Written Testimony of
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Subcommittee on Technology and Innovation
Committee on Science, Space and Technology
U.S. House of Representatives

Hearing on "The Next IT Revolution? Cloud Computing Opportunities and Challenges"

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Chairman, Ranking Member, and Members of the Subcommittee, my name is Dan Reed, and I am the Corporate Vice President of Microsoft's Technology Policy Group. Thank you for the opportunity to share perspectives on the opportunities and challenges surrounding cloud computing. I appreciate the time and attention that the Committee is spending on this topic, and I commend you for advancing the dialogue on information technology and cloud computing to drive innovation.

My testimony begins by describing the advent of the cloud and its importance, as a major technology inflection point with far-reaching effects and significant economic and competitive benefits for the U.S. It summarizes some of the key technologies behind clouds, notably massive data centers and infrastructure, wired and wireless networking, and the never-before-seen scale and access to information facilitated by these technologies. It then outlines the major opportunities clouds can enable to (1) accelerate scientific discovery for research; (2) create efficiencies and innovation for businesses and governments; and (3) enrich and empower the experiences of individual citizens. Finally, it concludes by providing a set of recommendations and next steps for the Federal government and others to allow the U.S. to benefit fully from the potential of clouds and to maintain its global leadership.

I. The Advent of the Cloud and its Importance

There has been extensive coverage of clouds in the popular media, and, as with all new technologies, considerable excitement about the benefits, as well as potential confusion. As a technologist and computing researcher for nearly 30 years, working in both academia and industry, I would like to separate the technical realities from the publicity.

Reviewing the history of modern digital computing reveals a prevailing theme – the fundamental questions do not change, but the technological answers change repeatedly, for the costs, capacities and speeds of the component technologies shift by many orders of magnitude. Today's smartphone was yesterday's supercomputer, and yesterday's national archive is now a child's digital music collection.

Since the late 1940s, we have experienced a series of computing revolutions, from the mainframe to the minicomputer, from the minicomputer to the workstation and then the PC and a variety of mobile and embedded devices. Each of these technological revolutions further democratized access to computing and extended its benefits. Today, I believe we are in the midst of another such revolution, enabled by inexpensive client devices and powerful cloud computing services.

Cloud services are not a sudden, new development. Each time we share digital photos, shop online, use an email service, download and use applications, or query a search engine, we are using the cloud. Every day, the combination of wired and wireless broadband networks, PCs and smartphones, and online services hosted in remote data centers connect individuals, deliver valuable data and insights, and drive business efficiency and innovation.

Although the cloud has already reshaped our lives, a converging set of technology trends in infrastructure, devices and communications will drive a new generation of experiences that will benefit society in ways we cannot yet imagine.

First, there is the increasingly expansive and efficient infrastructure that supports clouds. Today's cloud data centers are the largest computing capabilities ever built, a consolidation of computing at a truly massive scale— ten or more times the size of a football field for a single cloud data center. To put that fact in perspective, one cloud data center today contains more computers than the entire Internet did just a small number of years ago, and it contains as much digital data as would equal a substantial fraction of the text holdings of the Library of Congress.

Each of the major cloud operators, Microsoft and its competitors, is building a worldwide network of those data centers to support a new generation of cloud services. In doing so, they are changing the way the computing industry designs and builds systems, and they are drawing on the best practices and insights of operating infrastructure at large scale to make those clouds reliable 24/7, to make them secure, and to make them energy efficient.

The second trend is the explosive growth and availability of powerful consumer devices. While many think that the power of the cloud is predominantly about the massive computing and storage capabilities in data centers, the truly transformative effect comes from the intersection and interaction of the cloud with increasingly powerful devices.

With powerful sensors, wireless communications, and new natural user interfaces, coupled with the power of the cloud, new kinds of experiences emerge – for governments, for businesses and for consumers. Remote health care monitoring and early response, smart grids and more energy efficient homes, intelligent transportation systems and reduced commuting times, and a host of other possibilities are now realizable.

Finally, our continued investments in more powerful networking are coming to fruition. Cloud services rest on the foundational investment the U.S. has made in broadband networking, both wired and wireless, because communication networks are the oxygen that lets cloud services breathe. Reliable, high bandwidth, inexpensive and ubiquitous communications connect us in a true global village, albeit one on which demands and expectations continue to rise.

II. The Opportunities Presented by Clouds

Cloud services and data management bring several exciting opportunities for greater efficiency, innovation and discovery in domains as diverse as scientific research, business and U.S. competitiveness, and citizen empowerment.

Accelerating Scientific Discovery for Research. Throughout the history of science, data has been scarce and precious. Indeed, the modern scientific method is defined by a careful cycle of hypothesis and experiment, which gathers experimental data to test the hypothesis. Today, the same technological economics that have given us inexpensive computing, digital cameras and ubiquitous data-generating sensors, allow scientists to capture data at rates and volumes heretofore unimaginable.

In almost all domains, scientists and engineers are now drowning in a sea of data. In a few short years, they have gone from scarcity to an incredible richness, necessitating a significant change in how they manage and extract insight from all this data. In astronomy, the Sloan Digital Sky Survey in January 2011 released "the largest digital color image of the sky ever made. … This terapixel image is so big and detailed that one would need 500,000 high-definition TVs to view it at its full resolution."[1] In neuroscience, the researchers working on mapping the connections among the neurons in the brain are finding that the images necessary to make that map for a cube of mouse brain a millimeter on a side require roughly one petabyte of storage; this implies that similar maps of the human brain would require millions of petabytes.[2]

In a parallel shift, many of our scientific, engineering and societal questions increasingly lie at the intersections of traditional disciplines. Consider, for example, the recent oil spill in the Gulf of Mexico. Understanding the complexities of oil distribution in water is a problem related to computational fluid dynamics, but understanding the impact of that oil on the marine ecosystem is a biological problem. In both cases, observational data are essential. To fully understand the issue, researchers from multiple disciplines—from different cultures, using different research tools—must unite to build models and analyze data from diverse sources.

Increasing data volumes and the complexity of collaboration on interdisciplinary problems are challenging our historical approaches to discovery and innovation via computing. Researchers and research institutions are ill-prepared for the large-scale computing infrastructure management challenges posed by large data sets and complex models. The cloud and associated applications and tools offer a possible solution to this challenge by letting scientists be scientists.

Computing Infrastructure.

Today researchers, graduate students, and research support staff often spend inordinate amounts of time maintaining the computing systems needed to conduct research rather than devoting their time and talents to the research itself. The cost to maintain and refresh this computing infrastructure is becoming a larger and larger burden, and the economics are unsustainable,

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[1] See Sloan Digital Sky Survey Press Release of January 11, 2011 at http://www.sdss3.org/press/20110111.largestimage.php.

[2] See New York Times article of Dec. 27, 2010 on the Human Connectome Project at http://www.nytimes.com/2010/12/28/science/28brain.html.

particularly at a time when our research universities are under financial stress. As a result, much of our research funding has focused (because of the power of computing for scientific discovery) on equipment replacement and repeated infrastructure deployments on research campuses and in laboratories. Yet at even the best funded research organizations, the majority of researchers do not have access to the computing resources they need.

Cloud computing can provide software applications, computing and data analytics, with remote access via familiar tools on PCs and smartphones. Because the cloud is professionally managed and regularly upgraded, delivering computational resources on demand, one can "pay as you go," using large-scale computational capacity and data analytics only when needed. The cost to use 10,000 processors for an hour is the same as using ten processors for 1,000 hours, but will deliver results much faster to the researcher. Organizations can buy just-in-time services to process and exploit data, rather spending scare resources on infrastructure.

Enabling Computing Tools and Applications for Research.
Much of our historical investment in high-performance computing (HPC) has brought the benefits of advanced computing to only a subset of the research community. Although powerful, and offering breakthrough capabilities for scientific and engineering discovery, these systems are often difficult to use, with steep learning curves and software tools that are unfamiliar to many. The key lesson of the consumer computing world is the importance of the "killer app" that opens computing to a new community by solving an important problem or creating a new capability. Thus, for scientists to realize fully the acceleration enabled by the power of the cloud, they also need a full complement of powerful, yet easy to use tools that are accessible via familiar PC and smartphone interfaces.

To accelerate access to cloud computing for research discovery, data analysis and multidisciplinary collaboration, Microsoft has formed a deep partnership with the National Science Foundation (NSF) to provide researchers with scalable cloud tools and services, accessible via client PCs. Thirteen research teams from across the country, whose proposals were selected via the NSF peer review process, have been awarded funding through the program and are being given access to Windows Azure[3] for a two-year period. In addition, a Microsoft support group, composed of software developers and researchers, is working directly with the teams to help them quickly integrate cloud technology and equip them with a set of common tools, applications and data collections that can be shared with the broad academic community.

The NSF awardees cover a diverse set of topics, but two examples, as described in the NSF announcement of the awards, illustrate the opportunities made possible via the NSF-Microsoft partnership[4]:

- *University of South Carolina (Jonathan Goodall) and the University of Virginia (Marty A. Humphrey) - Managing Large Watershed Systems.* Understanding hydrologic systems at the scale of large watersheds is critically important to society when faced with extreme events, such as floods and droughts, or with concern about water quality. Climate change

[3] Windows Azure is Microsoft's cloud computing platform that provides on-demand computing and storage to host, scale and manage applications and data through Microsoft data centers.
[4] See NSF Press Release of April 20, 2011 at http://www.nsf.gov/news/news_summ.jsp?cntn_id=119248.

and increasing population are further complicating watershed-scale prediction by placing additional stress and uncertainty on future hydrologic system conditions. This project advances hydrologic science and water resource management by creating and using a cloud-enabled hydrologic model and data processing workflows to examine the Savannah River Basin in the Southeastern United States. This will provide the detail and scale necessary to address fundamental research questions related to quantifying impacts of climate change on water resources.

- *Virginia Tech (Wuchun Feng) - Conducting Intensive Biocomputing*. With DNA sequencers in the life sciences able to generate a terabyte—or one trillion bytes—of data a minute, the size of DNA sequence databases will increase 10-fold every 18 months. … This research team aims to create a new generation of efficient data management and analysis software for large-scale, data-intensive scientific applications in the cloud. They will leverage recent experience in delivering reliable computing over volatile cloud resources to further enhance the robustness of data management and analysis software. They will strive to eliminate the need to assume "no hardware failures" or "very infrequent failures" as is the case with traditional HPC data-management techniques.

Working in collaboration with the NSF teams, Microsoft has continued to develop client tools to leverage the power of the cloud and empower the research community. One example is an addition to Microsoft's Excel spreadsheet software, called Excel Datascope. Directly from Excel, a user can share data with collaborators around the world, discover and download related data sets, or sample from extremely large data sets in the cloud. It also provides new data analytics and machine learning algorithms, the execution of which transparently takes place on Windows Azure.

Driving Efficiencies, Innovation and Agility for Businesses and Governments.
The business questions are the same for any young entrepreneur or seasoned CEO.[5] How do I differentiate myself from my competition? How do I best deploy my resources and maximize the return on my investment? How can I be nimble? How can I survive and flourish? To answer these questions, a leader must understand and use the disruptive economic and technological forces of his or her time.

The cloud offers small and large companies alike new opportunities to focus on core capabilities, compete in new ways in new markets, reduce capital costs, and increase efficiencies.

Before the cloud, a small company could only create an Internet presence or harness IT capabilities by buying and building IT infrastructure and hiring IT support staff, a daunting and financially challenging prospect for many. Large companies who used IT to support their businesses in new or increased ways faced the same challenges. The best and worst experience that could happen to a company was that its latest "widget" would be suddenly popularized in the media, and a deluge of queries or orders would appear in a short time frame, overwhelming its IT infrastructure.

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[5] The business-related topics in this section were also discussed in a supplemental advertorial by Dr. Daniel A. Reed in the June 2011 issue of Harvard Business Review.

Cloud computing allows elastic scaling to meet varying demand, not only in the capability but also in the management of that infrastructure. With cloud computing, companies of all sizes can be nimble and make forward bets – quickly and without large capital costs. This enables those smaller companies to compete globally with companies of all sizes, fostering an environment of innovation and growth, and enables larger companies to scale and handle burst demand, as well as experiment with new products, approaches, or business models.

Moreover, by reducing infrastructure cost and IT staff requirements, the cloud also lets companies focus on their core competencies, delivering their unique products and services to their customers. The lesson of business over time has been that success accrues to those companies who focus on their differentiated competencies, and partner with the other companies who specialize in ancillary or support services. The core competency of healthcare providers, manufacturers, retailers and others is not the management of IT infrastructure.

Further, the cloud offers unique opportunities to support global, multi-party and neutral collaborations—allowing a diverse set of scattered experts to bring their expertise to bear on a joint activity. No matter how large a business is, there is both a collaborative as well as a competitive environment with other companies or entities. The ability to share and extract insights from information by virtue of partnerships with multiple parties is a powerful concept. This is particularly important in this time of converging industry sectors—smart vehicles are bringing auto manufacturers, energy utilities, and entertainment companies together. Collaboration among these diverse parties raises a host of issues—extracting the relevant data, correlating concepts, bridging cultural and technological divides, and alleviating competitive concerns. The cloud allows all these parties to access the data in neutral ways, using shared or separate tools, and to collaborate using many different models for responsibility, data ownership, and service delivery.

Just as it does for businesses, the cloud can enable local governments and federal agencies to focus on their core competencies rather than IT and to act nimbly. Rarely is IT a government service itself; it is an enabler that allows government to conduct essential operations and deliver services. Government can take advantage of the efficiencies of the cloud to lower operating costs for government services, to deliver new services in more nimble and adaptive ways, and to partner with other organizations.

The city of Miami, for instance, is using Microsoft's Windows Azure cloud platform for Miami311, an online service that allows citizens to map some 4,500 non-emergency issues in progress. The 311 package combines multiple IT capabilities, including mapping, communications, web-based interfaces, and databases and systems for tracking calls and responses. These combined capabilities have enabled the city to transform what had been a difficult-to-use list of outstanding service requests into a visual map that shows citizens each and every "ticket" in progress in their own neighborhood and in other parts of the city.

Clouds, together with data-generating sensors, provide the mechanisms to combine and analyze large data sets in new ways and extract insights. Consider all the data that has been collected by the U.S. government, much of which has been used sparingly or by single programs or agencies. Clouds could allow data from different agencies, different levels of government, state or federal, and even the private sector to be combined and used in powerful ways. One could think about connecting historical earthquake data with local information about building codes and private information about insurance policies, or using health data to analyze populations and respond to flu outbreaks or emergencies in real time.

One example of combining input from multiple government organizations is the Pew Voting Information Project. This project is building on Microsoft's cloud to provide official, customized data for voters on relevant information, such as polling place locations, including maps and directions, along with a list of candidates and issues on the ballot. The cloud implementation allows Pew to scale up the process of merging data from multiple sources and to facilitate interfaces and tools that allow others to create and disseminate applications that build on this information.

Enriching Experiences to Empower Individual Citizens.

Today, most of us own hundreds of computers, from PCs and smartphones to embedded devices in our cars, home appliances, and entertainment systems, and we interact with thousands of others embedded in society's everyday supporting infrastructure, from health monitors to traffic sensors. The number of such devices is soon projected to exceed 50 billion, most connected to the Internet, communicating device-to-device, device-to-cloud, and cloud-to-device. The future is a seamlessly connected world of devices and services.

Today, we can already see glimpses of this. While in transit, I can use my smartphone to connect to Microsoft's Bing search engine and ask a question. With the location from the smartphone's GPS, speech-to-text translation and location-specific data, Bing can return an answer—the nearest movie theater is four blocks away; click here for directions and to purchase a ticket. Such tailored, contextually appropriate experiences are only possible through the combination of devices, sensors and diverse cloud services.

In the future, my smartphone and the cloud might well cooperate with my plug-in hybrid car. The appointments in my smartphone's calendar, together with traffic data and my car's continuously monitored energy usage will allow the cloud to plan my driving route and charging plan, even alerting the utility as to the expected energy load from all cars being charged. While this might sound like science fiction, scenarios like this are being explored today, enabled by the combination of devices, networks and clouds.

III. The Next Steps: Recommendations for Moving Forward

To realize the opportunities that the cloud creates for research, business, government, and individuals, there are specific steps the U.S. government should consider in four areas.

1. Deploy the Cloud for Government and Research Use. The U.S. government, including research agencies, should be at the forefront of deploying the cloud in innovative and effective ways.

The federal government is actively exploring and implementing cloud solutions across many agencies. In so doing, it is discovering, as has the private sector, that clouds provide operational efficiencies and new sources of value. **The federal government should move expeditiously to adopt cloud capabilities, beginning with those services and data that directly match industry experiences and best practices.** NIST can and is playing a valuable role in disseminating cloud best practices across the U.S. government, in defining standards for cloud security and in working with other groups to foster understanding of opportunities afforded by clouds. In addition, **the government should explore how clouds could allow data from different agencies, different levels of government, and even the private sector, to be combined and used in powerful new ways.**

Second, and specifically, **federal research agencies should embrace the cloud to host large-scale data sets, accelerate scientific discovery and create new opportunities for data intensive exploration and multidisciplinary collaboration**. In addition, the **federal rules for allowable research expenses should encourage and enable the use of IT services, such as the cloud**, where appropriate, rather than duplicative purchase and maintenance of IT infrastructure.

Finally, **federal research agencies should also support the development and implementation of new algorithms and tools that simplify access to the burgeoning scientific data archive, facilitating collaboration and ease of use**. These tools would reduce the time researchers, staff and students spend on IT management, allow more scientists to tap the power of the cloud and more easily build and share analyses and insights. The tools and techniques developed by and for researchers analyzing and interpreting large quantities of heterogeneous data have potentially broad applicability in domains as diverse as health, security, energy, and business analytics.

2. Ensure Adequate Wired and Wireless Connectivity. The web and cloud services depend on broadband communications. Without them, service and information sharing are impossible. Concomitantly, ensuring reliable wired and wireless connectivity, with adequate bandwidth and latency, is critical to ensuring successful adoption of the cloud and realization of its benefits. The phenomenal growth of digital data, the rise of streaming media services, and the explosive growth of Internet-connected devices are all straining our nation's broadband infrastructure.

It is critical that we **continue to design and deploy new backbone networks that support higher data rates, develop and deploy new protocols and infrastructure for the next generation of wireless networks and define the global standards that will shape the future of the globe-encircling cloud**. We must also remember that digital access to information and services is increasingly the enabler of economic competitiveness, of lifelong education in a rapidly changing world, and of government efficiency and service delivery.

These are technology challenges, requiring new semiconductor approaches and device designs, optical networks and switches, and software and adaptive spectrum management. They are also policy challenges, where the growth of demand and shifting expectations challenge our existing approaches to network regulation, construction, deployment and operation. We need to adopt a new model that fosters innovation and rapid, large-scale deployment, recognizing that the pace of change is quickening.

3. Foster Continued Support for Computing Research and Education. Today's cloud technology—software and services, servers and storage, PCs and smart phones, wired and wireless networks—is derived from basic computing research conducted by universities, government laboratories, and companies over the past four decades. Yet each new computing era brings new questions and new research opportunities and needs. Clouds are no exception.

To ensure that the U.S. continues to remain at the forefront of cloud technology, continued investment in basic research is critical. There are deep and open questions in areas as diverse as the future of silicon scaling and system-on-a-chip design, energy-efficient system design, primary and secondary storage, data mining and analytics, wired and wireless networks, system resilience and reliability, privacy and security, and user interfaces and accessibility, to name just a few. Insights and innovations from this research will spawn new companies, create jobs and reshape our future.

In addition to continued research investment, it is critical to **support the pipeline that produces researchers, and others who will able to invent new uses of the cloud and information technology.** The Bureau of Labor Statistics estimates that the computing sector will have 1.5 million job openings over the next 10 years, yet the number of graduates receiving Bachelors, Masters or Ph.D. computer science degrees in 2009 was approximately 45,000. While the number of degrees is trending upward, it falls far short of where it needs to be to meet the demand. For example, in May, Microsoft had 4,551 unfilled job openings, of which 2,629 were for computer science positions.

To meet this current and future demand, the U.S. must strengthen the quality of and access to computing education at all levels, particularly K-12. Such efforts, by federal, state, and local governments, as well as by companies and non-profit organizations, will not only provide a more capable and larger workforce for IT research and operations, but also raise the overall computing-related capabilities of the population. Strong analytical thinking and understanding of technological systems will be necessary for many careers as IT continues to permeate more and more aspects of society.

Consistent with these concerns about the IT workforce and computing education, Microsoft is a founding member of the Computing in the Core coalition, which supports computer science education, particularly at the K-12 level. To tackle these challenges, the coalition advocates for coordinated efforts on a number of fronts: improving the training, certification, and support for K-12 computer science teachers, as well as increasing their numbers; improving the available standards and assessments, and developing appropriate courses, for K-12 computer science courses; ensuring that computing courses count toward a student's core graduation requirements; and expanding access to and participation in computing courses by under-represented populations.

4. Revise Policies in Light of Technology Change. Every new information technology shift brings change. In each case, the benefits of change accrue to the prepared and adaptable. **Many of our current policies and regulations have not kept pace with new technology developments, and their revision is important to accelerating the implementation and benefits of cloud.**

Many such issues are discussed in the report of the Commission on the Leadership Opportunity in U.S. Deployment of the Cloud (CLOUD2), which has been described by another witness at this hearing. For example, policies around the Electronic Communications Privacy Act, processes for pursuing and prosecuting cybercriminals, privacy frameworks, and transnational data flows require reconsideration in light of current technologies and in recognition that technology is rapidly evolving.

The best approach in a time of rapid technological change is to establish policy goals and a flexible framework for achieving them, and to avoid focus on specific technological approaches that could chill innovation or quickly become outmoded.

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The cloud is the foundation of the 21st century digital economy. This is an exciting time, when the future becomes the present. Access to the power of the cloud can be a great equalizer, providing access to the world's knowledge base to individuals, anywhere, anytime; empowering entrepreneurs and companies large and small to sell their products and ideas globally; and enabling scientists and engineers to discover and innovate in ways that will define the future.

Will we come together and take the steps necessary to prepare and enable this vision for the future? I believe we can and we will. Working together, the private and public sectors can ensure U.S. competitiveness and cloud adoption in the short term, and realize the benefits that result from the cloud's new capabilities and experiences in the long term.

In conclusion, let me thank you for this committee's longstanding support for scientific discovery and innovation. I would be pleased to answer any questions you might have.

Daniel A. Reed
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Microsoft Corporation

As corporate vice president of the Technology Policy Group, Dr. Daniel A. Reed helps shape Microsoft's long-term vision for technology innovations and the company's associated policy engagement with governments and institutions around the world. Given the centrality of information technology to communication and social interaction, research and development, education and learning, health and safety, the environment, and economic development, such strategic technology identification and policy coordination are critical to the company's future. In this capacity, Reed reports to and works closely with Craig Mundie, Microsoft's chief research and strategy officer.

The Technology Policy Group regularly publishes technical perspectives and engages in strategic technical projects on security and privacy, telecommunications and spectrum allocation, energy and environment, science and technology, STEM education and workforce, and the unlimited potential for cloud computing, among other topics, to illustrate alternative future possibilities and outcomes. Reed and his team frequently meet with various members of local and national governments, as well as nongovernmental organizations and industry thought leaders both in the U.S. and globally, to discuss technology advancements on the horizon and the many ways they will reshape our world.

Reed joined Microsoft in December 2007 as scalable and multicore computing strategist. In February 2008, he took on the added responsibility of directing a new Cloud Computing Futures initiative, which explored new approaches to cloud services and datacenter design, including ways to reduce hardware costs and power consumption, and increasing datacenters' adaptability and resilience to failure. In June 2009, Reed led the formation of the eXtreme Computing Group (XCG) within Microsoft Research, with the goal of developing new technologies and constructing integrated, solution-based prototypes. Soon thereafter, Reed added the role of corporate vice president, Technology Policy, and as a result of the growing opportunities and responsibilities within this area, began to focus solely on technology policy in July 2011.

Before coming to Microsoft, Reed held a number of strategic positions, including Gutgsell Professor, head of the Department of Computer Science and director of the National Center for Supercomputing Applications at the University of Illinois, Chancellor's Eminent Professor at the University of North Carolina (UNC) at Chapel Hill, and founding director of UNC's Renaissance Computing Institute. He was also the Chancellor's senior advisor for Strategy and Innovation at UNC. He received his PhD in computer science in 1983 from Purdue University.

In addition to his technical activities, Reed has been deeply involved in policy initiatives related to science, technology and innovation. He currently serves as a member of the U.S. Federal Communications Commission's Technical Advisory Committee and has served as a member of the U.S. President's Council of Advisors on Science and Technology (PCAST) and chair of the computational science subcommittee of the President's Information Technology Advisory Committee (PITAC).