributions to the advanced engineering of electronic materials and to engineering education.

PAUL E. GRAY, professor of electrical engineering emeritus and president emeritus, Massachusetts Institute of Technology, died September 18, 2017. Dr. Gray was elected to the NAE in 1975 for contributions to engineering education and to the management of educational institutions.

THOMAS L. HAMPTON, independent consultant, turbomachinery design, died October 4, 2017. Mr. Hampton was elected to the NAE in 1997 for contributions to design of large aircraft engines.

ANGEL G. JORDAN, University Professor Emeritus of Electrical and Computer Engineering and Robotics and provost emeritus, Carnegie Mellon University, died August 4, 2017. Dr. Jordan was elected to the NAE in 1986 for contributions to solid-state device research, and for innovative leadership in engineering education.

GORDON S. KINO, professor emeritus of electrical engineering, Stanford University, died October 9, 2017. Dr. Kino was elected to the NAE in 1976 for contributions to design of electron guns, microwave solid-state devices, and applications of high-frequency acoustics.

EDWIN N. LIGHTFOOT JR., Emeritus Hilledale Professor of Chemical Engineering, University of Wisconsin–Madison, died October 2, 2017. Dr. Lightfoot was elected to the NAE in 1979 for contributions to mass transfer and separation processes, and research on quantitative design procedures in biochemical and biomedical engineering.

HARRY W. MERGLER, retired Leonard Case Professor of Electrical Engineering, Case Western Reserve University, died September 29, 2017. Dr. Mergler was elected to the NAE in 1980 for teaching advanced concepts of mechanical, electrical, and computer technology, and designing sophisticated machinery.

WILLIAM F. MILLER, Herbert Hoover Professor of Public and Private Management Emeritus, Stanford University, died September 27, 2017. Dr. Miller was elected to the NAE in 1987 for research and leadership in advancing computing, and for organizational and manage-

ment contributions to outstanding engineering organizations.

E. PHILLIP MUNTZ, A.B. Freeman Professor of Engineering Emeritus, University of Southern California, died August 15, 2017. Professor Muntz was elected to the NAE in 1993 for technical and academic leadership in rarified-gas dynamics and non-equilibrium flow phenomena.

ROBERT B. ORMSBY JR., retired research advisor, Lockheed Corporation, died April 12, 2013. Mr. Ormsby was elected to the NAE in 1987 for contributions to the achievement of optimal combinations of aerodynamic performance with operational system requirements for efficient military transport aircraft.

SIMON OSTRACH, Wilbert J. Austin Distinguished Professor Emeritus of Engineering, Case Western Reserve University, died October 2, 2017. Dr. Ostrach was elected to the NAE in 1978 for research in the fields of fluid mechanics and heat transfer and contributions to undergraduate and graduate education.

ROBERT PLONSEY, Pfizer-Pratt University Professor Emeritus of Engineering, Duke University, died March 15, 2015. Dr. Plonsey was elected to the NAE in 1986 for the application of electromagnetic field theory to biology, and for distinguished leadership in the emerging profession of biomedical engineering.

GUSTAVO RIVAS-MIJARES, professor emeritus, Central University of Venezuela, died November 29, 2014. Dr. Rivas-Mijares was elected a foreign member of the NAE in 1981 for international leadership in environ-

mental health engineering, contributing to improved health of millions in tropical areas, and establishing exemplary academic excellence.

ROBERT K. RONEY, retired senior vice president, Hughes Aircraft Company, died August 4, 2017. Dr. Roney was elected to the NAE in 1990 for engineering contributions critical to the success of air-to-air missiles, lunar landing spacecraft, and communication satellites.

THOMAS L. SAATY, Distinguished University Professor, University of Pittsburgh, died August 14, 2017. Dr. Saaty was elected to the NAE in 2005 for the development and generalization of the

analytic hierarchy process and the analytic network process in multicriteria decision making.

JEAN E. SAMMET, programming language consultant and independent consultant, died May 20, 2017. Miss Sammet was elected to the NAE in 1977 for contributions to the development of high-level programming languages and leadership in computer science and engineering.

GEORGE W. SWENSON JR., professor emeritus, University of Illinois, died February 22, 2017. Dr. Swenson was elected to the NAE in 1978 for contributions to the theory and design of radio telescopes and to radio engineering.

CHARLES P. THACKER, technical fellow, Microsoft Corporation, died June 12, 2017. Mr. Thacker was elected to the NAE in 1994 for developing the first personal distributed computer system and for leadership in the design of workstations and networks.

LOTFI A. ZADEH, professor in the Graduate School and director, Berkeley Initiative in Soft Computing, University of California, Berkeley, died September 6, 2017. Dr. Zadeh was elected to the NAE in 1973 for contributions to time-varying circuits, general systems theory, and education.

Calendar of Meetings and Events

November 14	2018 Nominating Committee Meeting	February 8	NAE National Meeting Irvine, California
November 28	2017 Grand Challenges Scholars Program Annual Meeting	February 20	NAE Charles Stark Draper Prize for Engineering dinner and ceremony (by invitation only)
December 8–9	2018 Election Committee on Membership Meeting Irvine, California	February 26	NAE/NAM Regional Meeting: Engineering and Medicine— A Critical Partnership University of Miami, Coral Gables, Florida
2018			
January 1–31	2018 Election of new NAE members and foreign members	Late February– April 23	Call for new member nominations for 2019 election cycle (from current members/foreign members only)
January 1– April 1	2018 NAE awards call for nominations	March 1–31	Election of NAE officers and councillors
January 10–11	Educator Capacity Building in PreK-12 Engineering Education Committee Meeting	March 21	NAE Regional Meeting: History Anticipating the Future Chemical Heritage Foundation, Philadelphia
January 16	2019 Election Peer Committee Chair and Search Committee Chair Workshop Irvine, California	March 28	NAE Regional Meeting University of California, San Diego
February 1	EngineerGirl writing contest deadline		
February 1–2	Membership Policy Committee Meeting Irvine, California		
February 7–8	Announcement of Class of 2018 newly elected NAE members and foreign members		

All meetings are held in National Academies facilities in Washington, DC, unless otherwise noted.

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 NW—Keck 360, Washington, DC 20055. For more information or to place an order, contact NAP online at <www.nap.edu> or by phone at (888) 624-6242. (Note: Prices quoted are subject to change without notice. There is a 10 percent discount for online orders when you sign up for a MyNAP account. Add \$6.50 for shipping and handling for the first book and \$1.50 for each additional book. Add applicable sales tax or GST if you live in CA, CT, DC, FL, MD, NY, NC, VA, WI, or Canada.)

Memorial Tributes, Volume 21. This is the 21st volume in the Memorial Tributes series compiled by the National Academy of Engineering as a personal remembrance of the lives and outstanding achievements of its members and foreign members. These volumes are prepared as an enduring record of the many contributions of engineers and engineering to the benefit of humankind. In most cases, the authors of the tributes are contemporaries or colleagues who had personal knowledge of the interests and engineering accomplishments of the deceased. Through its members and foreign members, the academy carries out the responsibilities for which it was established in 1964.

Responding to the Threat of Sea Level Rise: Proceedings of a Forum. The future rate and extent of sea level rise

are highly uncertain, and responses to higher water levels will need to reflect this uncertainty. Sea level rise was a major topic of the NAE annual meeting on October 9–10, 2016, and the second day featured a forum on adaptation to it. This summary of the forum, which also incorporates material from Robert J. Nicholls' plenary presentation, outlines a rich and challenging set of problems for engineers, scientists, and those who work with them. Ebook, \$29.99.

Enhancing the Resilience of the Nation's Electricity System. Americans' safety, productivity, comfort, and convenience depend on the reliable supply of electric power. The electric power system is a complex cyberphysical system comprising a transcontinental network of millions of components that are owned, operated, and regulated by thousands of entities. Given the nature of the system, there is simply no way that outages can be completely prevented. This report calls for identifying, developing, and implementing strategies to increase the power system's resilience in the face of events that can cause large-area, long-duration outages. Resilience is about not only lessening the likelihood of outages but also limiting their scope and impact when they do occur, restoring power rapidly, and learning from these experiences to better deal with future events.

NAE members on the study committee were **Anjan Bose**, Regents Professor and Distinguished Professor of Electric Power Engineering, Washington State University; **Terry Boston**, president and CEO, Terry Boston LLC; **Elsa M. Garmire**,

Sydney E. Junkins 1887 Professor of Engineering Emerita, Dartmouth College; and **Thomas J. Overbye**, TEES Distinguished Research Professor of Electrical and Computer Engineering, Texas A&M University—College Station. Paper, \$75.00.

Software Update as a Mechanism for Resilience and Security: Proceedings of a Workshop. Software updates enable security changes and improvements, a seemingly simple concept that encompasses a variety of practices, mechanisms, policies, and technologies. To explore this landscape, the Forum on Cyber Resilience hosted a workshop with invited speakers from government, the private sector, and academia. This publication summarizes the workshop presentations and discussions.

NAE members on the organizing forum were **Fred B. Schneider** (chair), Samuel B. Eckert Professor of Computer Science, Cornell University; **David D. Clark**, senior research scientist, Computer Science and Artificial Intelligence Lab, Massachusetts Institute of Technology; **Paul C. Kocher**, president and chief scientist, Cryptography Research Inc.; **Butler W. Lampson**, technical fellow, Microsoft Research; and **Steven B. Lipner**, executive director, SAFECode. Paper, \$60.00.

Dual Use Research of Concern in the Life Sciences: Current Issues and Controversies. The potential misuse of advances in life sciences research raises concerns about national security threats. This report examines the US strategy for reducing biosecurity risks in life sciences research and considers mechanisms that would

allow researchers to manage the dissemination of research results while mitigating the potential for harm to national security.

NAE members on the study committee were **Richard A. Meserve** (cochair), Senior Of Counsel, Covington & Burling LLP, and president emeritus, Carnegie Institution for Science, and **Michael Ettenberg**, managing partner, Dolce Technologies. Paper, \$45.00.

Microbiomes of the Built Environment: A Research Agenda for Indoor Microbiology, Human Health, and Buildings.

In developed countries it is estimated that people spend 90 percent of their lives indoors. But the characteristics of “healthy” indoor environments cannot yet be defined, nor do microbial, clinical, and building researchers understand how to modify features of indoor environments (e.g., ventilation systems, the chemistry of building materials) in ways to promote health and prevent disease. The factors that affect environments in buildings, the ways building characteristics influence the composition and function of indoor microbial communities, and the ways these microbial communities relate to human health and well-being are extraordinarily complex and must be explored as a dynamic, interconnected ecosystem involving the fields of microbial biology and ecology, chemistry, building science, and human physiology. This report

reviews what is known about the intersection of these disciplines and how new tools may advance understanding of the ecosystem of built environments, indoor microbiomes, and effects on human health and well-being. It also offers a research agenda to help stakeholders make more informed decisions.

NAE member **Ronald M. Latanision**, senior fellow, Exponent Inc., was a member of the study committee. Paper, \$69.95.

Pain Management and the Opioid Epidemic: Balancing Societal and Individual Benefits and Risks of Prescription Opioid Use.

Drug overdose, largely related to the use of opioids, is the leading cause of unintentional death in the United States. The opioid crisis lies at the intersection of two public health challenges: reducing the burden of suffering from pain and containing the rising toll of harms from the use of opioid medications. The US Food and Drug Administration launched an Opioids Action Plan in early 2016 and asked the National Academies of Sciences, Engineering, and Medicine to convene a committee to update the science on pain research, care, and education; identify actions for the FDA and others to respond to the opioid epidemic; and inform FDA’s development of a method for incorporating individual and societal considerations in its risk-benefit framework for opioid approval and monitoring.

NAE member **Jonathan P. Caulkins**, professor of operations research and public policy, Heinz College, Carnegie Mellon University, was a member of the study committee. Paper, \$77.00.

Utilizing the Energy Resource Potential of DOE Lands.

The potential for energy resource development on Department of Energy–managed lands is a topic of interest for the DOE, Congress, and private developers interested in siting projects on DOE lands. The National Renewable Energy Laboratory (NREL) was tasked by the DOE Office of Legacy Management in 2013 with conducting a study to refine and build on previous analyses and to assess energy resource development potential on these lands. This report reviews and comments on the NREL study.

NAE members on the study committee were **Christine A. Ehlig-Economides**, professor and William C. Miller Endowed Chair of Petroleum Engineering, University of Houston; **William L. Fisher**, professor and Leonidas T. Barrow Chair, Jackson School of Geosciences, University of Texas at Austin; **Michael P. Ramage**, retired executive vice president, ExxonMobil Research and Engineering Company; and **Jean-Michel M. Rendu**, retired vice president, Resources and Mine Planning, Newmont Mining Corporation. Ebook, \$34.99.

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