Advanced Computing

Explore.

An Advanced Computing Agenda for Competitiveness

Compete.

Council on Competitiveness

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Table of Contents

SECTION I

From our President

On behalf of the Council on Competitiveness (Council), it is my pleasure to release *Explore: An Advanced Computing Agenda for Competitiveness*, a publication of the Advanced Computing Roundtable. For fifteen years, the Council has helped American leaders to understand and strengthen America's ability to leverage advanced computing to compete. America must continue to lead in this game-changing technology that pushes the frontiers of science and commerce in virtually every discipline and sector.

The Council brings together America's top advanced computing leaders from industry, academia, government and the national laboratories. This initiative facilitates expert analysis of emerging technologies and issues, then issues strategic recommendations to keep America's capabilities second to none. We know from experience that to out-compete, we must out-compute.

This report offers findings and recommendations generated by four Advanced Computing for Competitiveness Regional Forums held in 2017 and 2018, convening experts in New York, California, Ohio and Tennessee. This report contends that federal policies, partnerships and investments alone cannot drive advanced computing competitiveness. They must be supplemented by a renewed focus from state and local leaders to engage the private sector and integrate advanced computing capabilities into their innovation-based economic development strategies. Some outstanding work is already underway.

For many companies, the transition from desktop computing to advanced computing remains fraught with uncertainty, despite the promise of modeling and simulation, data analytics, artificial intelligence and other computer-enabled techniques. Most firms lack in-house talent to capitalize on these technologies, lack an understanding of risk and return in this space, and often struggle to find affordable, scalable software to solve their challenges in advanced computing environments.

This report puts forward an agenda for the public and private sectors to work together at the federal, state and local levels to keep the United States as the world leader in the transformational use of advanced computing. I would like to thank the U.S. Department of Energy, Office of Science, Office of Advanced Scientific Computing Research, for its support of this work.

Sincerely,

Deborah L. Wince-Smith

Deborah L. Wince-Smith
President & CEO
Council on Competitiveness

SECTION II

Introduction

In *A Short History of Nearly Everything,* author Bill Bryson shares two stories to explain why he, a non-scientist, decided to write a book about science. He begins by describing how as a young student, he became captivated by a diagram in his school textbook showing a cutaway of the Earth and its various layers, "ending in the center with a glowing sphere of iron and nickel, which was as hot as the surface of the Sun, according to the caption."[1]

Bryson remembers thinking with real wonder, "How do they know that? How did we end up with a Sun in the middle of our planet, and how do they know how hot it is?" Young Bryson took the book home to read but was disappointed to find no answers to the questions churning in his mind—only descriptions of geological features like anticlines and synclines. "There seemed to be a mystifying universal conspiracy among textbook authors to make certain the material they dealt with never strayed too near the realm of the mildly interesting and was always at least a long-distance phone call from the frankly interesting," writes Bryson. He grew up convinced that science was dull, but suspecting that it need not be.

In his second story, the author recalls himself years later on a flight across the Pacific, staring out the window at the ocean. "It occurred to me with a certain uncomfortable forcefulness that I didn't know the first thing about the only planet I was ever going to live on. I had no idea, for example, why the oceans were salty but the Great Lakes weren't." He continues, "Ocean salinity…represented only the merest sliver of my ignorance. I didn't know what a proton was, or a protein, didn't know a quark from a quasar, didn't understand how geologists could look at a layer of rock on a canyon wall and tell you how old it was—didn't know anything, really."

Advanced computing is at the heart of modern-day stories of "how people figure things out."

Bryson's book aimed to remedy his lack of knowledge on such matters "and to understand above all how people figured them out." He tells stories of curious people tackling great mysteries, including an ill-fated French expedition to Peru in 1735 that helped determine the size of the Earth. By explaining how people puzzled through great questions about the Earth; and its elements, animals and diseases; Bryson breathes life into fields like astronomy, geology, chemistry and biology.

As Bryson puts it, "The idea was to see if it isn't possible to understand and appreciate—marvel at, enjoy even—the wonder and accomplishments of science at a level that isn't too technical or demanding, but isn't entirely superficial either."

This report is animated by a similar spirit. Today, pioneers at the cutting edge of almost every scientific discipline rely on advanced computing—an ecosystem of hardware, software, application models, visualization tools and the talented people who know how to leverage them. Advanced computing is

1 Bryson, Bill. *A Short History of Nearly Everything.* Black Swan Books, 2003.

at the heart of modern-day stories of "how people figure things out." This report aims to convey what advanced computing is enabling people to achieve, and what Americans are and should be doing to leverage it more effectively.

In general, this is the realm of supercomputing, also known as high performance computing (HPC). It is an ever-evolving ecosystem, as evidenced by a steady progression of machines with exponentially greater processing speed, storage, memory and energy efficiency, and a capacity to crunch very big data sets. As hardware becomes more powerful, software and application models need to keep pace to take full advantage of these new capabilities. And as advanced computing moves in new directions—such as artificial intelligence and quantum computing—the importance of this foundational technology will grow.

I'm not a scientist seeking to unravel the mysteries of the universe or the subatomic world. Why is advanced computing important in my world?

HPC is about more than its crucial role in frontier research (which does play a major, if delayed, role in everyday life). Supercomputers are essential in the "here and now" for America's security and economy—i.e. one's safety and prosperity. Supercomputers are used to manage the nation's nuclear arsenal, gather intelligence, support the military, defend the homeland and enforce the law.

Advanced computing also fuels the competitiveness of the U.S. economy and the standard of living enjoyed by Americans. The Council on Competitiveness has long maintained that **to out-compete, we must out-compute™**. HPC enables more fuel-efficient aircraft, safer cars, smart cities, advanced electronics, computer-animated entertainment, new energy sources, higher-yield agriculture, new pharmaceuticals, and revolutions in production and customer service—just to scratch the surface.

Every major business sector in the United States uses HPC to engineer products and services that collectively determine the nation's productivity, prosperity and competitiveness. Advanced computing enables innovation—helping many companies bring better, more competitive products and services to market faster and less expensively than in the past. To succeed, Americans must not only lead in HPC technologies (hardware), but also in the crucial elements that enable U.S. businesses to apply those technologies—such as skills, software, and a strategic array of policies and partnerships—to leverage HPC for much greater advantage.

SECTION III

Executive Summary

Over the course of this three-year grant, the Council on Competitiveness (Council) has hosted six meetings of its Advanced Computing Roundtable made up of experts from a broad cross section of advanced computing users and manufacturers, and four Advanced Computing for Competitiveness Regional Forums to explore issues related to advanced computing in regions, states and localities. More than two hundred experts, stakeholders and policymakers from the federal and state levels participated in this work and provided their time and expertise to help define the opportunity in advanced computing and the barriers to it reaching its full potential as a game-changing competitive advantage for the United States economy and national security.

Building on the insights of the Council's Advanced Computing Roundtable and findings and recommendations from the four U.S. Department of Energy-supported Forums, the Council has identified several broad policy objectives for the United States related to advanced computing leadership and implementation. The United States must:

1. **Compete at the high end of advanced computing.** Continue investing to be a technology leader as the world moves toward exascale computing, including in hardware, software and applications. America also must lead in strategic areas like extending Moore's Law and quantum computing.
2. **Improve the ability of HPC-using firms to leverage advanced computing.** The Council recommends steps to improve computational skills, increase industry partnerships with laboratories and academia, and expand and strengthen software partnerships. Regulatory agencies also should accelerate efforts to use modeling and simulation within the regulatory process.
3. **Expand the number of HPC-using companies in America.** Too few firms are able to leverage advanced computing to innovate and compete. Federal, state and local economic development efforts should be utilized to lower barriers and teach small and medium-sized firms, particularly manufacturers, to use advanced modeling, simulation and analytics.
4. **Coordinate federal action.** Federal agencies should continue to act in a coordinated fashion on advanced computing challenges through the Joint Program Office for Strategic Computing.
5. **Leverage HPC to compete in strategic technologies and applications.** Leadership in advanced computing is tightly linked to leadership in artificial intelligence, the Internet of Things, cybersecurity, additive manufacturing and other emerging technologies. Public and private sector leaders should collaborate on research and partnership efforts that ensure world-class computing environments for strategic technology leadership.

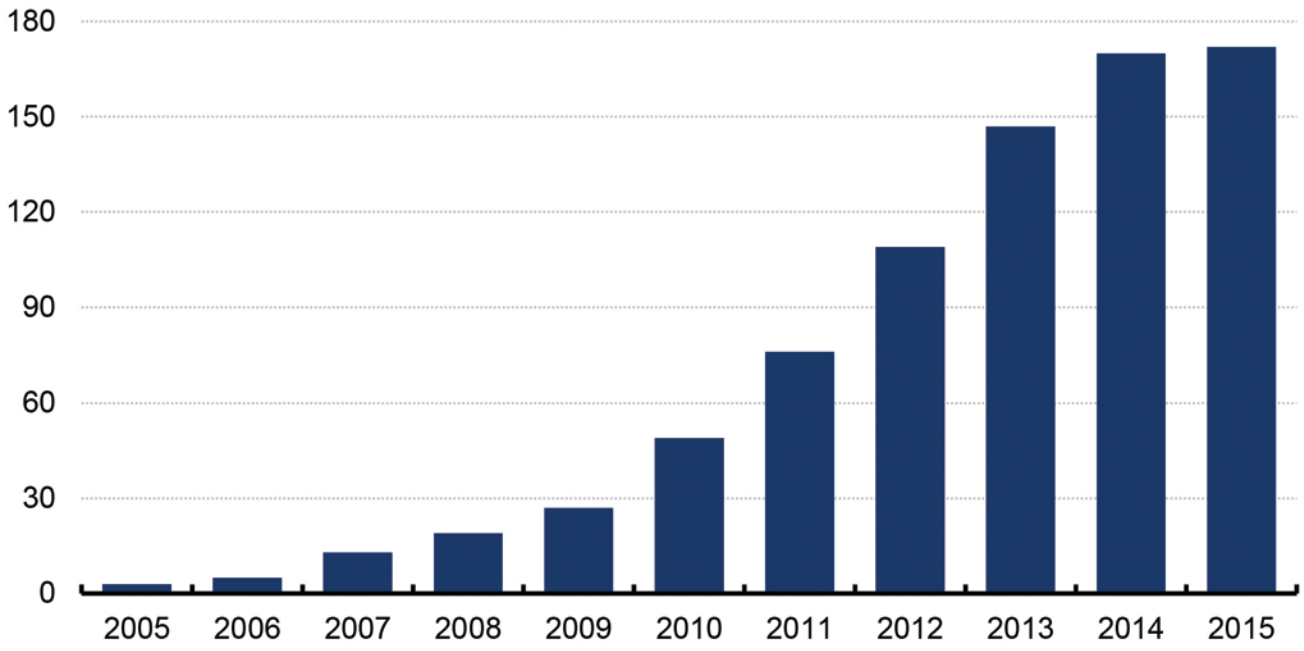
SECTION IV

Advanced Computing and Innovation-based Competitiveness

If you were to go back in time 15 years, most American states and localities either did not have, or were just beginning to consider, innovation and entrepreneurship strategies as part of their economic development strategy. Since that time, there has been a significant growth in collaboration between the public and private sectors to build innovation ecosystems—places with multiple mechanisms for entrepreneurs, investors, technologists, university researchers and representatives of existing companies to collaborate. Governors, mayors and legislators strive to create vibrant innovation cultures that generate high-growth start-ups, and enable existing firms to compete and attract new investment. They pursue these objectives because it helps their constituents prosper and secures a tax base that supports key investments in infrastructure, education and public safety.

One indicator of this trend is the growth of start-up accelerators. Accelerators are one piece of an innovation ecosystem that support early-stage companies through mentorship and financing for a fixed period. They help start-ups to build their initial products, identify potential customers, network with entrepreneurs, and locate employees and investors. Growth in U.S.-based accelerators took off after 2008, growing from 16 programs that year to 49 in 2010, and topping 170 programs in 2015 (Figure 1).

Figure 1. United States Accelerator Pool by Year
Source: Brookings Institute Metropolitan Policy Program



America's leaders need to consider how well they leverage this key innovation tool. They need to integrate advanced computing into their innovation-based strategies to compete.

The number of American accelerators increased an average of 50 percent each year between 2008 and 2014.[2]

The Council on Competitiveness (Council) was an early champion of innovation-based competitiveness, starting in the 1990s and assuming national leadership with the 2005 release of the *Innovate America* report of its National Innovation Initiative. The initiative marshalled leaders across the United States and made the case that innovation will be the single most important factor in determining America's success through the 21st century. The report noted that "for the past 25 years, we have optimized our organizations for efficiency and quality. Over the next quarter century, we must optimize our entire society for innovation."[3] Leaders across the country took note—and took action.

Even back in 2005, the Council's innovation initiative proclaimed:

> *"Few areas of technology hold more promise for stimulating innovation and propelling competitiveness than high performance computing…[M]odeling and simulation with high performance computers has become the third leg of science and a path to competitive advantage…A recent survey by the Council on Competitiveness of U.S. chief technology and chief information officers revealed that nearly 100 percent consider high performance computing tools essential to their business survival…But we are only beginning to reap the potential innovation and competitive benefits that use of this technology promises…By shrinking "time to insight" and "time to solution" through the use of high performance computing, companies in virtually every sector will be able to accelerate the innovative process in ways simply not seen in the past, resulting in new capabilities and revolutionary products and services that capture and cement global market share."*[4]

It is time to more fully realize this promise. For a variety of reasons, most firms and most communities remain unable to realize the promise of advanced computing despite many case studies that document the advantages it confers.

2 Hathaway, Ian. *Accelerating growth: Startup accelerator programs in the United States*, Brookings Metropolitan Policy Program, February 17, 2016.

3 Council on Competitiveness, *Innovate America*, 2005.

4 Ibid.

But that is changing. The Council's Advanced Computing Roundtable (ACR) regularly convenes American HPC leaders from industry, academia and the national laboratories. Together, they have identified key bottlenecks and proposed solutions. Meeting twice annually during the past three years, the ACR regularly addressed key trends in advanced computing and engaged multiple stakeholders from government and the private sector to best understand the implications of current and evolving technologies both impacting and impacted by advanced computing. Presentations and discussions on the economic and national security potential of technologies like artificial intelligence, quantum computing and cybersecurity highlighted the need for U.S. leadership in these fields and the importance of leveraging the full advanced computing ecosystem across the country.

Toward that end, the ACR convened four Advanced Computing for Competitiveness Regional Forums to explore new intersections of advanced computing and competitiveness, showcase model programs and suggest additional actions.

America's leaders—at all levels, from the public and private sectors—need to consider how well they leverage this key innovation tool. They need to integrate advanced computing into their innovation-based strategies to compete.

Several transformative technology areas are not only being discussed at ACR dialogues, but are in the news, such as artificial intelligence, genomic editing, materials science, the Internet of Things, additive manufacturing, digital manufacturing, robotics and big data.

These technologies share a common denominator. They rely on a robust computing ecosystem of powerful hardware, sophisticated software and creative people able to apply computational resources to unlock their full value. Advanced computing is the foundation.

Leadership in advanced computing is more than a national issue. Which U.S. states and metro areas will lead globally, rather than be forced to play catch up?

SECTION V

Advanced Computing for Competitiveness Regional Forums

The Council on Competitiveness (Council) organized four Advanced Computing for Competitiveness Regional Forums across the country:

1. **April 13, 2017**, hosted by the Center for Urban Science and Progress of New York University (NYU) in Brooklyn, NY;
2. **October 24, 2017**, hosted by the High Performance Computing Innovation Center of the Lawrence Livermore National Laboratory in Livermore, CA;
3. **July 10, 2018**, hosted by the Ohio Supercomputing Center on the campus of the Ohio State University in Columbus, OH; and
4. **December 6, 2018**, hosted by the Oak Ridge National Laboratory in Oak Ridge, TN.

The Forums brought together national and regional leaders to showcase programs that leverage advanced computing for competitiveness and economic development. The Forums also facilitated dialogues on how such programs could be improved, expanded or replicated—and explored computing technology advances (e.g. exascale computing, artificial intelligence, quantum computing) that may require new policies and partnerships.

FORUM 1—Brooklyn, New York

The Honorable Steven Koonin, Distinguished Fellow, Council on Competitiveness, and Director, Center for Urban Science and Progress (CUSP), New York University; the Honorable Deborah L. Wince-Smith, President & CEO, Council on Competitiveness; Dr. Paul Horn, former Distinguished Research Scientist, Office of Innovation, NYU Tandon School of Engineering; Ms. Dona Crawford, Senior Fellow, Council on Competitiveness, and President, Livermore Foundation; and the Honorable Patricia Falcone, Deputy Director for Science and Technology, Lawrence Livermore National Laboratory.

The Forum at NYU served several purposes. It reaffirmed the competitive edge that modeling, simulation and analytics (MS&A) confer to companies. It highlighted model programs to enable MS&A, address skill gaps and partner to address software limitations. Attendees learned about the regional economic impact of the Brookhaven National Laboratory and the remarkable insights being gleaned from the smart city initiative of NYU's Center for Urban Science and Progress. The agenda also highlighted industry partnership programs available at the national laboratories and explored how advanced computing underpins leadership in other emerging technologies like artificial intelligence and the Internet of Things.

Larry Patterson, Director, Advanced Computing Technologies, Gulfstream Aerospace Corporation, opened the Forum with a featured talk. He conveyed to the audience how Gulfstream has gained a decisive competitive edge from innovations implemented via modeling and simulation—citing several performance metrics.

The Honorable Patricia Falcone, Deputy Director for Science and Technology, Lawrence Livermore National Laboratory.

HPCNY Program

Next up was a panel that brought together two computational scientists, Mark Shephard, Professor of Engineering, Rensselaer Polytechnic Institute; and Shawn Matott, Computational Scientist, University at Buffalo; and Ed Wagner, Chief Scientific Officer, Sentient Science Corporation. The trio reviewed an innovative New York state high performance computing consortium called HPCNY. The program supports a consortium of universities to offer expertise and computing resources to companies of all sizes to innovate. Shephard and Matott reviewed the program and offered case studies of their engagements. The HPCNY program is designed to lower market barriers (such as cost, risk and software know-how) for firms to become HPC-innovating companies. It is funded by the Empire State Development Division of Science, Technology and Innovation as part of their mission to foster economic development in New York State.

Wagner shared how engaging with HPCNY was critical to the success of Sentient Science, which offers computational testing products to predict early failure mechanisms in rotating equipment and for design optimization. "The only reason we exist is because HPCNY enabled us to exist," asserted Wagner. The company's principle customers are in wind energy, aerospace and rail. Sentient's early work with the Center for Computational Research at the University of Buffalo enhanced the company's technology, and helped it grow from 15 to more than 70 employees. From 2017 to 2018, contracts to model turbines grew from covering 18,000 wind turbines to 40,000, and Sentient Science projects to have 168,000 wind turbines under contract globally by 2020.[5]

NIST Digital Manufacturing Initiative

David Stieren, Director, Partnerships and Program Development, National Institute of Standards and Technology (NIST), reviewed a national digital manufacturing initiative being implemented at Manufacturing Extension Partnership centers across the country

5 Szpylman, Jill. *Sentient Science Digitalizes 35% of World's Wind Turbine Models*, Sentient Science Blog Post, http://blog.sentientscience.com/media/sentient-science-digitalizes-30-of-worlds-wind-turbine-models, May 9, 2018.

Figure 2. National Network of NIST Manufacturing Extension Partnership Centers

(Figure 2). Stieren stated the centers engaged more than 25,000 manufacturers the previous year, and that the initiative aims to infuse technology and disruptive perspectives into production, business strategy and manufacturing infrastructure connections. The initiative is supported by computing resources in Illinois through the Digital Manufacturing and Design Innovation Institute and underscores the importance of advanced computational capability for manufacturing competitiveness.

Skills

A panel on skills covered three dimensions related to advanced computing: (1) teaching computational science; (2) addressing K-12 pipeline issues into computational fields; and (3) lessening the educational burden required to use advanced computing systems by simplifying the interfaces.

Ms. Dona Crawford, Senior Fellow, Council on Competitiveness, and President, Livermore Foundation.

Dr. Jess Gehin, Acting Director, Advanced Scientific Computing, Nuclear Science & Technology Directorate, Idaho National Laboratory.

Dona Crawford, Senior Fellow, Council on Competitiveness, and President, Livermore Foundation, moderated the panel and opened with remarks to help frame the issue. Crawford noted the growing national gap between the computer science job openings and the supply of computer science students (Figure 3). She also offered data on New York State for average salaries in computing occupations, participation in the field by women and minorities, and student participation in advanced placement courses for computer science. The average salary in New York State for a computing occupation is $103,853, compared to an average salary for all occupations of $60,100.[6] Of the state's 3,801 computer science graduates in 2015 (latest available data), only 18 percent were female. Only 339 schools (23 percent of schools with AP programs) offered any AP Computer Science course in 2016-2017, although that represents 139 more schools than the previous year. Female students represented 32 percent of the exams taken in 2017, and 23 percent of exams were taken by underrepresented minority students.[7]

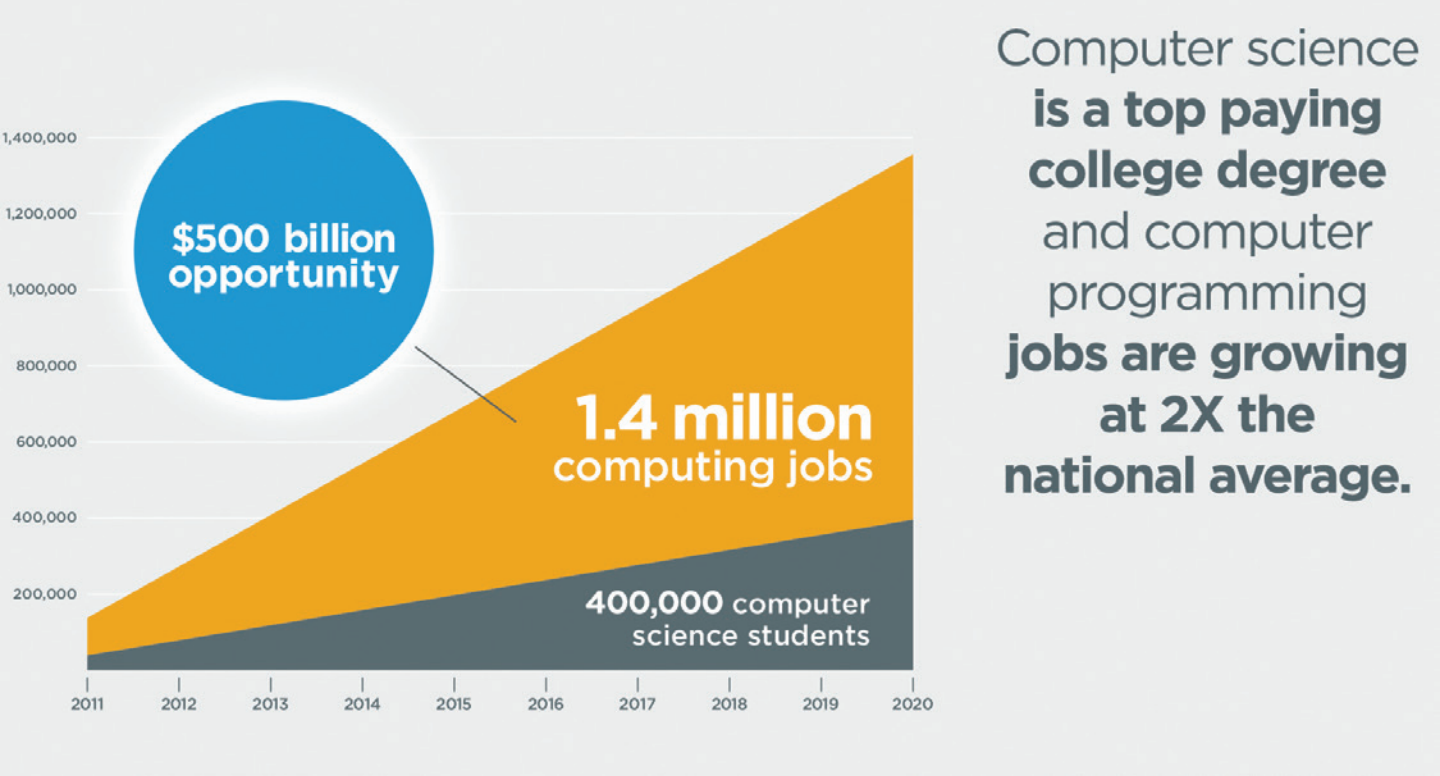
David Joiner, Associate Professor, Kean University shared how his university examined models to build a computational science program. Computational science, also known as scientific computing, is an emerging discipline teaching how to apply mathematical models to computations for scientific disciplines. In overly simple terms, computer science is about optimizing computer systems. Computational science is about using those systems across disciplines to solve problems.

Kean drew largely on the Ralph Regula School of Computational Science in Ohio, a virtual program spanning multiple campuses and the Ohio Supercomputer Center. The effort required all of the

6 Code.org. ***State Fact Sheet***, New York, 2018.

7 Code.org Advocacy Coalition and the Computer Science Teacher Association. State of Computer Science Education - Policy and Implementation, 2018.

Figure 3. 1,000,000 More Jobs Than Students by 2020
Source: Code.org



schools to define what they mean by "computational science" and defined a set of competencies for what a minor in computational science would mean across all of their schools. This was followed with standards for their graduate programs and data science programs. Kean developed a five-year program to earn a bachelor's and master's degree in computational science (Figure 4).

Diane Levitt, Director of K-12 Education, Cornell Tech, reviewed her institution's K-12 initiative. Cornell Tech is a graduate school, but it is working with academic, nonprofit, philanthropic and corporate partners to build the capacity of teachers and schools to bring computing to life for K-12 students in New York City schools. Through its Teacher in Residence program, Cornell Tech not only mentors teachers, but also studies how teachers and students best learn computer science and share what they learn. As the academic partner for New York City's Computer Science Teachers Association, the program serves as a local and national model for building the pipeline of computing and computational science disciplines. The program also sponsors student competitions and an annual To Code and Beyond conference.

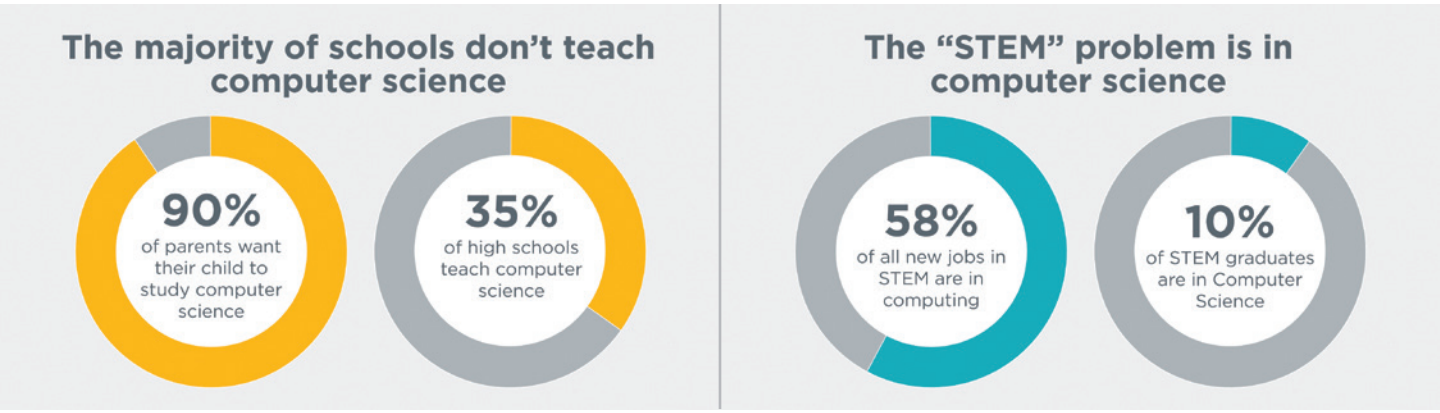
Figure 4. Kean University 5-Year Combined BS/MS in Computational Science

- 124 semester hour BS (90 in STEM courses)
  - 6 of which are graduate level
- 1-Year, 30 semester hour MS (total of 36)
- Science fundamentals
  - 16 semester hours chemistry, biology, physics
- Math fundamentals
  - 12 semester hours calculus (I, II), linear algebra, statistics
- Programming fundamentals
  - 4 semester hours programming lab tied to each math course (MATLAB, R)
  - Procedural programming (JAVA)
  - Object oriented programming (JAVA)
  - Data structures (JAVA)
- Research experience
  - 11 semester hours of planned research sequence at undergraduate level
- Additional major requirements
  - Continue calculus sequence through differential equations Continue programming sequence through software engineering
  - Introduction to modeling and simulation
  - Numerical analysis
  - Electives to further specialized applications
- Graduate requirements
  - Advanced modeling and simulation
  - Partial differential equations
  - High performance computing (C++, CUDA)
  - Data visualization
  - Science writing
  - Computer science electives in web programming, data science (R)
  - 6 semester hours thesis

Levitt made the case for K-12 programs by noting that the majority of schools do not teach computer science, despite the growing importance of computer science and computational literacy in the workforce. She also noted that a large share of science, technology, engineering and mathematics (STEM) jobs are in computing (Figure 5), but few STEM graduates are in computer science. Levitt also explained that diversity issues in STEM begin in K-12, stating that, "women who try AP computer science in high school are ten times more likely to major in it in college, and Black and Hispanic students are seven times more likely."

Alex Larzelere, Senior Fellow, Council on Competitiveness, discussed two additional facets of the skills challenge in advanced computing. First, he noted that advanced computing could be more accessible and require less intensive training if the interfaces were simplified. He also reiterated a point raised in meetings of the Council's Advanced Computing Roundtable—that senior business leaders often lack

Figure 5. Computer Science in Schools
Source: Code.org



the computational literacy to know which problems could be solved computationally and to work through issues like return on investment or the risk associated with the confidence level in the results generated by computer models.

Keynote

Doon Gibbs, Director, Brookhaven National Laboratory (BNL) delivered the luncheon keynote, explaining the BNL's mission to use its world-class facilities and expertise to: (1) advance energy and environment-related basic research and apply it to critical 21st century problems; and (2) advance fundamental research in nuclear and particle physics to gain a deeper understanding of matter, energy, space and time. Gibbs relayed how BNL serves regional and national economic competitiveness, including through the use of its computational resources and capabilities.

BNL conducts highly data-intensive research through its user facilities, often in partnership with industry, universities or other national laboratories. The major user facilities include the Relativistic Heavy Ion Collider (used to understand fundamentals of nuclear physics and matter), the National Synchrotron Light Source II (which enables nanoscience research with important applications), and the Center for Functional Nanomaterials (which offers additional research tools for nanomaterials science, such as electron microscopy and nanofabrication).

Gibbs also offered insights on the laboratory's role in advanced computing, noting that BNL holds the second largest data archive in the United States and the fourth largest in the world. A Computational Science Initiative (CSI) brings together expertise across user facilities. A particular focus of CSI's work will be to improve the analysis of big data to accelerate scientific discovery across disciplines and scientific user communities. Gibbs noted applications in national security, electric grid, medicine, finance, manufacturing and other areas. BNL seeks to expand existing industry, academia and state partnerships, and to establish new ones.

Gibbs also previewed that new systems were coming online at the laboratory. In November 2018, BNL unveiled the Minerva system, designed to take on complex artificial intelligence challenges. The NVIDIA DGX-2 is one of the first available systems worldwide and serves as a user-accessible multipurpose machine focused on computer science research, machine learning and data-intensive workloads.[8]

Software

Rick Arthur, Director, Advanced Computing, GE Global Research, helped participants understand some of the challenges posed by the current software environment. He reviewed the findings of the Council's Advanced Computing Roundtable Software Working Group, noting that several software factors are a critical barrier to greater industrial adoption of advanced computing.

The findings include that:

- Software is intimately entwined with workforce skills challenges;
- Confidence in results requires validated software and sufficient fidelity;
- Software licensing models often discourage high-end use;
- At the onset of a project, costs are precise, but benefits may be fuzzy;
- The high-end computing market is complex, while software makers seek mass market appeal; and
- There are often challenges to aligning responsibilities and legal agreements between industry, government and academia

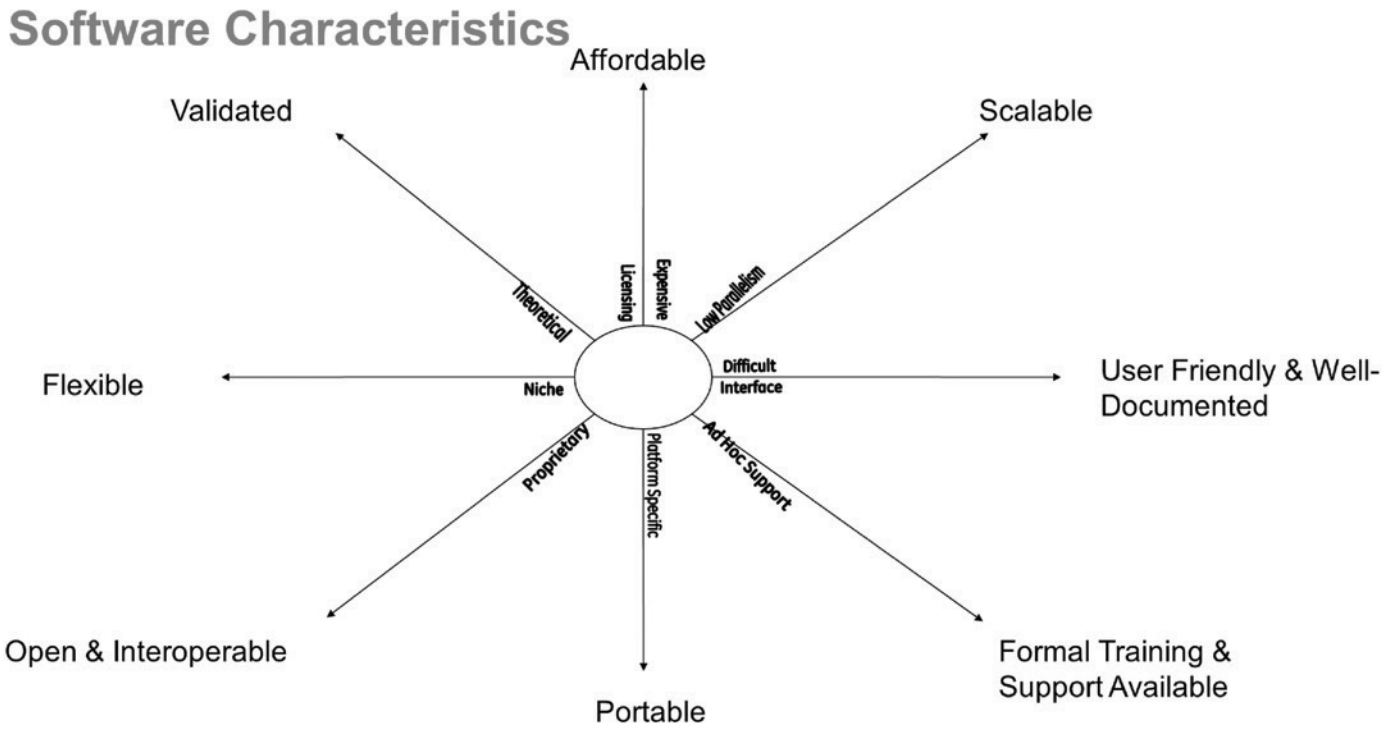
Arthur presented a series of diagrams (Figures 6 and 7) to illustrate shortcomings in the software market for companies seeking to solve problems on advanced systems. The diagrams show desirable software characteristics at the outer radius and less desirable ones near the center. Arthur offered an estimate of the strengths and shortcomings of the different kinds of software available—software from the national laboratories, the open source community and commercial vendors. Companies also leverage their own proprietary software, but as new projects arise, they often would prefer to purchase software than to develop it in-house.

Following the working group review, the software panel covered two topics: (1) an industry-national laboratory collaboration called the Consortium for Advanced Simulation of Light Water Reactors (CASL); and (2) partnership efforts by software vendors to meet demand.

Robert Oelrich, Manager, PWR Fuel Technology, Westinghouse; and Jess Gehin, Director, CASL, Oak Ridge National Laboratory, discussed the partnership that brings modeling and simulation capabilities to improve the performance of light water nuclear reactors. The 10-year initiative includes representatives from national laboratories, universities, and industry in the nuclear power, software and computing sectors. The partnership seeks to improve currently operating reactors and those to yet be built. Gehin explained CASL's development of the Virtual Environment for Reactor Applications (VERA), which includes computational tools and supporting infrastructure for more realistic modeling and simulation of a reactor's behavior. With VERA as its vehicle, CASL works to solve major challenges faced by consortium members.

8 Brookhaven News Room, *Leading-edge AI Computing System now at Home with Brookhaven Lab's Computational Science Initiative*, November 6, 2018.

Figure 6.
Source: Richard Arthur, GE Global Research



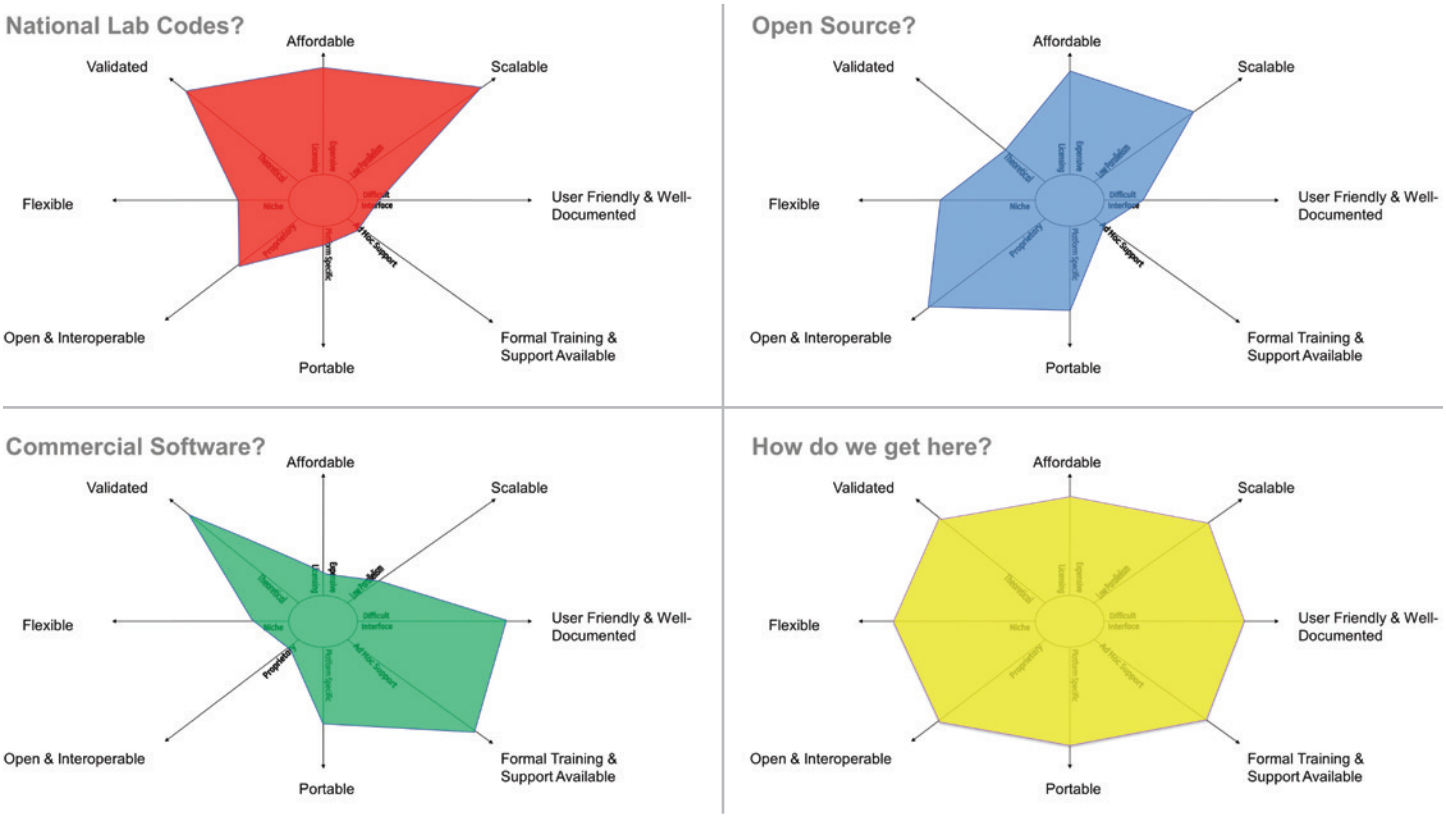
One of those challenges is crud, a yellowish substance that can be flaky, porous or hard, depending on its chemical make-up. In most cases, it reduces the power output of nuclear reactors—the deposits absorb the neutrons that keep the fission reaction going. Crud also can lead to more serious concerns, contributing to corrosion that can create a rupture in the fuel rod cladding and enable the fission product to be released into the coolant.[9]

Understanding crud formation requires an ability to predict core chemistry and coolant corrosion product content, crud deposition, crud chemistry, and local thermal-hydraulic and neutronic behavior.[10] The aim is to uncover insights that enable nuclear plant operators to adjust their operating strategies to avoid crud formation and enable peak plant efficiency and safety.

9 McAlpine, Kate. *How Crud Forms on Nuclear Fuel*, Michigan Engineer News Center, Nov 27, 2012.

10 Consortium for Advanced Simulation of Light Water Reactors. *Development of Preliminary VERA-CS Crud-Induced Localized Corrosion Modeling Capability*, June 15, 2018.

Figure 7.
Source: Richard Arthur, GE Global Research



Oelrich reviewed the role of Westinghouse in the nuclear industry, serving more than 60 operating plants worldwide that require fueling, maintenance, and sometimes upgrades and enhancements. Westinghouse is a major nuclear fuel provider, monitors and designs reactors, and operates an Engineering Center of Excellence to drive innovation and serve each component of the business.

CASL, said Oelrich, offers a higher-fidelity and more integrated tool than has ever been available to do things like predicting temperatures, stresses, and material performance over the long-term operation of a facility.

The software panel was concluded by a conversation with representatives from two independent software vendors—Al Bunshaft, Senior Vice President, Americas Global Affairs, for Dessault Systèmes, and Stig Panduro, Director of Partner Ecosystems for ANSYS, Inc. The two software executives described a host

of academic and industry partnerships entered into by their firms to address sector or technology challenges. Both firms have created partnership ecosystems to further develop their software offerings for a variety of applications and to teach partners to use their products.

Smart Cities

Steven Koonin, Distinguished Fellow, Council on Competitiveness, and Director, Center for Urban Science and Progress (CUSP), New York University, kicked off a talk about another way that advance computing is leveraged for regional competitiveness, smart city initiatives. Koonin, who also serves as a co-chair of the Council's Advanced Computing Roundtable, gave an overview of CUSP and introduced speakers from the center to spotlight their work.

CUSP's mission is to develop novel data- and technology-driven solutions for complex urban problems. The center's research and educational initiatives seek to improve city services; optimize decision-making by local governments; create smart urban infrastructures; address urban issues such as crime, environmental pollution and public health issues; and inspire urban citizens to improve their quality of life. Using data from a network of agencies, CUSP works to transform New York City into a living laboratory and classroom. It uses the vast amount of data it collects to help New York and other cities around the world become more productive, livable, equitable and resilient.

Figure 8. Image of NYC Taken
Source: CUSP Urban Observatory

One of the projects spotlighted at the Forum was by Gregory Dobler, Visiting Scholar, CUSP. He is an astrophysicist who specialized in multi-wavelength, full sky data sets from radio to gamma-ray energies, and led the discovery of one of the largest structures in the Milky Way. His expertise is in image analysis, computer vision, time series, statistical analysis and mathematical modeling of large data sets.

As the Chief Scientist of CUSP's Urban Observatory, Dobler applies data analysis techniques from astronomy, computer vision and machine learning to images of New York City's skyline to study air quality, energy consumption, lighting technology, public health, and sustainability (Figure 8). Every 10 seconds the observatory takes a panorama of Manhattan. Across hundreds of wavelengths of light,

Dobler's team records the rhythmic pulse of the city, just as astronomers capture the activity of a variable star. "Instead of taking pictures of the sky to see what is going on in the heavens, we are taking pictures of the city from a distance to see if we can figure out how the city is functioning," says Dobler.[11] CUSP collaborates with New York City officials on the project. Its major goal is to discover information about the urban landscape that cannot be seen at other scales.

HPC4 Manufacturing and HPC4 Model of Advanced Computing Collaboration

Lori Diachin, then the Director, Center for Applied Scientific Computing and Research, Lawrence Livermore National Laboratory, spoke about an innovative program first proposed as part of the Council's Energy and Manufacturing Competitiveness Partnership.

Diachin also served as the Director of the HPC4 Manufacturing Program, a competitive program for industry to collaborate with a consortium of national laboratories.

FORUM 2—Livermore, California

The Advanced Computing for Competitiveness Regional Forum hosted at Lawrence Livermore National Laboratory (LLNL) was designed to engage a broad community of leaders on how advanced computing can strengthen the competitiveness of companies, regions and the nation. The agenda aimed to: (1) convey the value of advanced computing in driving innovation and competitiveness; (2) raise awareness of policies and programs that leverage advanced computing; and (3) exchange ideas on how the computing ecosystem is evolving and what new approaches could help Americans to take better advantage of this strategic and essential tool to compete.

Dr. Brent Stacey, Senior Advisor, Idaho National Laboratory; Dr. Brice Hendrickson, Associate Director for Computation, Lawrence Livermore National Laboratory; Mr. William Bates, Executive Vice President, Council on Competitiveness; and Ms. Dona Crawford, Senior Fellow, Council on Competitiveness, and President, Livermore Foundation.

For more than 60 years, LLNL has applied science and technology to make the world a safer place. Livermore's defining responsibility is ensuring the safety, security and reliability of the nation's nuclear deterrent. Yet LLNL's mission is broader than stockpile stewardship, as dangers ranging from nuclear proliferation and terrorism to energy shortages and climate change threaten national security and global stability. LLNL's science and engineering capabilities are being applied to achieve breakthroughs for counterterrorism and nonproliferation, defense and intelligence, energy and environmental security.

11 Hotz, Robert Lee. *As World Crowds In, Cities Become Digital Laboratories*, Wall Street Journal, December 11, 2015.

National Strategic Computing Initiative

After opening remarks from William Bates, Executive Vice President, Council on Competitiveness; and Brice Hendrickson, Associate Director for Computation, LLNL, Mark Sims, Head of the Joint Program for Strategic Computing, Trump Administration, outlined why advanced computing is essential for the United States, and why is it critical that America lead. He was joined by Irene Qualters, Director, Division of Advanced Cyberinfrastructure, National Science Foundation.

Mark and Irene described the goals of the current administration's Strategic Computing Initiative:

- Accelerating delivery of a capable exascale computing system that integrates hardware and software capability to deliver approximately 100 times the performance of the current 10 petaflop systems across a range of applications representing government needs;
- Increasing coherence between the technology base used for modeling and simulation and that used for data analytic computing;
- Establishing, over the next 15 years, a viable path forward for future HPC systems even after the limits of current semiconductor technology are reached (the "post- Moore's Law era");
- Increasing the capacity and capability of an enduring national HPC ecosystem by employing a holistic approach that addresses relevant factors such as networking technology, workflow, downward scaling, foundational algorithms and software, accessibility and workforce development; and
- Developing an enduring public-private collaboration to ensure that the benefits of the research and development advances are, to the greatest extent, shared between the United States government and industrial and academic sectors.

They challenged those in the room to consider what role states and governors can and should play in supporting these goals, and what the impact would be regionally and locally.

Partnerships

The discussion then turned to examples of university-industry partnerships in the advanced computing space. Mike Norman, Director, San Diego Supercomputing Center, highlighted the tremendous opportunity these partnerships have to drive skills development through industry feedback and to provide students with hands-on experience and access to mentors and other industry professionals. Dan Stanzione, Executive Director, Texas Advanced Computing Center, echoed these remarks and spoke of the importance of demonstrating to students the real-world relevance of their work. He also noted the importance of these partnerships as test beds for new technologies and highlighted the oil and gas industry as one that has particularly benefited from these arrangements in Texas. Steve Conway, Senior Research Vice President, Hyperion Research, clarified that university-industry partnerships were more than job connectors; that they are foundational to the innovation process.

The impact on manufacturing

The next panel of the day looked at the potential for advanced computing to reshape U.S. manufacturing. Jim Davis, Vice Provost & Chief Academic Technology Officer, UCLA; and Gregg Profozich, Director, Advanced Manufacturing Technologies, California Manufacturing Technology Consulting, briefed attendees on the status and development of CESMII, the Smart Manufacturing Institute housed at UCLA and a key piece of the larger Manufacturing USA network of hubs across the country. CESMII's mission is the:

> *Research and development of technologies and solutions that can capture, share and process in real-time the increasing amounts of information available at manufacturing facilities. These technologies are expected to enable dramatically improved process control and operation, and enable benefits such as improved energy efficiency, equipment reliability, productivity gains, as well as related improvements in safety, quality and yield in manufacturing processes.*

Advanced computing is the engine that enables the processing of the mountains of data created by smart manufacturing. The work of CESMII combined with the work of MxD (formerly the Digital Manufacturing and Design for Innovation (DMDI) Institute) is at the cutting edge of integrating advanced computing throughout the manufacturing supply chain. Speakers emphasized the importance of ensuring that small and medium-sized companies not be left behind as these technologies become more ubiquitous, noting that the stronger the supply chain is, the stronger overall U.S. competitiveness is. And this has huge implications for state and regional competitiveness.

Dr. David Turek, Vice President of HPC Marketing Engagement, IBM.

Equally important is the integration of cybersecurity into the digital manufacturing infrastructure, especially as the proliferation of sensors and the Internet of Things continues unabated. Late in 2018, the Council issued a major report, *Secure*, that outlined a national cyber agenda for the nation. Central to that agenda was the necessity to build cybersecurity into the hardware that is being deployed in the manufacturing space.

Keynote: Where America Stands

The lunchtime keynote address by David Turek, Vice President of HPC Marketing Engagement, IBM, focused on the state of global competition in advanced computing and where America stands. A major focus of his remarks was on the software challenge facing U.S. industrial users, which includes certification of new software (who is doing the certifying) and the use of proprietary software by large OEMs. He strongly supported U.S. efforts to further develop HPC capabilities and do so within the framework of a national computing strategy. This

being particularly important given the strategic priority competitors like China are placing on advanced computing and the tremendous resources they are bringing to bear.

Enabling next-gen technology

Nidhi Chappell, Head of HPC and High Performance Data Analytics, Intel Corporation; and Barry Boldin, Senior Vice President and Chief Strategy Officer, Cray Inc., then led a discussion on how advanced computing is enabling new technologies and creating tremendous advantage for the United States across a myriad of nascent industries. The implications for economic development and job creation in states and regions with HPC centers is huge. Boldin spoke of efforts by Cray to support a myriad of foundational technologies upon which others will rely. Artificial intelligence and machine learning were two technologies often raised by those in attendance as poised to grow tremendously, supported by advances in computing, IF software and workforce skills can keep up. This is a challenge for the states and regions, if they are going to reap value from the HPC capabilities that exists at national laboratories and universities. Further, Chappell noted the importance of reaching out to and engaging with small businesses who have traditionally stayed away from advanced technology due to cost, licensing and other barriers.

Echoing earlier comments, a number of attendees highlighted the need for greater awareness among young people of the opportunities in advanced computing, not just in the computing space, but in the various derivative industries that rely upon it. There was strong agreement that the Council could play an important role in building awareness with both policy makers and the general public.

Artificial intelligence

Mark Minevich, Senior Fellow, Council on Competitiveness, and Principal Founder, Going Global Ventures, then took attendees on a deeper dive into the latest developments nationally and globally in artificial intelligence. He cautioned that countries such as China, Russia and Germany were making large investments in artificial intelligence, and doing so strategically, while the United States lacks any kind of overarching plan or national agenda. Still the United States remains in the lead for now, but that leadership is by no means guaranteed. “Who will lead in 2030?” is anyone’s guess, he noted. For now, companies like Google, Amazon, Microsoft and IBM are at the forefront of artificial intelligence investment, coupled with investments in robotics, a related and similarly growing field.

Leveraging the national laboratories

The Forum concluded with a bookended discussion on partnerships, but focused on the national laboratories and industry. Bruce Hendrickson, Associate Director for Computation, LLNL; Miller Allen, Director, Process Engineering, Applied Materials; and Brent Stacey, Senior Advisor, Idaho National Laboratory, offered their perspectives on the potential of the laboratories to serve as key regional anchors for interactions between industry, academia and government. Hendrickson noted that the National Strategic Computing Initiative was driving interest in laboratory/industry partnerships and cross-agency collaborations. Allen shared that laboratory partnerships were driving both the development of HPC and applications for its use. And Stacey noted that universities were often the “glue” that brought laboratories and industry together. All speakers emphasized the regional nature of these partnerships and the importance of maximizing local assets for economic development.

FORUM 3—Columbus, Ohio

The third Forum was held at the Ohio Supercomputer Center (OSC), a statewide resource that provides supercomputing services and computational science expertise to Ohio university researchers as well as Ohio industries. Hosted by David Hudak, Executive Director and Director of Supercomputing Services, attendees were welcomed and briefed on OSC's more than 30 years as a national center that drives research and development in computational science and the applications of supercomputing. OSC seeks to:

> *. . . empower Ohio researchers to new innovations and discoveries that will lead to new products, businesses and services; by partnering with Ohio industries to use supercomputing and computational science as a competitive force; and, in collaboration with Ohio's colleges and universities, in educating Ohio's workforce in the key skills required for future jobs.*[12]

Partnerships

The Forum kicked off with two panels discussing partnerships between universities and industry, and between industry and national laboratories. Alan Chalker, Director of Strategic Programs and Director of Awesim (OSC's industry outreach program), joined William Gropp, Director and Chief Scientist, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, to discuss the importance of industry as partners and treating the relationship like a business transaction. Gropp noted that they currently have about 40 partners across

The Honorable Patricia Falcone, Deputy Director for Science and Technology, Lawrence Livermore National Laboratory.

sectors and offer free consulting on what firms' issues and opportunities would be should they enter into a formal collaboration. Both presenters highlighted their work on security issues with industry and regulatory compliance (i.e. HIPPA, ITAR).

Chalker and Gropp both emphasized the need for universities and industry to define problems and challenges in detail, and to have regular contact with people who can work through issues as they arise. Clarity within the relationship is key. With regard to smaller firms, early and open communication is vital. Helping them to validate value propositions and understand the potential return on investment of a partnership, focusing on what the firm needs, not what the computer center does. Standardizing the price sheet and marketing materials is also important. As with prior discussions, the issue of software availability and compatibility was raised with no easy answers at hand.

12 https://www.osc.edu/about/mission, 5/16/2019.

Mr. Thomas Lange, Principal, Technology Optimization and Management, LLC.

The discussion then turned to laboratory-industry partnerships and was led by Amitoji Singh, Deputy Head of High Performance Computing, Fermi National Accelerator Laboratory; and Robin Miles, Program Manager, HPC4Manufacturing Program, LLNL. Singh highlighted a number of Fermi's areas of focus including:

- Quantum sensor capabilities;
- Superconducting technology;
- High-energy physics applications for quantum complex algorithms; and
- Quantum networks.

Fermi and LLNL partnerships are predominantly with major cloud computing players such as Google, IBM and Amazon.

Miles briefed attendees on the tremendous interest in the HPC4Manufacturing program. More than 250 proposals have been submitted, 50 projects funded and 38 companies engaged. She noted that applicants do not need to be U.S. companies, but they must manufacture in the United States. Importantly, participating companies are from all over the United States and cut across several sectors, including welding, paper towels, LED lightbulbs, papermaking, energy use and automotive turbine engines.

Summarizing, both presenters emphasized the importance of constant outreach and education to potential partners, as laboratory capabilities and challenges are constantly evolving.

Advancing U.S. competitiveness

Patricia Falcone, Deputy Director for Science and Technology, LLNL, presented her perspectives on the role advanced computing plays in supporting current critical laboratory missions and emerging technologies. LLNL's supercomputers obviously support the laboratory's national security and nuclear stockpile management missions, but what is exciting is their potential to impact an expanding portfolio of critical technologies, including:

- Data science and simulation;
- Applications in the biomedical area;
- Hardware applications in precision medicine; and
- Artificial intelligence and machine learning.

Participants in Advanced Computing for Competitiveness Regional Forum 3 at the Ohio Supercomputing Center.

In response to questions, Falcone closed by noting the importance of the National Strategic Computing Initiative (NSCI) as a facilitator for interagency cooperation—a key to addressing many of these technologies, which cut across multiple industries and state/federal agency jurisdictions—and further explained that to date, bipartisan support for the NSCI was strong and funding appeared to be stable.

Breaking down barriers to small business engagement in advanced computing

As prior Forums have made clear, reaching out to small and medium-sized businesses is critical to reap the regional economic benefits from advanced computing assets in a state/region. Dennis Thompson, President and Managing Partner, Equus Partners; and Thomas Lange, Principal, Technology Optimization and Management, LLC (and formerly head of HPC with Procter & Gamble), led a discussion on how best to achieve this goal.

Thompson suggested bringing groups of small manufacturers together or going to meetings where they are gathered, and making the business case for what advanced computing can accomplish, rather than leading with the technology. Lange added the need to emphasize short-term cost savings as slow learning cycles are replaced by virtual cycles, noting that expenses related to research and development costs and research and development physical testing can be reduced by 10 percent by moving from physical testing to virtual. Overall, the pain of change must be less than the pain of staying the same.

Barriers can be difficult to overcome, especially the belief that the old ways of doing things work just fine, so why change? And, as had been discussed, software remains a major sticking point, as small businesses usually just need a specific problem addressed and therefore do not want to pay for a comprehensive software solution.

The skills challenge/jobs opportunity

While a common thread through many of the panels and previous Forums, the issue of the skills needs and opportunities was called out specifically in this next segment of the day. Led by Katherine Cahill, Education and Training Specialist, OSC; and Kelly Gaither, Director of Visualization, Texas Advanced Computing Center, this session put forward various ideas for engaging students in careers related to high performance computing, and modeling and simulation. Cahill highlighted model programs for computation science, as well as summer programs to get students engaged in modeling and simulation with university professors who act as mentors. She also suggested a program that targets girls at the 7th or 8th grade level, as that is when interest in science and math seems to wane. Gaither added that focusing these programs on issues students cared about would be an important first step. She also noted that better metrics were needed related to the specific needs of industry in order to best align education and training with the job opportunities.

Impacting the Region

Concluding the Forum, Ted Griffith, Managing Director, Information Technology, Logistics and Distribution, JobsOhio; and Gail Towers Nolan, Principal Partner, Towers Nolan Consulting, reiterated the economic development opportunity that advanced computing presents for the Ohio region. Touching on many of the themes of the day, they talked about the urgency for outreach and education to potential partners and businesses, and clear communication regarding the services available and their costs. Finally, the session closed with an idea for a path forward regarding the software challenge—namely to forge partnerships between industry, academia and government, and treat this challenge like the "grand challenge" it is. For it is the roadblock holding back much of the economic development power that advanced computing could bring to Ohio and to the nation.

FORUM 4—Oak Ridge, Tennessee

The fourth and final Forum was hosted by Thomas Zacharia, Director, Oak Ridge National Laboratory. Oak Ridge National Laboratory (ORNL) is the largest U.S. Department of Energy (DOE) science and energy laboratory, conducting basic and applied research to deliver transformative solutions to compelling problems in energy and security. Established in 1943 as part of the Manhattan Project, ORNL's diverse capabilities span a broad range of scientific and engineering disciplines, enabling the Laboratory to explore fundamental science challenges and to carry out the research needed to accelerate the delivery of solutions to the marketplace.

Zacharia welcomed attendees to ORNL, noting its positive impact on society, the economy and national security. And, importantly for the purposes of the discussion, he emphasized, high performance computing is one of the areas where ORNL and the United States expect to be a global leader.

Mr. Bill Bates, Executive Vice President, Council on Competitiveness, Dr. Thomas Zachaira, Director, Oak Ridge National Laboratory, and Dr. Suzanne Lacey, Superintendent of Talladega County Schools.

Dr. Suzy Tichenor, Co-Executive Director, ECP Industry Council, Oak Ridge National Labortory and Mr. Robert Oelrich, Manager, Global ATF Technology, Westinghouse Electric Company.

The software challenge

Picking up where the prior Forum left off, Douglas Kothe, Director Exascale Computing Project, DOE; and Robert Oelrich, Manager, Global ATF Technology, Westinghouse Electric Company, led a discussion on critical partnerships for advanced computing software development. Highlighting that any software today is a snapshot in time, speakers suggested that what really mattered were the ideas and intent, not the specific code. As to the development of new software, it was pointed out how critical it is to develop it in collaboration whenever possible.

Citing the DOE's Exascale Project as an example, Kothe referenced software development kits for opensource development, highlighting the importance of agreeing to a set principles and policies up front for how to work together. Oelrich used the Consortium for Advanced Simulation of Light Water Reactors (CASL) as an example from the nuclear industry where cooperation and collaboration have led to advance modeling and simulation tools to help confirm the safety and accuracy of first-of-kind nuclear reactors. Once they have seen the efficacy of the software demonstrated, regulators have greater confidence in such tools to confirm safety.

Partnerships

Highlighting partnerships between the national laboratories and industry, Fred Streitz, Director, HPC Innovation Center, LLNL; and Jeff Nichols, Director National Center for Computational Sciences, ORNL, provided an overview of their respective laboratories' missions with regard to engaging industrial partners. Clearly, one of the central benefits to these collaborations for the laboratory is to work on large scale projects with outside partners who bring new ideas and thinking to the table. Similarly, the laboratories tend to be years ahead of industry with regard to computing capability, so often industrial partners are not even aware of what problems might be solved.

Dr. Fred Streitz, Director HPC Innovation Center, Lawrence Livermore National Laboratory

Dr. Mark Johnson, Director of the Center for Advanced Manufacturing, Clemson University.

Streitz highlighted the success of LLNL's High Performance Computing for Energy Innovation (HPC4EI) Program that now includes:

- Manufacturing (HPC4Mfg)
- Materials (HPC4Mtls)
- Mobility (HPC4Mobility)

Spring 2019 marks the second joint solicitation for HPC4EI, and is the eighth solicitation for the HPC4Mfg Program, the third for the HPC4Mtls Program, and the first for the HPC4Mobility Program.

Smart Cities

Mina Sartipi, Director, Center for Urban Informatics and Progress, University of Tennessee, Chattanooga; and William Copeland, Director, Business Intelligence, EPB Strategic Research, discussed the impact of advanced computing on the evolution of smart cities. The Center for Urban Informatics is an independent research entity focused on solutions to urban challenges. Bringing together initiatives related to energy, mobility, healthcare, public safety, water and waste, the Center is developing methods and models for use around the world. Advanced computing makes much of their work possible.

To glean useful information from the vast volume of data associated with smart cities requires strong computing capabilities and algorithms. Examples include gaining intelligence about buildings—energy efficiency, water use, etc. Much of this is driven by localities and/or consumers wanting to expand renewable energy use or get off the grid all together. Speakers noted the growth of hybrid buildings that generate off-grid power, but are still connected to the main power supply and can seamlessly choose based on need and cost. Advanced computing modeling and simulation can create a virtual model of energy usage.

Another area of great interest and potential is urban mobility. With an expected sharp rise in connected and/or autonomous vehicles, advanced computing will likely play a critical part in helping to manage the flow of traffic and predict the likelihood and location of accidents. The end goal is to make urban areas more accessible, livable and healthy for all.

Continuing the skills discussion

While discussions around workforce skills and education related to advanced computing have been a part of all four Forums, in this case attendees looked more closely at K-12 challenges and opportunities, recognizing that many students move away from STEM in middle school. Suzanne Lacey, Superintendent, Talladega County Schools; and Mark Johnson, Director, Center for Advanced Manufacturing, Clemson University, shared several important insights covering the educational spectrum from kindergarten through college.

Lacey highlighted several efforts underway in Talladega County to integrate STEM into the K-12 curriculum. In 2015, the school system was selected as a member of the League of Innovative Schools, recognizing the county's leadership in innovation and technology. Most recently, the school system is embarking on a major STEAM project (STEM plus the Arts) to include makerspaces and laboratories available to all students to help them prepare for and understand at an early age the potential in science and technology careers. After all, as Lacey pointed out, computational thinking starts in kindergarten.

Johnson, formerly head the DOE's Advanced Manufacturing Office, addressed his work with Clemson University to leverage the assets of the university to expand the use of advanced computing in the manufacturing sector. He noted that the effort was focused on bringing together complementary programs, not creating a new center. Similarly, he emphasized the need to identify and establish partnerships across supply chains. And, most importantly, students must be engaged across all of these efforts to develop a stronger link between education and opportunity.

Advanced computing and the manufacturing process

Closing out the Forum, presenters and attendees took a final look at the impact of advanced computing on the manufacturing process. John Hopkins, CEO, Institute for Advanced Composites Manufacturing Innovation (IACMI); Daniel Norman, Advanced Composites Technical Specialist, NIST MEP, University of Tennessee; and Clayton Walden, Director, Center for Advanced Vehicle Systems, Mississippi State University, provided their perspectives on the game changing nature advanced modeling and simulation can have on the entire manufacturing ecosystem in the United States.

Without advanced computing, it would be impossible to manage the tremendous volume of data being generated on the factory floor. Specific to the materials sector, advanced modeling and simulation is key to removing barriers to getting composite materials into vehicles, which will both decrease weight and increase safety. Computing underpins each phase of the manufacturing process: materials, design and development. In short, advanced computing is now powering the U.S. manufacturing sector.

SECTION VI

Advanced Computing Agenda

The Council on Competitiveness (Council), through its Advanced Computing Roundtable and insights from the four Advanced Computing for Competitiveness Regional Forums, has established several broad objectives for the United States:

1. **Compete at the high end of advanced computing.** Continue investing to be a technology leader as the world moves toward exascale computing, including in hardware, software and applications. America also must lead in strategic areas like extending Moore's Law and quantum computing.
2. **Improve the ability of HPC-using firms to leverage advanced computing.** The Council recommends steps to improve computational skills, increase industry partnerships with laboratories and academia, and expand and strengthen software partnerships. Regulatory agencies also should accelerate efforts to use modeling and simulation within the regulatory process.
3. **Expand the number of HPC-using companies in America.** Too few firms are able to leverage advanced computing to innovate and compete. Federal, state and local economic development efforts should be utilized to lower barriers and teach small and medium-sized firms, particularly manufacturers, to use advanced modeling, simulation and analytics.
4. **Coordinate federal action.** Federal agencies should continue to act in a coordinated fashion on advanced computing challenges through the Joint Program Office for Strategic Computing.
5. **Leverage HPC to compete in strategic technologies and applications.** Leadership in advanced computing is tightly linked to leadership in artificial intelligence, the Internet of Things, cybersecurity, additive manufacturing and other emerging technologies. Public and private sector leaders should collaborate on research and partnership efforts that ensure world-class computing environments for strategic technology leadership.

Federal Agenda

The federal government plays a crucial role in advanced computing leadership. Consistent with the preceding objectives, a federal advanced computing agenda should include:

Continued investment in the Exascale Computing Project

Only the federal government has the resources to continually press the frontiers of advanced computing through research and engineering. The federal government has critical missions in security, energy, science and other realms where leadership at the cutting edge of computing is synonymous with achieving the mission. Council studies show that government-led advances in computing migrate rapidly into the commercial sphere, contributing to economic competitiveness and innovation. As other nations, principally China, Japan and those in Europe, seek to gain advantage through next-generation computing technologies, it is essential that the United States remains competitive.

Regional computing centers patterned after the German Fraunhofer Institutes
The centers would focus explicitly on research with industrial partners in the system prototype phase (typically technology readiness level 6) and be funded through a combination of government and industry. Such centers would encourage best practices among members and build a stronger HPC-skilled workforce. The centers could be established near national laboratories to leverage infrastructure for computing and validation.

Measures to encourage more software partnerships
The U.S. Department of Energy (DOE) and the National Science Foundation (NSF) should coordinate a multi-agency effort to create incentives and eliminate technical and legal barriers to software partnerships between industry, independent software vendors (ISVs), national laboratories and academia.

- Industry users bring problems and real data, and would gain exclusive rights to solution and output data.
- ISVs bring software expertise and gain validation against real data and enhanced code to resell.
- Laboratories and university centers bring scientific and computing expertise, and would gain experience and rights to enhanced code.

The NSF's Software Infrastructure for Sustained Innovation (SI2) Program is also a strategic tool to support software research. In 2016, the SI2 program launched two software institutes, one centered on molecular science and another on science gateways. Gateways are mobile or web-based applications that provide broad access to the nation's shared cyber-infrastructure for scientists and citizens alike. They enable greater collaboration among researchers and greater access to advanced computing resources. The software institutes could be expanded or serve as models for public-private partnerships to collaborate on pre-competitive software development for advanced industry applications.

Programs at the national laboratories to develop standards, validation and mesh data
Laboratories would partner with industry groups to develop and disseminate standard problem/solution sets with which to validate new codes. The programs also would offer a collaborative environment for mesh generation that benefits multiple applications and industries. Laboratories would act as neutral parties with no commercial interest in the results. The lack of appropriately validated models is a primary barrier to the adoption of new software. An accepted methodology to validate software also would benefit regulatory agencies.

A national examination of HPC-related credential programs
The NSF should partner with other federal agencies, industry, private groups and relevant leaders in academia to examine and improve how HPC-related credential programs and experiential learning could be used more effectively to train students and life-long learners more quickly and cost effectively.

An industry collaboration resource
The DOE, in partnership with the NSF, should establish or support a web-based point of reference for federally operated and funded HPC centers that offer access for industry collaboration. For each center, the reference should offer:

- The host organization of the HPC center;
- The office or program that interfaces with industry;
- Contact information;
- A description of the center, including its mission and focal points;
- A summary of expertise at the laboratory, including research subjects and software capabilities;
- A link to the policies and options that govern industry access; and
- A technical overview of the systems available to industry—FLOPs, memory, storage, etc.

A search tool should be available for potential partners to find specific competencies or technical capabilities, and a management structure should be put in place to keep the information current.

Academic HPC centers seeking industry partners should have the option to join the tool at their expense. An interagency group should consider how to note or include other agencies with HPC capacity that offer more targeted industry access, including the U.S. Department of Defense, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the National Institutes of Health, the National Institute of Standards and Technology and the U.S. Department of Homeland Security.

Common model user agreements across the national laboratories
Common models, or more harmonized models, would ease and speed negotiations between industry and laboratories.

Greater industry collaboration
Examine existing HPC access programs at federal or federally-funded facilities to find ways to increase industry collaboration. In cases where peer review favors basic over more applied proposals, a percentage industry set-aside within which companies could compete should be implemented. Other reforms centered on IP flexibility and protection have the potential to increase industry collaboration.

Continued support or expansion of strategic programs
The Forums highlighted the importance of targeted efforts to leverage federal or federally-funded advanced computing technology and expertise to advance America's economic competitiveness. The HPC4EI model of competitive bids for partnership projects (in manufacturing, materials and mobility) at reduced cost is an excellent example.

In addition, the Manufacturing Extension Partnership (MEP) program of the National Institute of Standards and Technology is partnering with Manufacturing USA, a network of 14 public-private research institutes. Building on a backbone of advanced computing capacity at the institutes, especially the Digital Manufacturing and Design Innovation Institute, MEP centers across the country are working to help U.S. manufacturers enhance their competitiveness by adopting digital technologies.

Finally, several federal programs support education and training in STEM skills or computational skills. A greater focus on computational science skills in advanced computing environments is warranted. In addition, education and training support to programs that raise the computational literacy of business leaders is a crucial element of the United States becoming better able to leverage not only advanced modeling, simulation and analytics, but a host of other emerging technologies.

State and Local Agendas

Incorporating computer science and computational thinking into K-12 curriculums
States and localities should adopt model curriculums that have been established through organizations like the Computer Science Teachers Association, Code.org and Project Lead The Way. Cities such as New York, Chicago and San Francisco have launched initiatives to mandate computer science coursework or make it available for every student. The Forums also highlighted programs like the Computational Thinking Initiative of Digital Promise that supports K-12 school systems across the country to integrate computational thinking and problem-solving techniques across
a variety of school subjects.

Growing the number of post-secondary computer science curriculums that teach HPC-specific skills
Leverage organizations like HPC University and model curriculums such as those offered by the Ralph Regula School of Computational Science to increase the workforce of people with computer science and computational science credentials for advanced computing environments. Some of the most acute HPC skills gaps identified in a Council survey of HPC-user companies were training people to:

- Approach problems holistically using computational thinking;
- Create computational models;
- Identify flaws in computational models and simulations; and
- Improve computational performance of models and simulations.

Recognition for university faculty who produce research artifacts like software, data or algorithms
States and universities should consider not only publication, but also these highly valuable accomplishments as a basis for tenure, grants, awards, etc.

Business school programs that teach computational literacy for decision makers
States and universities should ensure that more students and life-long learners in business management disciplines gain a greater degree of computational literacy. A Council survey of HPC-user companies identified several areas requiring significant educational improvement or cultural change at most companies, including:

- Employing computational models for "what if" planning;
- Using computational models for situational awareness of existing conditions;
- Investing in or prioritizing computational models over alternatives like physical testing; and
- Making qualitative assessments of confidence, sources of error, accuracy and validity.

Partnerships to expand the base of HPC-user companies
State and county innovation and economic development strategies should include programs that lower the cost, skill and technology barriers for firms to learn how to leverage advanced computing. Many small and medium-sized enterprises could grow and become more competitive if they were to utilize advanced modeling, simulation and analytics. Often, however, such firms do not move beyond desktop CAD/CAM. They often lack: (1) an ability to evaluate cost versus risk and return; (2) technical expertise to solve problems on advanced systems; and/or (3) cost effective access to compute capacity and software.

The Forums highlighted two states—New York and Ohio—that have established model programs whereby firms can partner with advanced academic computing centers to overcome these barriers. In other locations, individual universities or local MEP centers have launched partnerships to tackle these problems. Such programs, however, remain fairly limited and often lack an adequately funded or staffed outreach component to reach a pool of firms who might benefit from the programs.

Additional Agenda Items

Building a robust advanced computing for competitiveness environment requires leadership from many stakeholders. The public sector has a critical role in bringing stakeholders together, making targeted investments, and creating a supportive regulatory environment. Industry and academia also must lead with innovative collaborations that create baseline frameworks for their industries and real-world opportunities for students and faculty to work on contemporary or emerging challenges.

Another opportunity for private sector leadership would be to encourage competition by establishing a ranking system to be published annually of the top computational science programs for advanced computing.

SECTION VII

Advanced Computing Roundtable Meetings

The Council's Advanced Computing Roundtable (ACR) aims to increase national competitiveness through the transformational use of advanced computing. The ACR defines advanced computing as: "the systematic use and development of domestic high-end computer hardware, operating and applications software; data management and analytics; visualization tools; and necessary infrastructure, talent and knowledge to exploit these capabilities (the HPC ecosystem) to solve science, engineering, industrial and commercial, and energy and national security challenges."

ACR Members include representatives of industry, academia and the national laboratories. The committee also invites regularly strategic government leaders, topic experts and private sector practitioners who contribute to the HPCAC deliberations. The bi-annual meetings serve to report on progress toward objectives, identify new priorities and examine emerging issues.

At the April 2016 ACR meeting, members received a briefing on an industry survey that offered insights into which HPC-related skills are in high demand, which software limitations are most acute for industry, and the state of industry use and awareness of HPC access programs at the national laboratories and in academia. Members also received briefings

about how HPC is used at Northrop Grumman and Micron Technologies, learned of legislative developments from the director of the United States Coalition to Advance Supercomputing, and heard a keynote about the path to HPC Competitiveness from Dona Crawford, retiring Associate Director for Computation, Lawrence Livermore Laboratory.

The November 2016 ACR meeting featured sessions on communications, legislation, the HPC for Manufacturing program and the implications of what lies "beyond Moore's Law." Thomas Campbell, National Intelligence Officer for Technology, United States National Intelligence Council, delivered a luncheon keynote on HPC and emerging technologies. Members also continued their discussion on future issues, with an interest in regulatory reforms that take advantage of modeling, simulation and analytics to advance public interests and ease compliance burdens.

At the April 2017 ACR Meeting, members were briefed on developments in Washington, D.C., including the status of HPC appropriations, the exascale computing project and the national strategic computing initiative. ACR members also kicked off a conversation on the scope of their work in light of the ways computing is changing. Developments such as artificial intelligence, the push to extend Moore's Law, the challenges of exascale, quantum computing, and the Internet of Things represent an evolution of technology, architectures and applications. Paul Horne, Senior Vice Provost for Research and Senior Vice Dean for Strategic Initiatives and Entrepreneurship, New York University, discussed the links between entrepreneurship, engineering and advanced computing. Lori Diachin, Director, HPC for Manufacturing Program, updated members about that program.

OPPOSITE PAGE

Members of the Advanced Computing Roundtable meet at the Council on Competitiveness headquarters in Washington, D.C., April 2016.

THIS PAGE

Top: *Dr. Mike Trutt, Chief Engineer–Algorithmic Warfare Department, Northrop Grumman Mission Systems; and Dr. Gary Mastin, Senior Fellow, Corporate Engineering, Technology & Operations, Lockheed Martin.*

Bottom: *Dr. Barry C. Bolding, former Vice President, Marketing and Business Development, Cray Inc.; Mr. David W. Turek, Vice President, Technical Computing OpenPOWER, IBM Systems Group, IBM Corporation; Dr. Mark Seager, Intel Fellow, Chief Technology Officer for the HPC Ecosystem, Intel Corporation; and Mr. Scott Misage, Vice President and General Manager for High Performance Computing, Hewlett-Packard Company.*

Top: *Mr. Bill Cave, CEO, Predictsys; and Mr. Richard Arthur, Senior Principal Engineer/Senior Director–Computational Methods Research, GE.*

Bottom: *Mr. Robert Meisner, Director, Advanced Simulation and Computing, National Nuclear Security Administration; Dr. J. Steve Binkley, Associate Director, Advanced Scientific Computing Research, Office of Science; and Mr. Chad Evans, Executive Vice President, Council on Competitiveness.*

The October 2017 ACR Meeting featured a deeper conversation on the new landscape of advanced computing and what that means for the ACR. The conversation was moderated by ACR Co-Chair Patricia Falcone, Deputy Director for Science and Technology, Lawrence Livermore National Laboratory; and Barry Bolding, former Vice President, Marketing and Business Development, Cray, Inc. Members also were briefed on the NSCI by members of the Joint Program Office. Steve Conway, Senior Research Vice President, Hyperion, discussed a new report: *Worldwide Best Practices in Partnerships between HPC Centers and Industrial Users*.

On April 11, 2018, the ACR gathered to be briefed on and discuss a series of potentially disruptive technologies enabled by advanced computing, including quantum computing, artificial intelligence and machine learning. Jerry M. Chow, Manager of Experimental Quantum Computing, IBM Corporation; René Copeland, President, D-Wave (Government) Inc.; Robert Sorensen, Vice President of Research and Technology and Chief Analyst for Quantum Computing, Hyperion Research; and R. Paul Stimers, Partner, K&L Gates, and Organizer of the Quantum Industry Coalition reviewed the latest advancements in quantum computing and described several exciting applications. John Langford, Principal Researcher, Microsoft Corporation, presented on the promise of artificial intelligence for U.S. competitiveness. Debra Goldfarb, Chief Analyst, Competitive Performance and Market Intelligence, Intel Corporation; and Rick Stevens, Associate Director for Computing, Argonne National Laboratory, updated the ACR on development in machine/deep learning and its implications for competitiveness and national security.

Top: *Ms. Dona Crawford, Senior Fellow, Council on Competitiveness, and President, Livermore Foundation; Dr. J. Michael McQuade, former Senior Vice President for Science and Technology, United Technologies Corporation; the Honorable Patricia Falcone, Deputy Director for Science and Technology, Lawrence Livermore National Laboratory; the Honorable Steven Koonin, Distinguished Fellow, Council on Competitiveness, and Director, Center for Urban Science and Progress (CUSP), New York University; and the Honorable Deborah L. Wince-Smith, President & CEO, Council on Competitiveness.*

Bottom: *Ms. Debra Goldfarb, Chief Analyst, Intel Fellow, Intel Corporation; and Dr. Rick Stevens, Director for Computing, Environment and Life Sciences, Argonne National Laboratory.*

Top: *Mr. Bob Sorenson, Vice President of Research and Technology, Hyperion Research; Dr. Rick Stevens, Director for Computing, Environment and Life Sciences, Argonne National Laboratory; and Dr. Fred Streitz, Chief Computational Scientist, Lawrence Livermore National Laboratory.*

Bottom: *Mr. Chad Evans, Executive Vice President, Council on Competitiveness; and Mr. Vipin Chaudhary, Program Director, National Science Foundation.*

On October 31, 2018, the ACR met to continue their review and assessment of evolving technologies powered by advanced computing, with presentations on HPC's impact on cybersecurity, the economic potential for new blockchain technologies and a keynote from DARPA on advanced microelectronics. Marcus H. Sachs, Partner, Technology Practice, RIDGE-LANE Limited/RIDGE-LANE Capital, and Brent Draney, Group Lead, Networking, Servers and Security Group, National Energy Research Scientific Computing Center, Lawrence Berkeley National Laboratory, discussed the pitfalls and potential of HPC and cybersecurity, as well as broader issues associated with the proliferation of sensors and other connected devices to streamline processes and resource usage, but also create new vulnerabilities if cyber security is not built into these systems. William Chappell, Director, Microsystems Technology Office, Defense Advanced Research Projects Agency, keynoted the meeting and highlighted projects underway at DARPA in the field of microelectronics and challenges related to extending Moore's Law. The meeting concluded with a presentation by Robert Frazier, Principal Cyber Architect, Lockheed Martin Corporation; and Michael E. Mylrea, Senior Advisor for Cyber Security & Energy Technology and Blockchain Lead, Pacific Northwest National Laboratory on recent developments with blockchain technology and various potential applications to facilitate secure transactions.

Mr. Robert Frazier, Development Engineer at Kinney Group, Inc.; and Dr. William Chappell, Special Assistant to the Director, Defense Advanced Research Projects Agency (DARPA).

SECTION VIII

About the Council on Competitiveness

For more than three decades, the Council on Competitiveness (Council) has championed a competitiveness agenda for the United States to attract investment and talent and spur the commercialization of new ideas.

While the players may have changed since its founding in 1986, the mission remains as vital as ever—to enhance U.S. productivity and raise the standard of living for all Americans.

The members of the Council—CEOs, university presidents, labor leaders and national laboratory directors—represent a powerful, nonpartisan voice that sets aside politics and seeks results. By providing real-world perspective to Washington policymakers, the Council's private sector network makes an impact on decision-making across a broad spectrum of issues—from the cutting edge of science and technology, to the democratization of innovation, to the shift from energy weakness to strength that supports the growing renaissance in U.S. manufacturing.

The Council's leadership group firmly believes that with the right policies, the strengths and potential of the U.S. economy far outweigh the current challenges the nation faces on the path to higher growth and greater opportunity for all Americans.

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SECTION XI

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