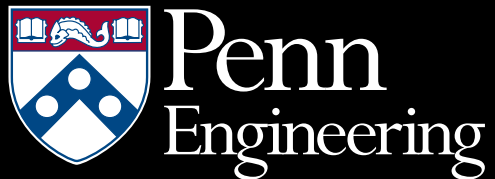
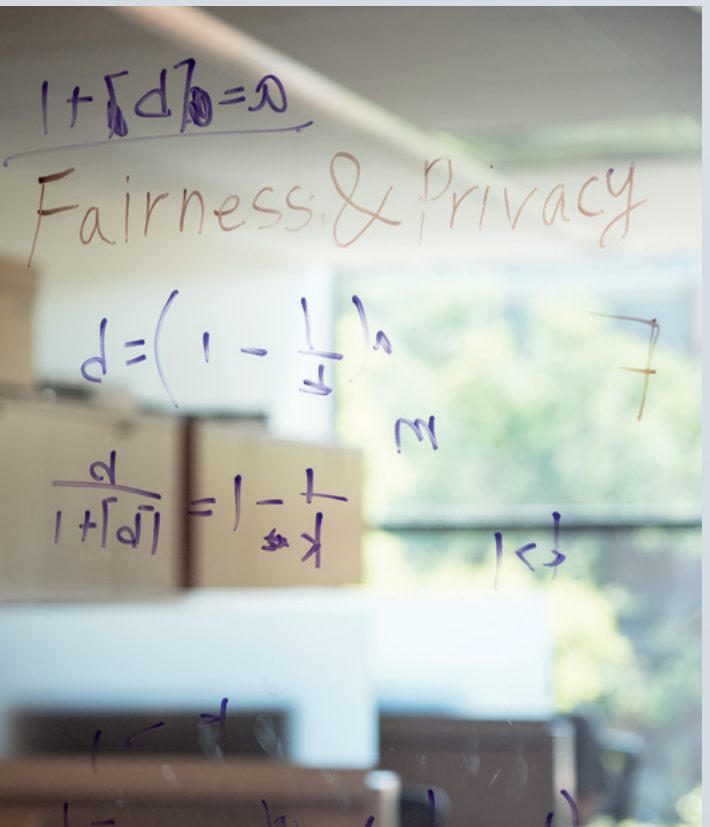


# THE WARREN CENTER

*Five-Year Report*







# Making Connections

The Warren Center's mission is to foster research and innovation in interconnected social, economic and technological systems. And like those systems, the Center itself is deeply interconnected; based in the University of Pennsylvania School of Engineering and Applied Science, the Center's faculty affiliates come from across Penn.

It is driven by the enthusiasm of these faculty affiliates, united in a common interest in the role of data and algorithms to understand networked systems. Like many who take up service in reason's empire, they are propelled by a desire to understand the world and an ambition to improve it. Within these pages you will find a summary of both the depth and breadth of the Center's activities. What the pages cannot capture are the serendipitous meetings, the lively conversations, the thrill of discovery and the joy of insight.



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# Social Norms for Algorithms

A tremendous amount of research and development in computer science is devoted to automating decision-making to improve efficiency. Automated decisions now inform whether we are approved for credit cards, receive mortgages, are shortlisted for job interviews, whether prisoners are released on bail, what advertisements we are shown, what search results we see and where police are deployed. But as increasingly consequential decisions are made by (often opaque) automated procedures, the fairness of these procedures becomes a vital concern — and one that often has legal consequences.

It has been argued that automation, by removing the human element, guarantees fairness — or at least gives us the ability to transparently evaluate fairness by examining the algorithm's code. Recent empirical research, however, demonstrates that automation is no panacea, and does not prevent "unfair" discrimination. Moreover, the reasons for this unfairness can be complex and non-obvious. This research initiative investigates how social norms, such as privacy, fairness and security, can be introduced into algorithms at the level of the code itself.

Warren Center faculty affiliates from Arts & Sciences, Engineering, Law and Wharton have been delving deeply into these issues. Their collaborations on the implications of the widespread use of algorithms have resulted in many successful publications, and workshops have provided a platform for them to share their findings. The Warren Center has helped facilitate the connections between these faculty affiliates by organizing and sponsoring events to encourage further research into the ways privacy, fairness and security are affected by technological advances.

## Publications

**Preventing Fairness Gerrymandering: Auditing and Learning for Subgroup Fairness**  
Michael Kearns, Seth Neel, Aaron Roth, Zhiwei Steven Wu  
*International Conference on Machine Learning (2018)*

**Regulating Robo Advice Across the Financial Services Industry**  
Tom Baker, Benedict G. C. Dellaert  
*Iowa Law Review (2018)*

**Algorithms: How Companies' Decisions About Data and Content Impact Consumers**  
Michael Kearns  
*Congressional Testimony (2017)*

**Regulating by Robot: Administrative Decision Making in the Machine-Learning Era**  
Cary Coglianese, David Lehr  
*Georgetown Law Journal (2017)*

**Forecasting Domestic Violence: A Machine Learning Approach to Help Inform Arraignment Decisions**  
Richard Berk, Susan B. Sorenson, Geoffrey Barnes  
*Journal of Empirical Legal Studies (2016)*

**Private Algorithms for the Protected in Social Network Search**  
Michael Kearns, Aaron Roth, Zhiwei Steven Wu, Grigory Yaroslavtsev  
*Proceedings of the National Academy of Sciences (2016)*

**The Algorithmic Foundations of Differential Privacy**  
Aaron Roth, Cynthia Dwork  
*Foundations and Trends in Theoretical Computer Science (2014)*

**Algorithmic Criminology**  
Richard Berk  
*Security Informatics (2013)*



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## Events Conferences Workshops

### Optimizing Government Workshop Series

This interdisciplinary project draws together computer scientists, data analysts, social scientists and legal scholars to tackle both current and future challenges related to applying artificial intelligence techniques in governmental and public policy settings.

### Fairness for Digital Infrastructure Workshop

The aim of this workshop was to better understand issues surrounding "unfairness" associated with the use of machine learning and automated decision-making. This included the frictions that are the cause of such inadvertent unfairness, and novel technical solutions to solve these problems.

### The Warren Center Distinguished Lecture: Cynthia Dwork, "Fairness, Awareness and Privacy"

Cynthia Dwork is a Distinguished Scientist at Microsoft Research and the Gordon McKay Professor of Computer Science at the Harvard Paulson School of Engineering. Her talk addressed fairness in classification, where the goal is to prevent discrimination against protected population subgroups in classification systems while simultaneously preserving utility for the party carrying out the classification.

### University of Pennsylvania Teach-In 2018 Talk: "The Future of Technology: Artificial Intelligence and Society: Stories from the Warren Center"

At Penn's first Teach-In since March 1969, Aaron Roth, Rakesh Vohra and Michael Kearns discussed algorithmic decision-making and questions about the fairness, privacy and efficiency of algorithms.

### Robo Advisors at the Regulatory Crossroads Workshop

This workshop brought together representatives from diverse backgrounds to explore best practices and potential regulatory principles for automated financial advice. A main goal of the workshop was to identify opportunities for research on a variety of topics including consumers' responses to this technology, automated advisor technology to provide consumer guidance and regulatory principles to support better financial decisions with automated financial advice.



# Resilience in Networked Systems

Resilience is a system's ability to retain its basic functionality in the presence of stresses and failures. Some failures are caused by risks that are exogenous, like storms and earthquakes. Other failures, particularly in networked systems, are endogenous. They are generated by the risky actions of individuals which cascade through the network. Managing such risks requires examining interactions between and across institutions. Investigating the structure of networks helps to determine which are more or less resilient to endogenous risks.

Whether it's investment bankers participating in the global economy or doctors working in a busy hospital, the more freedom any individual has to act on the network, the bigger risk of a "shock," be it a marketplace meltdown or a runaway infection. Despite widespread consequences for human health, the economy and the environment, events leading to loss of resilience — such as cascading failures in technological systems and financial networks — are rarely predictable and often irreversible. This research initiative investigates how all manner of networks can structure themselves so they are more protected against collapse from within.

The Warren Center brings together faculty affiliates from across the University to explore how to maximize the benefits of networks while minimizing the potential for real catastrophe. This includes a particular focus on increasing the resilience of a networked system to endogenous risks by increasing the resilience of the individual components, as well as anticipating how agents in the system will respond to these changes. Through workshops, conferences and invited speakers, The Warren Center supports faculty in their research and collaboration in this area.

## Publications

### Minimal Edge Addition for Network Controllability

Ximeng Chen, Sérgio Pequito, George J. Pappas, Victor M. Preciado  
*IEEE Transactions on Control of Network Systems* (2018)

### Network Design for Controllability Metrics

Cassiano O. Becker, Sérgio Pequito, George J. Pappas, Victor M. Preciado  
*Proceedings of the IEEE Conference on Decision and Control* (2017)

### Can We Make Our Financial Systems More Resilient?

Rakesh Vohra  
*zilent.org* (2017)

### The Good, the Bad, and the Differences: Better Network Diagnostics with Differential Provenance

Ang Chen, Yang Wu, Andreas Haeberlen, Wenchao Zhou, Boon Thau Loo  
*ACM Special Interest Group on Data Communications* (2016)

### Moment-based Analysis of Spreading Processes from Network Structural Information

Victor M. Preciado, Ali Jadbabaie  
*IEEE Transactions on Networking* (2013)

### Higher Standards: Regulation in the Network Age

Kevin Werbach  
*Harvard Journal of Law and Technology* (2009)

### Flocking in Fixed and Switching Networks

Herbert G. Tanner, Ali Jadbabaie, George J. Pappas  
*IEEE Transactions on Automatic Control* (2007)

### Beyond Network Neutrality

Christopher S. Yoo  
*Harvard Journal of Law and Technology* (2005)



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## Events Conferences Workshops

### Penn Workshop on Network Resilience

Co-sponsored by The Rockefeller Foundation, this workshop brought together researchers from a variety of scientific disciplines to discuss emerging frameworks to analyze resilience in complex networks in order to prevent the collapse of complex networked systems, and to guide the design of technological and economic systems to be resilient against both internal failures and environmental changes.

### Workshop on Trade & Diffusion of Shocks in Networks

Talks at this workshop included topics such as "Supply Disruptions and Optimal Network Structures," "Network Formation and Systemic Risk," and "Bottleneck Links, Essential Intermediaries and Competing Paths of Diffusion in Networks."

### Warren Center Distinguished Lecture: Éva Tardos, "Composable Mechanisms, Learning and Price of Anarchy in Auctions"

Éva Tardos, Jacob Gould Schurman Professor of Computer Science at Cornell University, is most known for her work on network-flow algorithms, approximation algorithms and quantifying the efficiency of selfish routing. In this talk, she showed how to provide robust guarantees for the performance of many simple auctions even in complex environments.

### Workshop on Networks & Systemic Risk

This interdisciplinary workshop featured speakers who have made key contributions to recent research efforts working to analyze, optimize and regulate systemic risk. Speakers included Benjamin Golub, Assistant Professor at Harvard University, and Alireza Tahbaz-Salehi, Associate Professor at Northwestern University.

### New Perspectives on Spectrum Policy Workshop

This workshop, co-sponsored by Penn's Center for Technology, Innovation and Competition, delved into topics such as wireless service competition, network pricing and spectrum resources. Talks included Christopher S. Yoo's "Revisiting the Justifications for Unlicensed Spectrum" and Michael Honig's "The Value of Shared Spectrum."



# Evolution, Emergence and the Brain

Every living thing on Earth exists in a vast, interconnected web, with one species' fate directly impacting the fortunes of its neighbors and competitors. These sorts of dynamics are replicated inside every living thing as well, with networks of individual cells pushing and pulling their way into complex biological processes, and electrical signals tracing their way through ever-shifting neural connections.

Recent advances in network science have greatly increased our understanding of the structure and function of many networked systems, ranging from transportation networks and ecosystems to biochemical and gene transcription pathways. By integrating tools from data analysis, mathematical modeling and statistical inference with network science, our faculty work to determine fundamental organizational principles of biological processes. This research initiative investigates these networked systems and how biological phenomena arise from the structure of networks, whether they are genes, cells, neurons or organisms.

This cross-disciplinary research brings together faculty with interests in molecular, cellular and organismal biology, mathematics, statistics, chemistry, engineering and more. Work in this field by Warren Center faculty affiliates includes developing mathematical tools to understand how brain networks reconfigure over time, using machine learning algorithms to infer RNA biogenesis, looking at neural modeling to understand how information is processed in the nervous system, and using computational algebraic geometry techniques for estimating evolutionary trees.

## Publications

### Positive Affect, Surprise, and Fatigue Are Correlates of Network Flexibility

Richard F. Betzel, Theodore D. Satterthwaite, Joshua I. Gold, Danielle S. Bassett  
*Scientific Reports (2017)*

### Network Neuroscience

Danielle S. Bassett, Olaf Sporns  
*Nature Neuroscience (2017)*

### Two's Company, Three (or More) is a Simplex: Algebraic-topological Tools for Understanding Higher-order Structure in Neural Data

Chad Giusti, Robert Ghrist, Danielle S. Bassett  
*Journal of Computational Neuroscience (2015)*

### RNA: State Memory and Mediator of Cellular Phenotype

Junhyong Kim, James Eberwine  
*Trends in Cell Biology (2010)*

### Damage and Fluctuations Induce Loops in Optimal Transport Networks

Eleni Katifori, Gergely J. Szöllősi, Marcelo O. Magnasco  
*Physical Review Letters (2010)*

### Small-world Brain Networks

Danielle S. Bassett, Edward T. Bullmore  
*The Neuroscientist (2010)*

### Bayesian Integration in Sensorimotor Learning

Konrad P. Körding, Daniel M. Wolpert  
*Nature (2004)*

### Computational Challenges for Integrative Genomics

Junhyong Kim, Paul Magwene  
*Genomics & Informatics (2004)*



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Indiana University

## Events Conferences Workshops

### Algebraic and Topological Methods for Biological Networks Workshop

Speakers at this two-day workshop included Warren Center faculty affiliates Robert Ghrist, Eleni Katifori and others. Talks focused on using applied topology to explore developments in neuroscience, biochemical systems and biological distribution networks.

### Warren Center Distinguished Lecture: Olaf Sporns, "Network Neuroscience"

Olaf Sporns is a Distinguished Professor, Provost Professor and the Robert H. Shaffer Chair at Indiana University Bloomington. In this lecture, he gave an overview of his work characterizing the structure of complex brain networks, with particular emphasis on studies demonstrating how the network topology of the connectome constrains and shapes its capacity to process and integrate information.

### Warren Center Distinguished Lecture: Sebastian Seung, "The Retinal Connectome: From Mapping to Explaining Brain Function"

Sebastian Seung is a Professor at the Princeton Neuroscience Institute and Department of Computer Science, and has done influential research in both computer science and neuroscience. He discussed research aimed at further improving advanced technologies used for brain mapping and classifying retinal projection neurons into cell types.

### Warren Center Speaker: Chad Giusti, "A (Very Gentle) Introduction To Algebraic Topology For (Biological) Networks"

In this talk, Chad Giusti, now an Assistant Professor at the University of Delaware, surveyed how a new field of "algebraic-topological" tools for the analysis of network structure is being used to understand higher-order structures. He focused on their applications to a wide range of networked biological systems, including evolutionary biology, plant and human circulatory systems, gene regulatory networks and human and animal neuroscience.



# Consensus and Contagion in Society

The way that information is shared — or not shared — determines what decisions can be made and how groups of people will act. With social media allowing individuals to share information more quickly and with fewer filters than ever before, the structure of these networks have an increasingly powerful role in politics, economics, health and other aspects of the public sphere. This research initiative investigates the role social influence plays when it comes to our decisions and behavior, and how developments in digital networks have affected mass media, public opinion and popular culture.

Technology determines how we interact and communicate. By analyzing the digital mark we leave, researchers work to better understand how people interact and communicate, both online and in real life, and how social media affects public behavior and social interaction. This includes predicting behavior change following exposure to persuasive messages, understanding what makes successful ideas spread and exploring how a small but committed group can potentially have the power to change the behavior of an entire population.

Faculty affiliates from The Warren Center combine strategies from network science, machine learning and computational sociology to determine how social motivations directly impact people's choices. The Warren Center supports research in this area that focuses on political psychology and mass political behavior, health communication, social status formation and more.

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## Publications

### **Persuasion, Influence, and Value: Perspectives from Communication and Social Neuroscience**

Emily Falk, Christin Scholz  
*Annual Review of Psychology* (2018)

### **Decoding the Social World: Data Science and the Unintended Consequence of Communication**

Sandra González-Bailón  
*MIT Press* (2017)

### **Social Media and the Science of Health Behavior**

Damon Centola  
*Circulation* (2013)

### **From Neural Responses to Population Behavior: Neural Focus Group Predicts Population-level Media Effects**

Emily Falk, Elliot T. Berkman, Matthew D. Lieberman  
*Psychological Science* (2012)

### **The Dynamics of Protest Recruitment Through an Online Network**

Sandra González-Bailón, Javier Borge-Holthoefer, Alejandro Rivero, Yamir Moreno  
*Scientific Reports* (2011)

### **The Spread of Behavior in an Online Social Network Experiment**

Damon Centola  
*Science* (2010)

### **Mix It Up: Popular Culture, Mass Media, and Society**

David Grazian  
*W.W. Norton & Company* (2010)

### **Online Groups and Political Discourse: Do Online Discussion Spaces Facilitate Exposure to Political Disagreement?**

Magdalena E. Wojcieszak, Diana C. Mutz  
*Journal of Communication* (2009)



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## Events Conferences Workshops

### **Warren Center Lecture: Matthew O. Jackson, "Gossip: Identifying Central Individuals in Networks and Diffusion Processes"**

Matthew O. Jackson is the William D. Eberle Professor of Economics at Stanford University. In this talk, he examined how to identify the most influential nodes in a network for initiating diffusion, and whether people are able to easily identify those people in their communities who are best at spreading information. Using theory and recent data, his goal was to see how the structure of social networks affects information transmission ranging from gossip to the diffusion of new products.

### **Annenberg Colloquium Series/Warren Center Speaker: Matthew Salganik, "Wiki Surveys: Open And Quantifiable Social Data Collection"**

Matthew Salganik is a Professor of Sociology at Princeton University, with research interests including social networks, quantitative methods, and web-based social research. In this talk, he described the methodological challenges involved in collecting and analyzing open and quantifiable social data, and presented a case study of a wiki survey created by the New York City Mayor's Office.

### **Center for Media at Risk Launch Symposium**

This new center within the Annenberg School for Communication brought together media practitioners, media scholars and media organizations to define what "media at risk" means globally in circumstances of political intimidation and what can be done to resist it. The Warren Center is an affiliate of the Center for Media at Risk.

### **Elihu Katz Colloquium Series: Damon Centola, "The Spontaneous Emergence of Conventions: An Experimental Study of Cultural Evolution"**

In this Annenberg School for Communication colloquium, Warren Center faculty affiliate Damon Centola explored social conventions and how they form. He emphasized that norms are not always desirable, functional or beneficial; that they emerge through social processes.



# Ubiquity of Data

In almost every area of intellectual inquiry, the quality and quantity of available data has exploded. In economics, we are able to track in real time pricing and demand. In astronomy, Moore's law means that the amount of data we have on our universe is doubling every year. Experimental tools in neuroscience are yielding larger and more complex data sets than ever before. Biomedical informatics draws on a huge amount of biomedical data, information and knowledge to help improve human health. This research initiative investigates the ability to manage and mine these diverse data sets and apply them to communications and public policy, statistics, economics, astrophysics, machine learning and artificial intelligence, and more.

Data is used to make decisions, understand observations, and solve problems. Connections between data can often be ambiguous, so it's crucial to develop data science tools that let us effectively link data, pose and evaluate hypotheses and ensure trustworthy results. This is a highly interdisciplinary field, with new data science techniques being evaluated using real data and hypotheses, and data integration enabling research and discovery in interconnected social, economic and technological systems.

Warren Center faculty affiliates are furthering data-related research with projects focusing on statistics in sports, internet search engine results, data and text mining on social media, urban analytics and using behavioral data to understand and forecast shopping/purchasing activities across a wide range of industries. Through conferences, seminars and workshops, The Warren Center facilitates and fosters collaborative data science research and projects across the University.

## Publications

### Principles of Data Integration

AnHai Doan, Alon Halevy, Zachary Ives  
*Elsevier (2012)*

### Customer Centricity: Focus on the Right Customers for Strategic Advantage

Peter Fader  
*Wharton Digital Press (2012)*

### Cosmological Tests of Gravity

Bhuvnesh Jain, Justin Khoury  
*Annals of Physics (2010)*

### Bioinformatics Challenges for Genome-wide Association Studies

Jason H. Moore, Folkert W. Asselbergs, Scott M. Williams  
*Bioinformatics (2010)*

### Path Data in Marketing: An Integrative Framework and Prospectus for Model Building

Sam K. Hui, Peter Fader, Eric T. Bradlow  
*Marketing Science (2009)*

### Bayesball: A Bayesian Hierarchical Model for Evaluating Fielding In Major League Baseball

Shane T. Jensen, Kenneth E. Shirley, Abraham J. Wyner  
*The Annals of Applied Statistics (2009)*

### Comparing Predictive Accuracy

Francis X. Diebold, Robert S. Mariano  
*Journal of Business & Economic Statistics (2002)*

### System and Method for Scheduling Broadcast of and Access to Video Programs and Other Data Using Customer Profiles

Frederick Herz, Lyle Ungar, Jian Zhang, David Wachob, Marcos Salganicoff  
*U.S. Patent Number 5758257 (1998)*



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## Events Conferences Workshops

### Warren Center Speaker: Michael Zargham, "On Engineering Economic Systems"

Michael Zargham, Founder and CEO of BlockScience, discussed an emerging field that blends economics, mechanism design, optimization, signal processing and control engineering, which shares a great deal with the network science area of research. The goal of this talk was to connect key concepts in these mature fields with interesting practical problems in the emerging space.

### Machine Learning for Macroeconomic Prediction and Policy Conference

This conference, co-sponsored by the Federal Reserve Bank of Philadelphia, focused on topics like DeepMacro data challenges, recession forecasting with bayesian classification and the similarities and differences between machine learning and econometrics.

### Big Data in Predictive Dynamic Econometric Modeling Conference

Themes of interest for this conference centered around scalable methods for high-dimensional dynamic econometrics, in particular high-dimensional aspects of selection, shrinkage toward sparsity or reduced rank, summarization and visualization, optimal filtering, time-varying parameters, mixed-frequency and missing data, and real-time vintage data.

### Warren Center Speaker: Andrew Connolly, "Cosmology in the Era of Big Data"

Andrew Connolly is a Professor in the Department of Astronomy at the University of Washington. In this talk, he discussed some of the practical and statistical challenges when analyzing data that, while massive in size, is intrinsically noisy and incomplete, and how this data can be applied to address questions about the detection of potentially Earth-impacting asteroids and the nature of dark energy and dark matter.



# The Warren Center

Fred and Robin Warren are the founding donors of The Warren Center. Their support in establishing The Warren Center stems from a sincere desire to increase Penn Engineering's leading role in furthering the potential of artificial intelligence and machine learning to improve human life.

Mr. Warren's interest in the technological aspects of innovation were formed at the University of Pennsylvania School of Engineering and Applied Science, where he earned a Bachelor of Science in Mechanical Engineering and Applied Mechanics. He was among the first students to co-matriculate in Engineering and Business and Finance at The Wharton School, a program that later became the Management & Technology (M&T) Program, the oldest dual-degree program at Penn.

Upon graduation, Mr. Warren became an investment banker on Wall Street. One year later, he became a venture capitalist and was a pioneer in the development of the management buyout. In 1972 he co-founded Brentwood Associates, one of the oldest and largest private equity firms in the U.S. The firm was one of the original venture backers of Apple Computer. In 1984, he initiated and led Brentwood's formal entry into the leveraged buyout business and its evolution as a private equity investment firm.

In 2000, he founded Sage Venture Partners, a "friends and family" venture capital fund. Sage focuses on early-stage, venture capital investments in telecommunications infrastructure and other web-enabled productivity enhancements.

Mr. Warren was a founding board member of the National Venture Capital Association and serves on the boards of numerous public and private companies. His devotion to supporting Penn and Penn Engineering includes years of service on the University's Board of Trustees, where he is now an emeritus member, and on Penn Engineering's Board of Overseers, where he currently serves as an advisor for the School's planning process and as an ambassador to the engineering and corporate community.

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