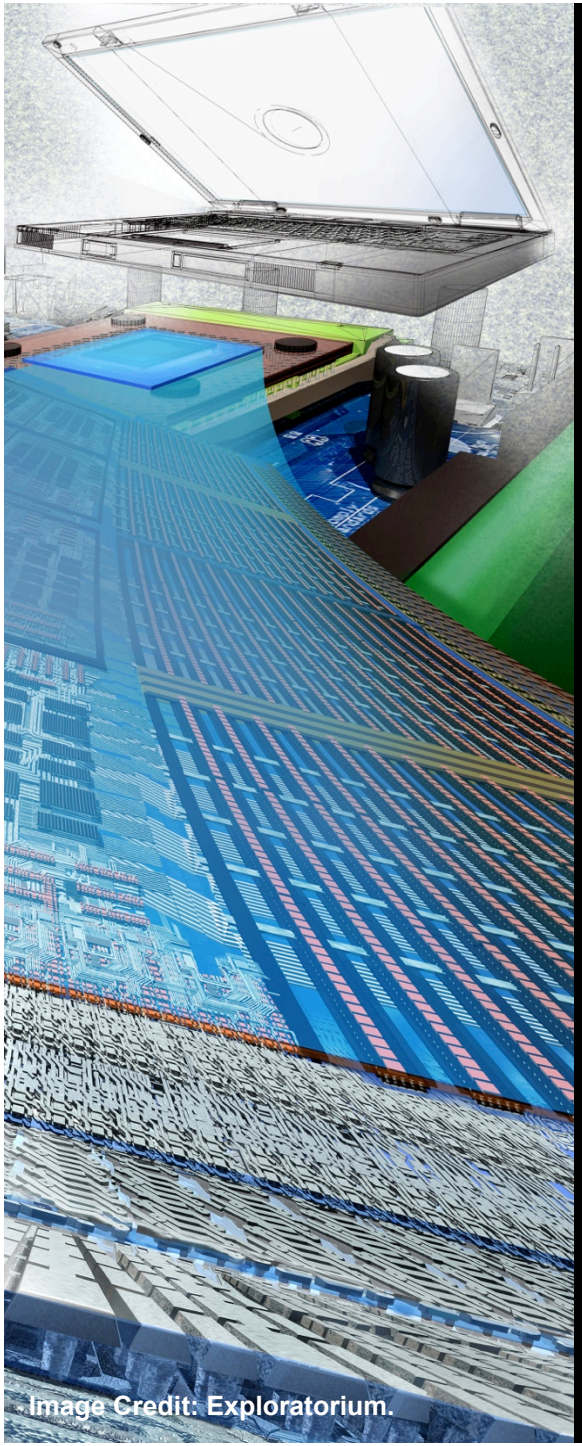


Innovating for Society: The Transformative Impact of Computing in a Data-Driven World

Farnam Jahanian
CISE Directorate
National Science Foundation

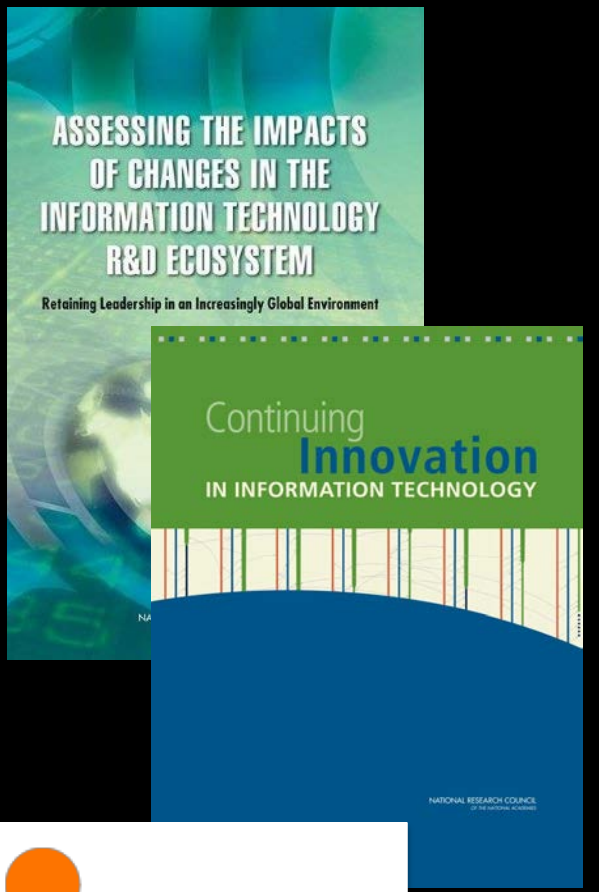
2014 CRA-W Graduate Cohort Program
Santa Clara, CA
April 11, 2-14

Pervasive Impact

- We are at the center of an ongoing societal transformation and will be for decades to come.
- Advances in computing, communication and information technologies:
  - Underpin our **economic prosperity and national security**;
  - Serve as a key driver of **U.S. competitiveness** and sustainable **economic growth** in an increasingly global market;
  - **Accelerate the pace of discovery and innovation** in nearly all other fields of inquiry;
  - Are crucial to achieving our major **national and societal priorities**.

Economic Impact of IT

- Growth of IT industry coupled with productivity gains across the entire economy have had enormous impact.
- IT industries accounted for 25% of US economic growth since 1995.
  - In 2010, IT industries grew 16% and contributed 5% to overall US GDP
- Use and production of IT accounted for ~2/3 of the post-1995 growth in labor productivity.
- IT sector generates jobs: IT jobs have grown 125x faster than employment as a whole between 2001 and 2011, and in 2011, IT workers earned 74% more than the average worker.
- IT diversifies regional economies to include idea-driven “creative” industries.



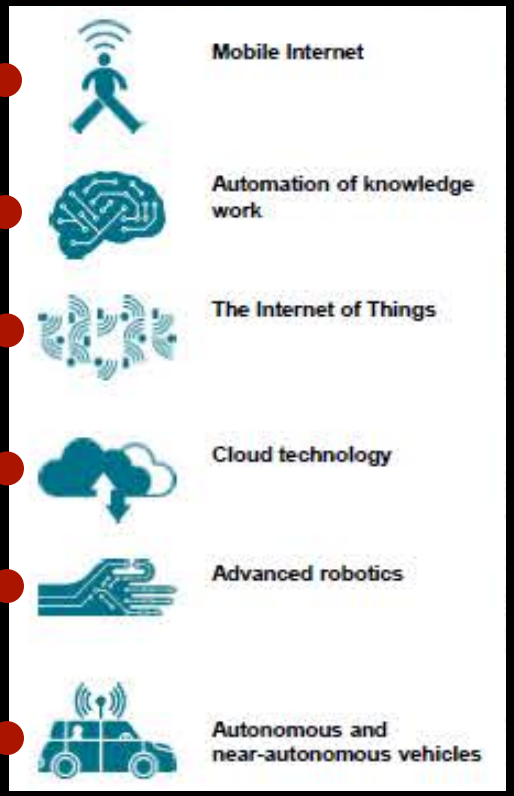
ITIF
The Information Technology & Innovation Foundation

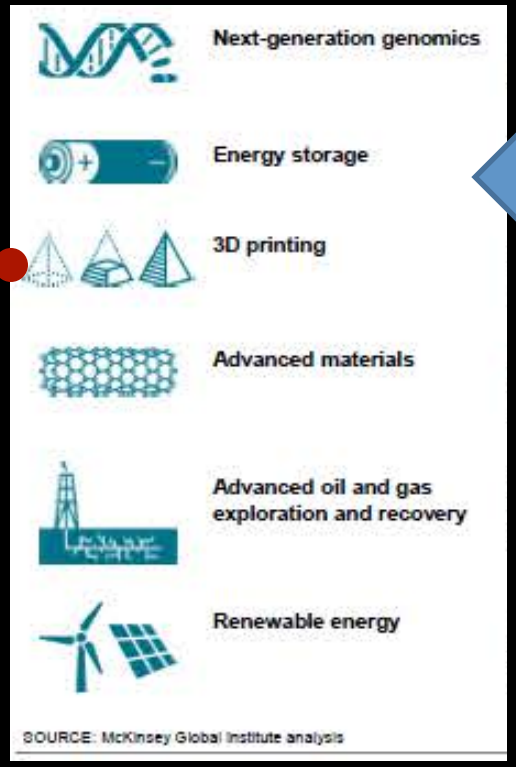
NSF

Sources: NRC (2009). *Assessing the Impacts of Changes in the IT R&D Ecosystem*.; NRC (2012). Continuing Innovation in Information Technology.; ITIF (2012). *Looking for Jobs? Look to IT in 2010 and Beyond.*

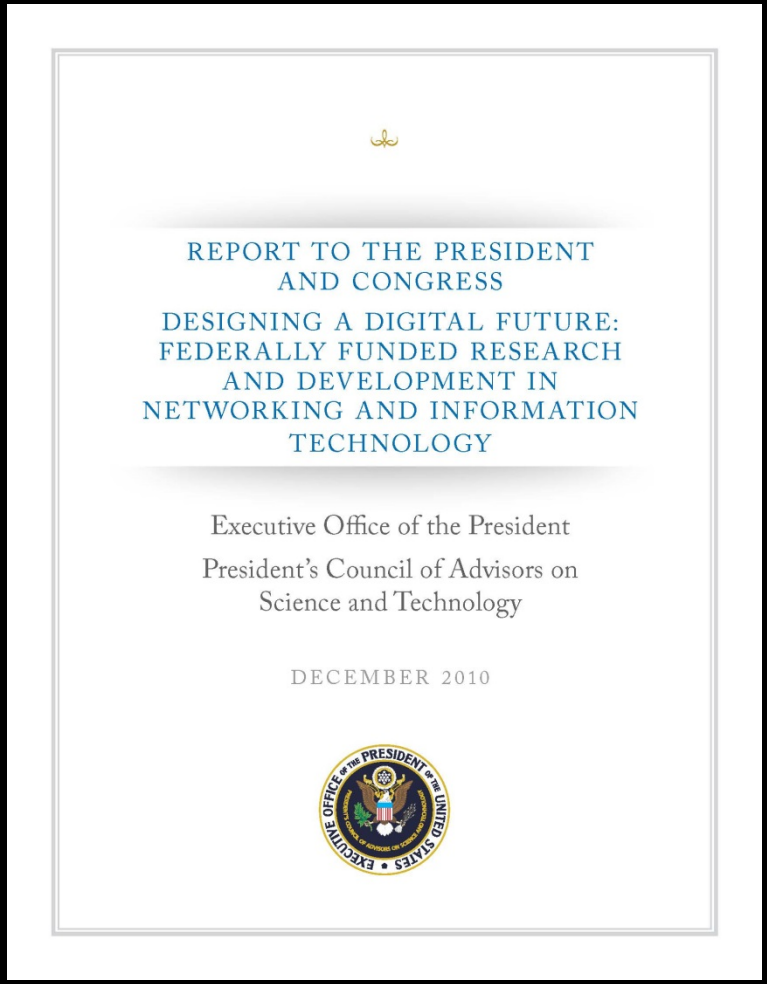
The Future …

Top twelve economically disruptive technologies (by 2025)





A National Imperative

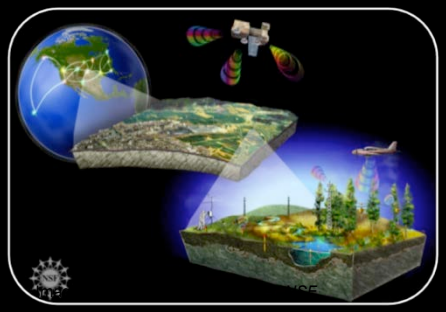


http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf

"Recent technological and societal trends place the further advancement and application of networking and information technology squarely at the center of our Nation's ability to achieve essentially all of our priorities and to address essentially all of our challenges."

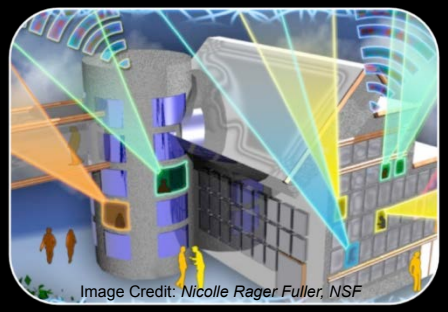
Source: PCAST (2010). Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology. – A periodic congressionally-mandated review of the Federal Networking and Information Technology Research and Development (NITRD) Program.

National Priorities



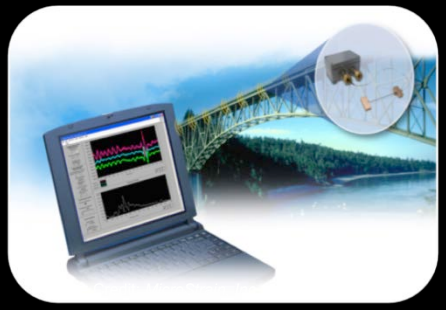
Environment & Sustainability

Health & Wellbeing



Universal Access

Emergency Response & Disaster Resiliency



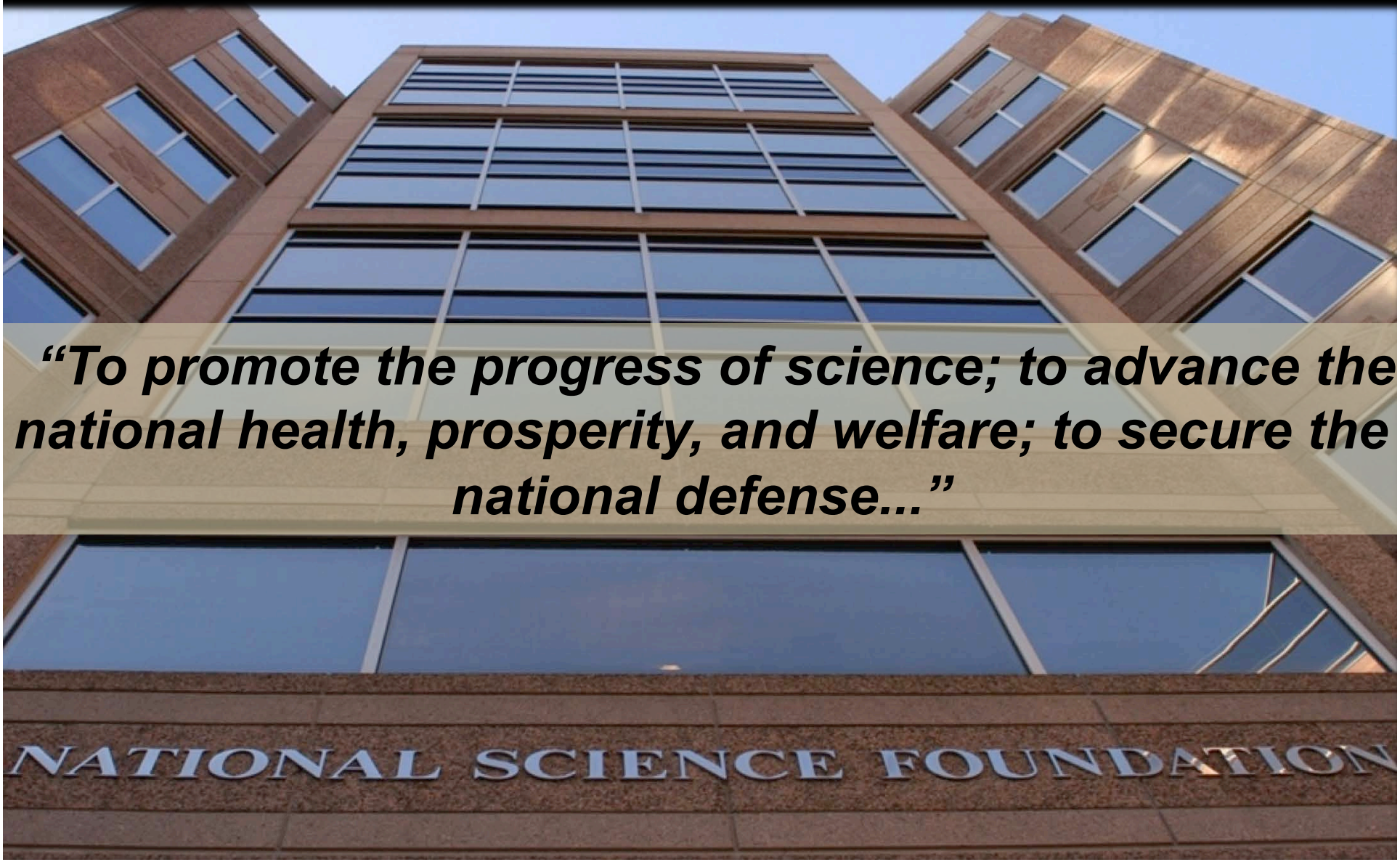
Manufacturing and Automation

Secure Cyberspace

Transportation & Energy

Education and Workforce Development

National Science Foundation's Mission



"To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense..."

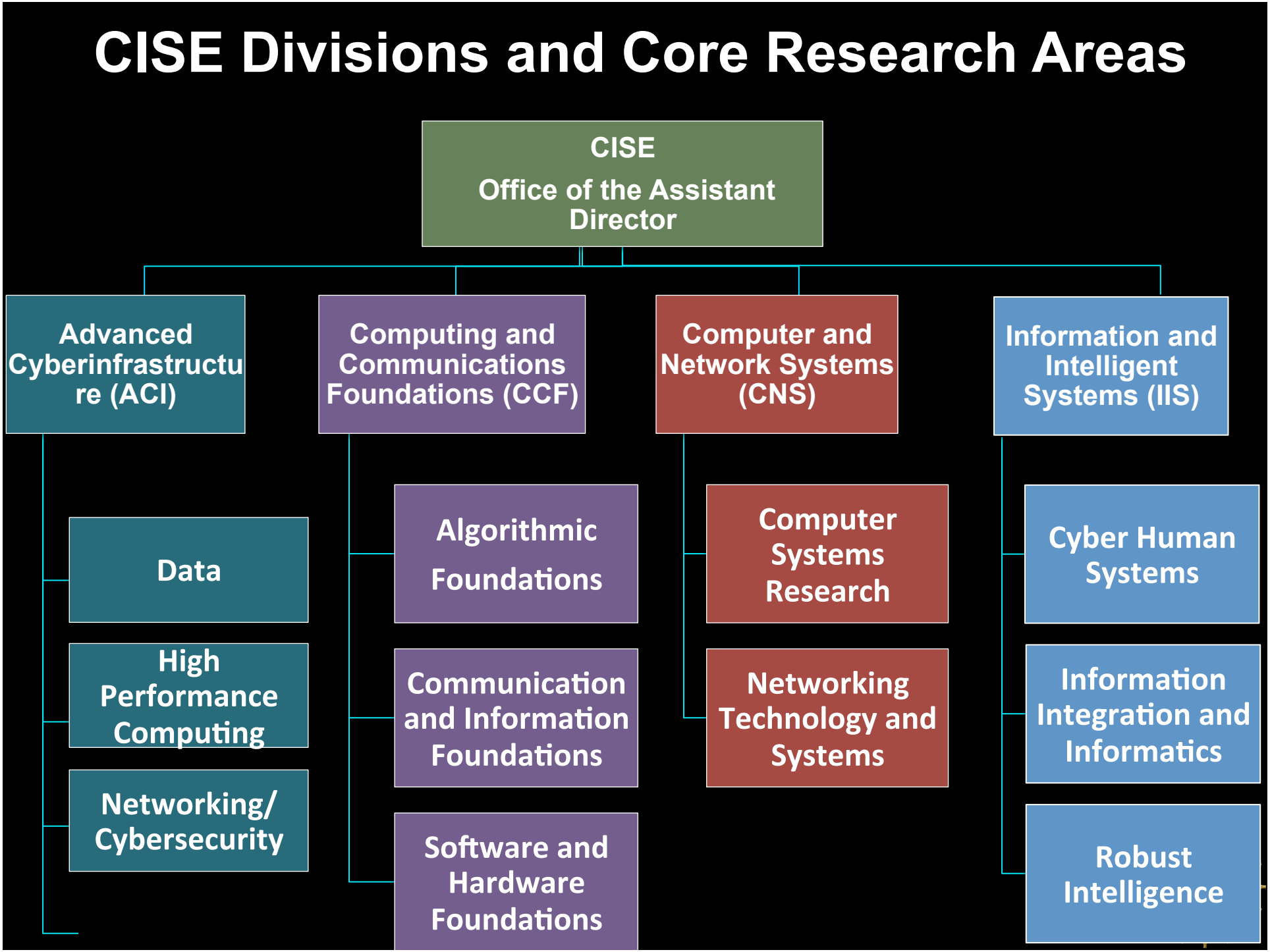
Computer and Information Science and Engineering (CISE) Directorate

Exploring the frontiers of computing

- Promote progress of computer and information science and engineering research and education, and advance the development and use of cyberinfrastructure.
- Promote understanding of the principles and uses of advanced computer, communications, and information systems in support of societal priorities.
- Contribute to universal, transparent and affordable participation in a knowledge-based society.

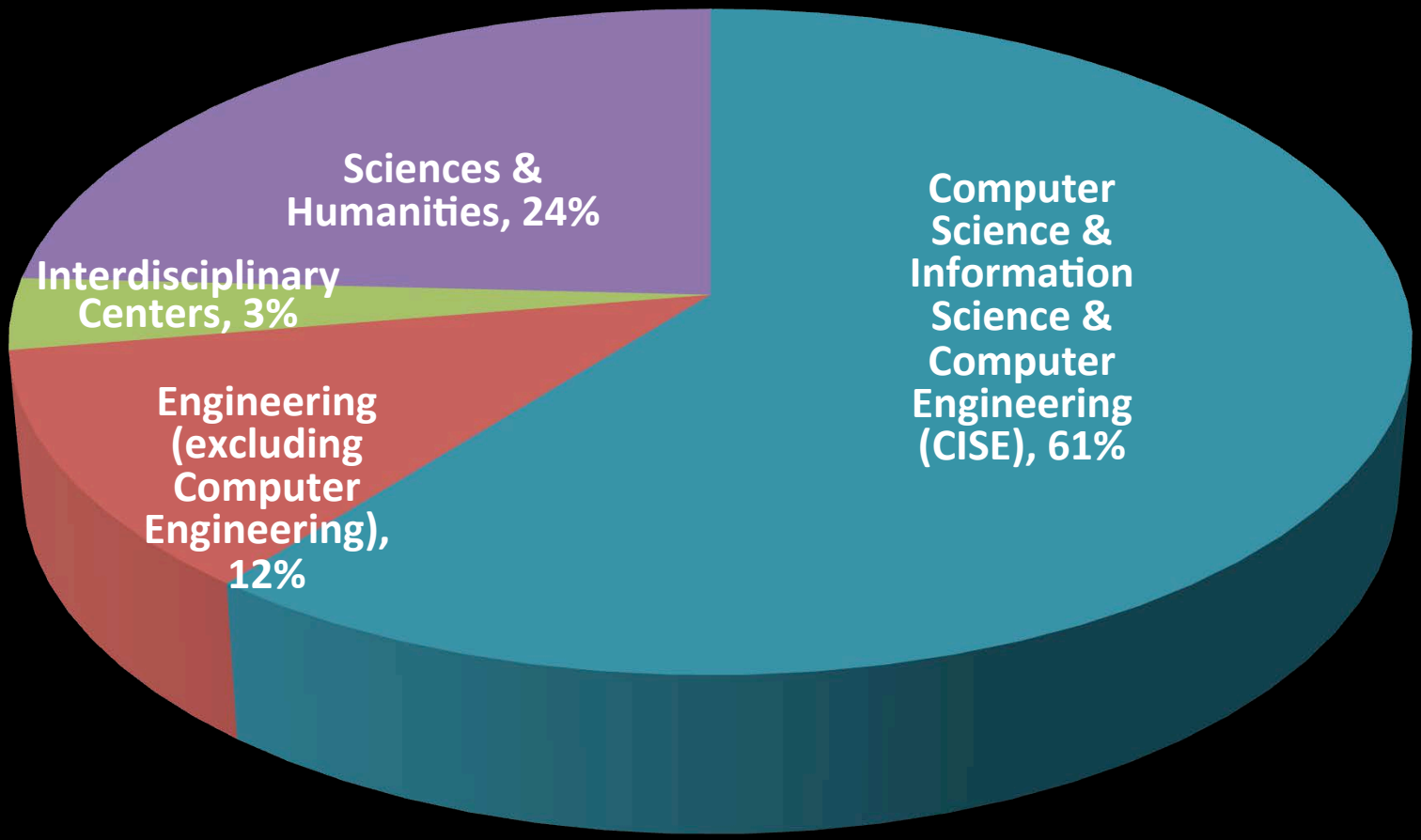
These frontiers have interfaces with all the sciences, engineering, education and humanities and a strong emphasis on innovation for society.

CISE Divisions and Core Research Areas



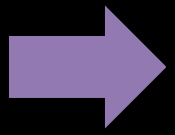
Who is the CISE Community?

PI and Co-PI Departments for FY 2013 Awards Funded by CISE



Snapshot of CISE FY 2013 Activities

	CISE
Research Budget	$858M
Number of Proposals	7,821
Number of Awards	1,616
Success Rate	~21%
Average Annualized Award	$204K
Number of Panels Held	344
Number of People Supported	17,227



	CISE
Senior Researchers	6,652
Other Professionals	1,186
Postdoctoral Associates	475
Graduate Students	6,609
Undergraduate Students	2,305

Budget Process (Brief) Overview

Community Input

- Societies and Academies
- CCC and CRA visioning activities
- CSTB Studies
- CISE Advisory Committee and Industry
- Workshops and direct engagement of PIs

Administration Priorities

- Office of Science and Technology Policy (OSTP)
- Office of Management and Budget (OMB)

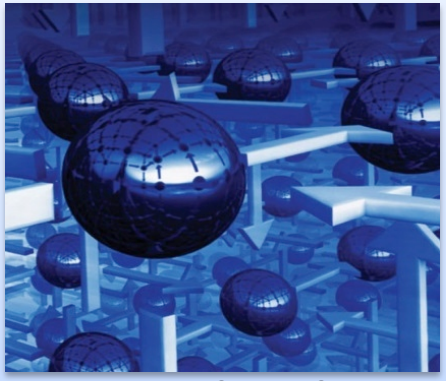
Internal Deliberation and Negotiation

- within directorate
- cross-foundation
- cross-agency

Emerging Frontiers

Data Explosion

Smart Systems: Sensing, Analysis and Decision



Expanding the Limits of Computation

Secure Cyberspace

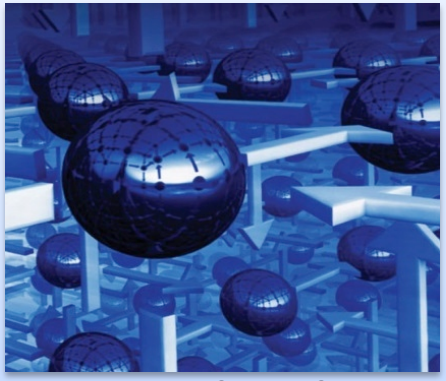
Universal Connectivity

Augmenting Human Capabilities

Emerging Frontiers

Data Explosion

Smart Systems: Sensing, Analysis and Decision



Expanding the Limits of Computation

Secure Cyberspace

Universal Connectivity

Augmenting Human Capabilities

From Data to Knowledge to Action

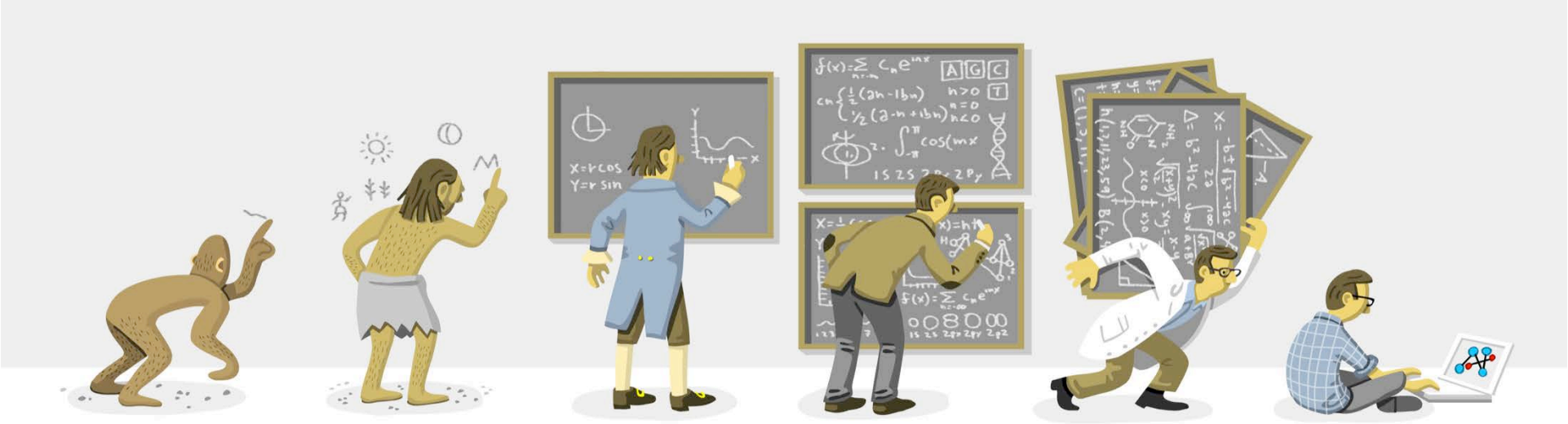
Data represent a transformative new currency for science, engineering, education and commerce.

Image Credit: CCC and SIGACT CATCS

Seizing the Big Data Revolution

- **Data Tsunami: Explosive Growth in Size, Complexity, and Data Rates**
  - Enabled by experimental methods, observational studies, scientific instruments, simulations, email, videos, images, click streams, Internet transactions … and sensors everywhere!

- **The Age of Data: From Data to Knowledge to Action**
  - Widespread use of data to create actionable information leads to timely and more informed decisions and actions.



Hypothesis-driven to Data-driven Discovery

The Economist, The data deluge and how to handle it: A 14-page special report (Feb 25, 2010).

The Fourth Paradigm: Data-Intensive Scientific Discovery (2009, Microsoft Corporation).

http://www.sciencemag.org/site/special/data/ http://www.economist.com/node/15579717

http://research.microsoft.com/en-us/collaboration/fourthparadigm/

Data are motivating a profound transformation in the culture and conduct of scientific research.

What is possible?

From **data** to **knowledge** to **discovery** by

- Enabling **extraction of knowledge** from very large, heterogeneous data sets
- Providing novel approaches to **driving discovery** and **decision-making**
- Yielding increasingly more **accurate predictions**, potentially saving lives
- Providing deeper understanding of potential **causal connections** based on advanced data analysis

Extracting Knowledge from Data

Classifying Breast Cancers
via Image Analysis

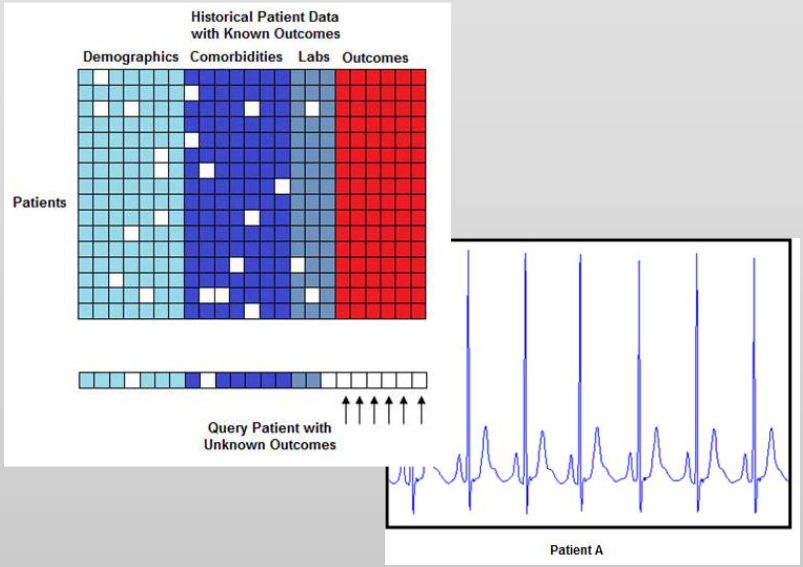
Energy Savings
in the Home

Reducing Traffic Congestion
in Urban Areas

Data at the Forefront of Diagnosis

Predicting Risk of Cardiovascular Death

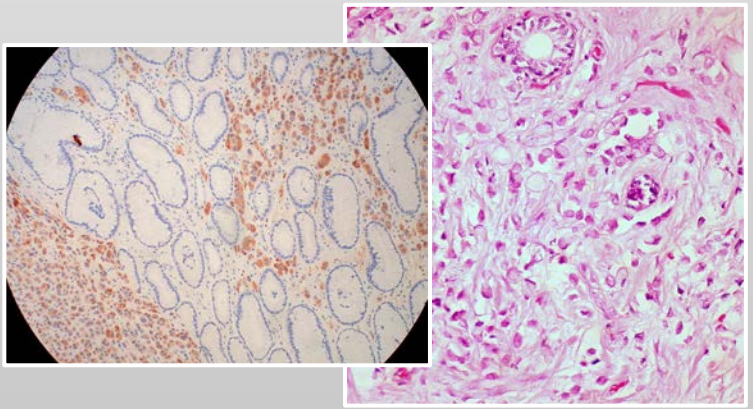
- Applying **data mining and machine learning** techniques to EKGs has identified new "computational biomarkers."
- These markers can help determine **heart abnormalities and defects**, leading to significant improvement in identifying and treating at-risk patients.



Zeeshan Syed, University of Michigan and John Guttag, MIT

Predicting Survival Time of Breast Cancer Patients

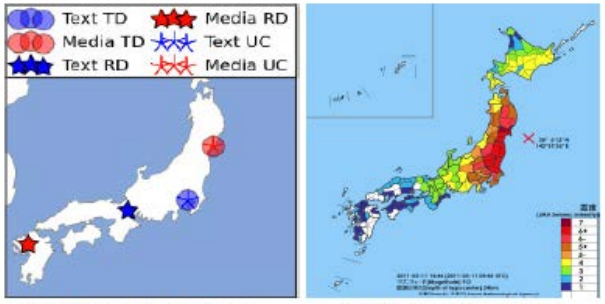
- Applying **image analysis techniques** to breast cancer biopsy images has identified a small subset of cellular features (out of 6,000 possible) predictive of survival time among breast cancer patients.
- This feature set that is the best predictor were not from the cancer tissue itself, but rather from adjacent tissue – something that previously **had gone undetected by pathologists and clinicians**.



Social Media and Big Data

Social Media Provides Rapid Insight into the Extent of Damage Following a Catastrophic Event

- Researchers at Texas A&M **analyzed and modeled** the spatial coverage of social media following the 2011 Tokhuku earthquake in Japan and the the 2011 Christchurch earthquake in New Zealand.
- Analyzed tweet density, re-tweet density, and tweet count to estimate the **epicenter** and model **intensity** attenuation of each earthquake.

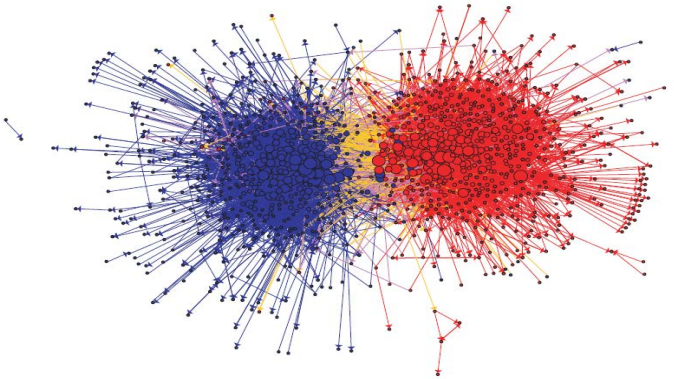


(a) Estimated Epicenter (b) Actual Epicenter

Yuan Liang, James Caverleeand John Mander, Texas A&M

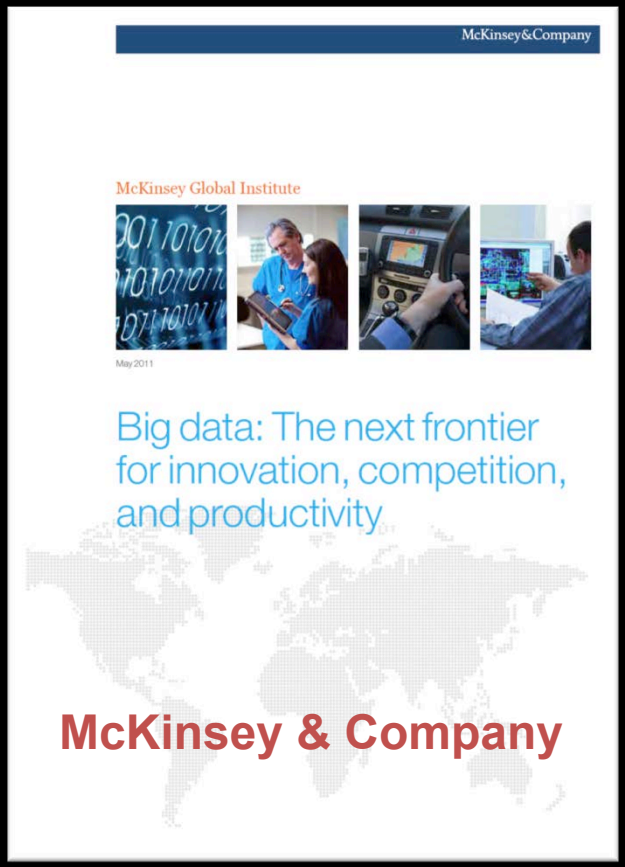
Understanding Political Communities

- Measuring the degree of interaction between liberal and conservative blogs uncovered differences in the **structure of the two communities.**
- Found **differences in the behavior** of liberal and conservative blogs, with conservative blogs linking to each other more frequently and in a denser pattern.



From "The Political Blosphere and the 2004 US Election: Divided They Blog" by Lada Adamic and Natalie Glance

Education, Learning, Workforce Development, Computational and Data-enabled Science



"By 2018 the United States alone faces a shortage of 140,000 to 190,000 people with analytical expertise and 1.5 million managers and analysts with the skills to understand and make decisions based on the analysis of big data."[1]

[1] McKinsey&Company (May 2011), "Big data: The next frontier for innovation, competition, and productivity." Available at: http://www.mckinsey.com/Insights/MGI/Research/Technology_and_Innovation/Big_data_The_next_frontier_for_innovation

“Our ability to generate data far exceeds our ability to digest it!”

Too Big to Ignore: The Business Case for Big Data
By Phil Simon

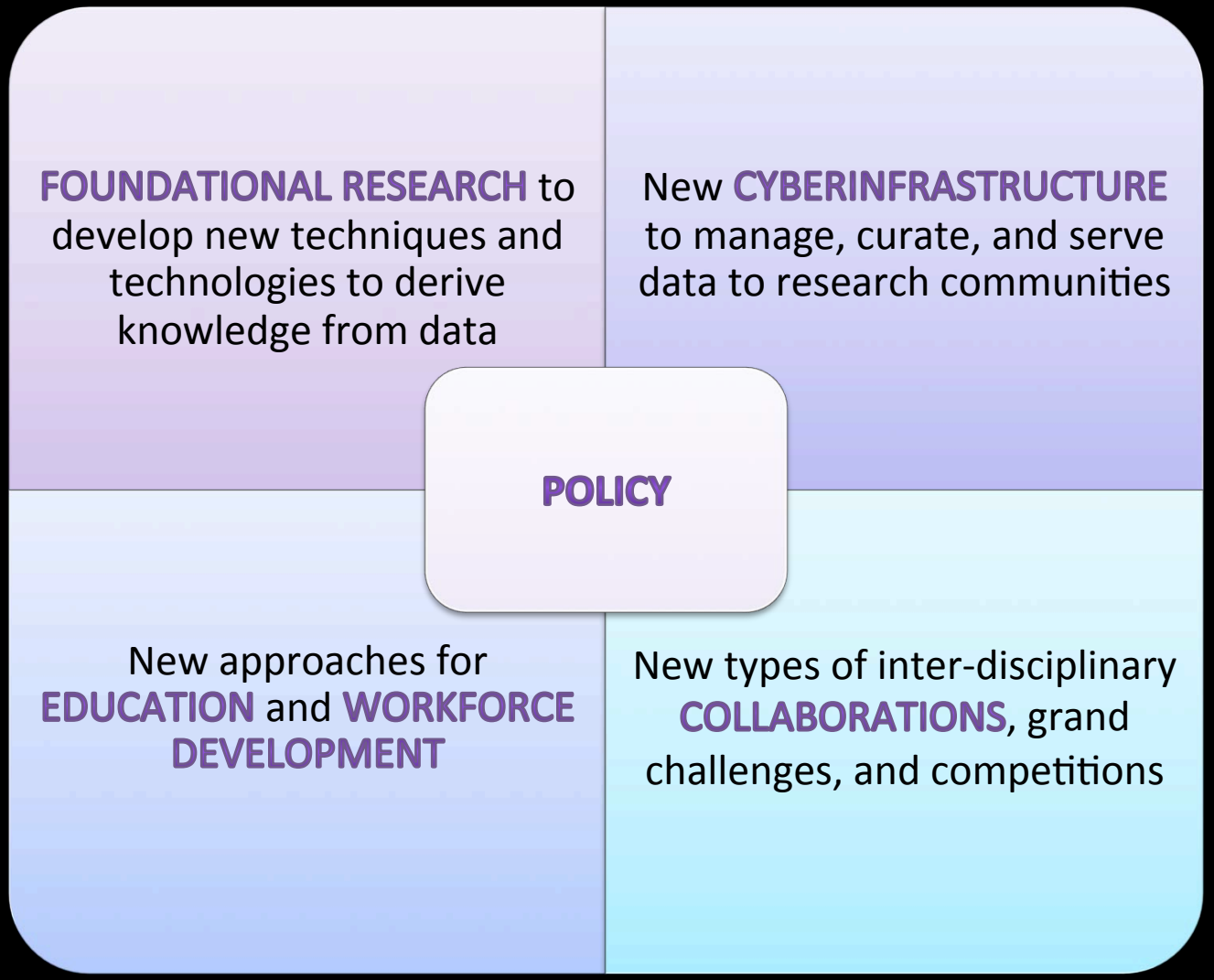
Federal Big Data R&D Initiative

- **Cross-agency "Big Data" Senior Steering Group –** chartered in spring 2011 by OSTP:
  - Co-chaired by NSF and NIH
  - Significant research community input

- **Launched** by OSTP on March 29, 2012
  - **Major Announcements**: NSF, NIH, USGS, DoD, DARPA, DOE

- **Data to Knowledge to Action** event hosted by OSTP November 12, 2013
  - Encouraging **public-private partnerships** across the country

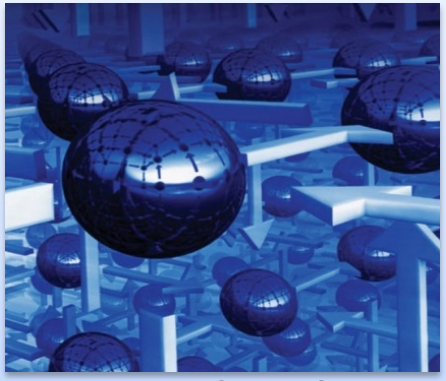
NSF's Big Data Strategy



Emerging Frontiers

Data Explosion

Smart Systems: Sensing, Analysis and Decision



Expanding the Limits of Computation

Secure Cyberspace

Universal Connectivity

Augmenting Human Capabilities

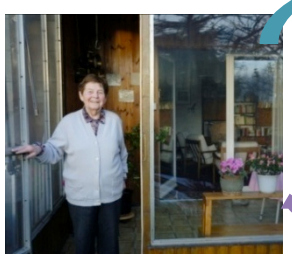
Ubiquitous deployment of sensors

The melding of the cyber and physical worlds enables smart systems all around us.

Smart Systems: Sensing, Reasoning, and Decision

Environment Sensing



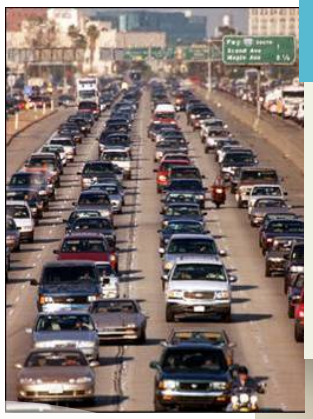

Percepts (sensors)

Agent (Reasoning)

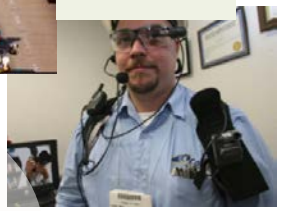

Actions (controllers)

Pervasive Computing

Emergency Response



Situation Awareness : Humans as sensors feed multi-modal data streams


People-Centric Sensing

Social

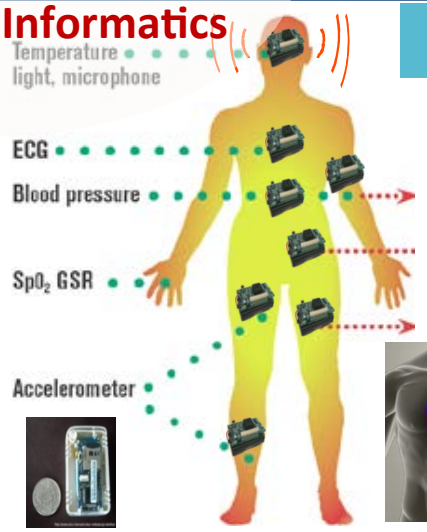



Public Sensing

Personal Sensing

Social Sensing

Informatics



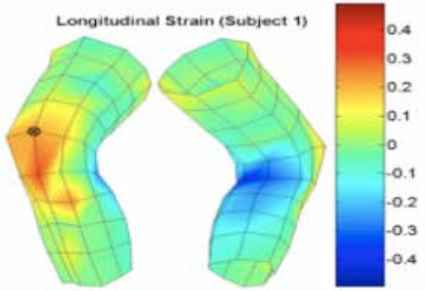
Smart Health Care

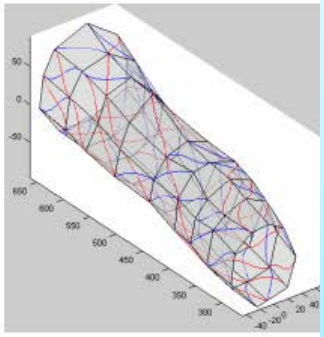

Source: Sajal Das, Keith Marzullo

Credit: Image courtesy of University of Florida

Proliferation of Sensors at all Scales

Assistive Medical Technologies: Programmable second skin senses and re-educates injured nervous systems. (Eugene Goldfield, Harvard Medical School)

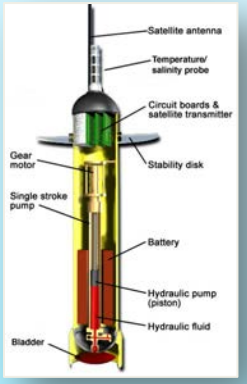




Autonomous Vehicles: Development of precision and real-time sensors, smart algorithms, and verification tools enabling self-driving cars. (Ragunathan "Raj" Rajkumar, CMU, et al.)

http://www.nsf.gov/news/special_reports/science_nation/carswithoutdrivers.jsp

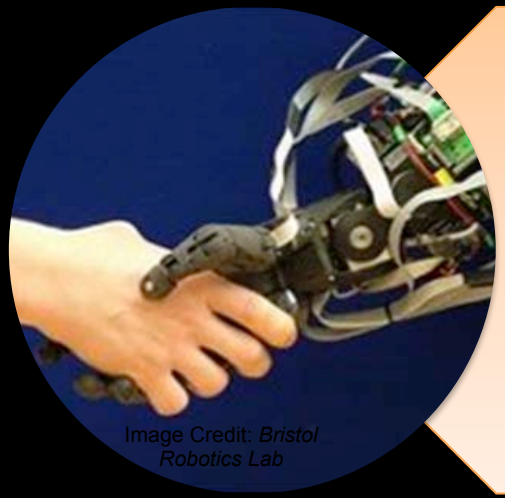
Science and Engineering Across the Oceans: Cyber-enabled ocean-observing networks made possible by more than three decades of float technology research



Research to Enable Smart Systems

Cyber-Physical Systems (CPS)

- ***Deeply integrate computation, communication, and control into physical systems***
- Aspects of CPS include pervasive computation, sensing and control; networking at multi- and extreme scales; dynamically reorganizing/reconfiguring systems; and high degrees of automation
- Dependable operation with high assurance of reliability, safety, security, and usability



National Robotics Initiative (NRI)

- ***Develop the next generation of collaborative robots, or co-robots, that work beside and cooperatively with people***
- A nationally concerted cross-agency effort among NSF, NASA, USDA, and NIH
- Initiative includes aim to understand the long-term social, behavioral, and economic implications
- Potential to enhance personal safety, health, and productivity

Application sectors

Transportation

Energy and Industrial Automation

Health and Medical Care

Critical Infrastructure

NSF

The National Robotics Initiative (NRI)

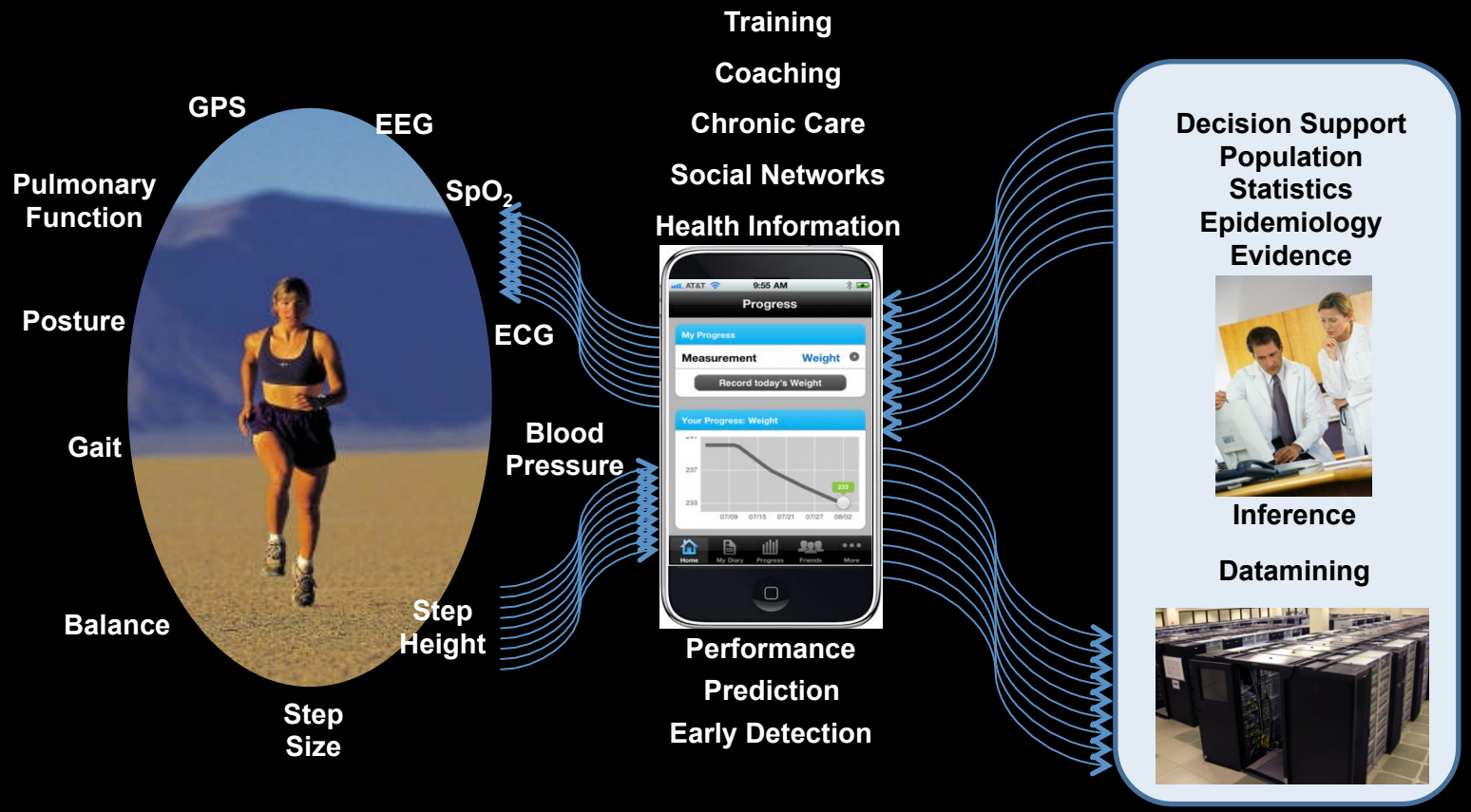
A **nationally coordinated** program across multiple government agencies to develop the **next generation of robotics**, to advance the **capability and usability** of such systems and artifacts, and to encourage existing and new communities to focus on **innovative application areas**.

NSF NASA NATIONAL INSTITUTES OF HEALTH USDA

United States Department of Agriculture
National Institute of Food and Agriculture

Smart and Connected Health

Transforming healthcare from reactive and hospital-centered to preventive, proactive, evidence-based, person-centered and focused on wellbeing rather than disease



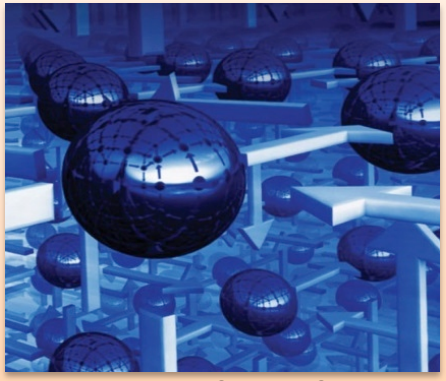
Joint NSF and NIH Program

Cross-Directorate Program: CISE, ENG, and SBE

Emerging Frontiers

Data Explosion

Smart Systems: Sensing, Analysis and Decision



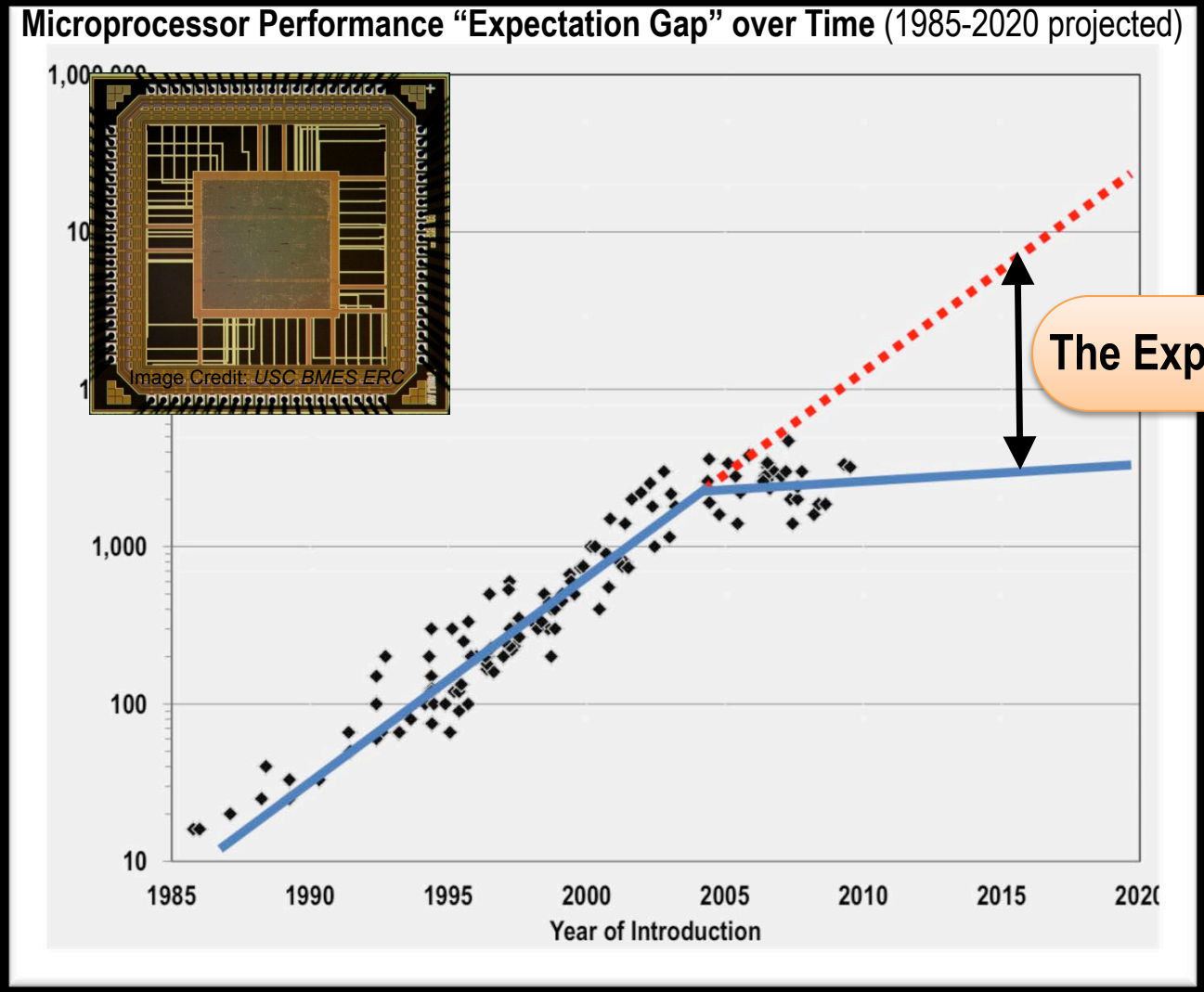
Expanding the Limits of Computation

Secure Cyberspace

Universal Connectivity

Augmenting Human Capabilities

Processor Performance Plateaued Around mid-2000s



Credit: Graph reprinted with permission from *The Future of Computing Performance: Game Over or Next Level?* National Academy of Sciences (2011).

Impact of Single-Processor Performance

Accentuated by emergence of **massive data sets,** scientists have an increasing appetite and need for speed and performance.

Important new science questions in **physics, materials, biology, health and medicine, and climate change** require increased processing power.

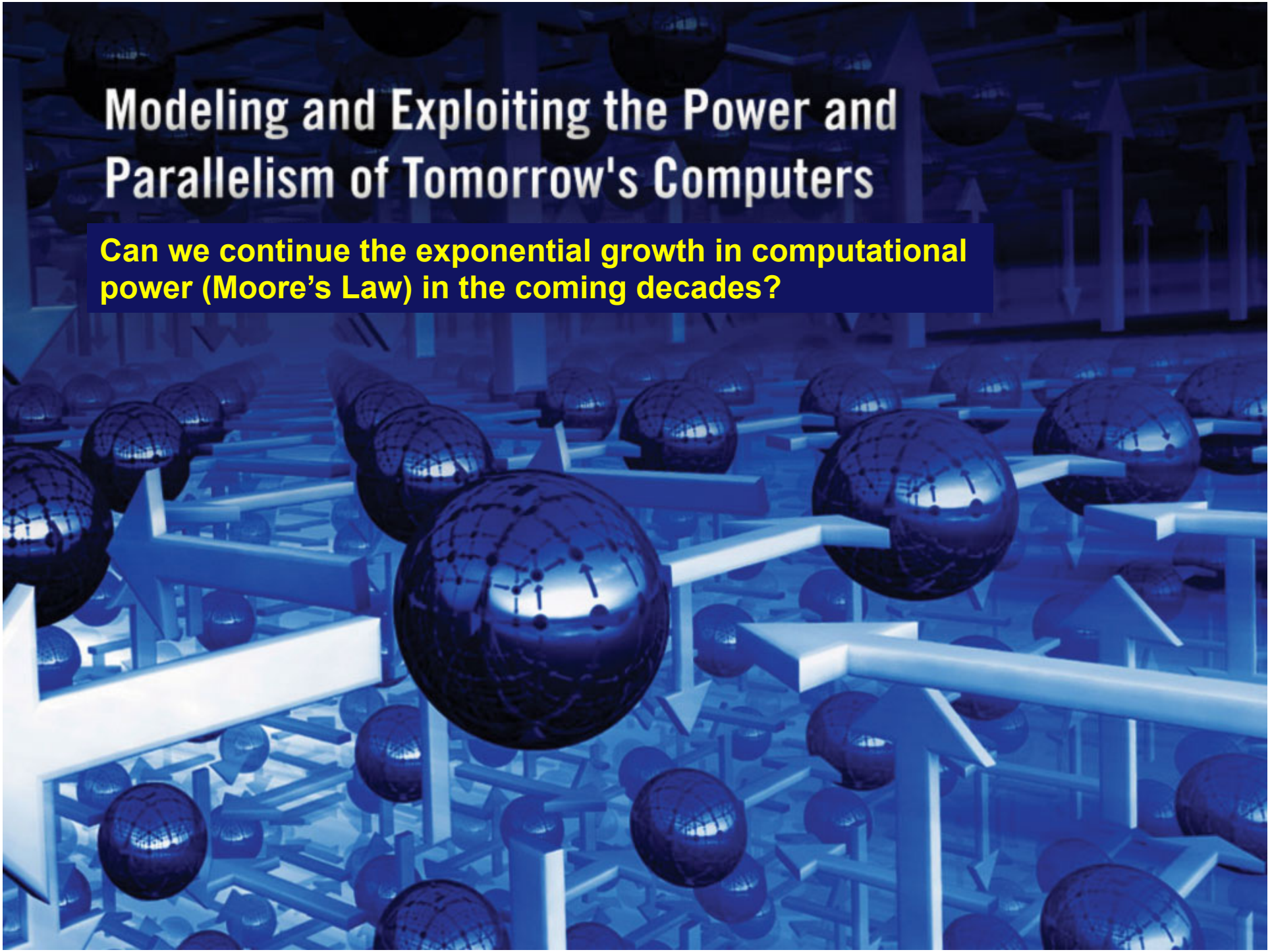
Support of national defense and intelligence community will need increasingly more processing power.

Applications include training simulations, autonomous robotic vehicles, airport security, surveillance, video analytics, infrastructure defense against cyber attacks, and data analysis for intelligence.

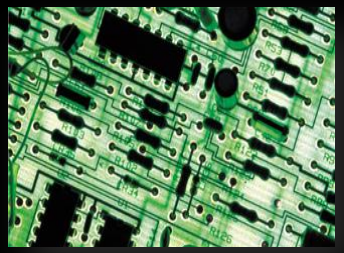
Both **consumer and enterprise needs** are increasing.

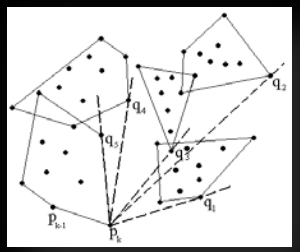
Applications include search and data mining, real-time decision-making, web services, digital content creation, speech recognition, and simulation and modeling for product design.

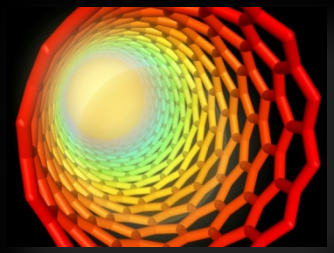
“Predicting Tornadoes”


Modeling and Exploiting the Power and Parallelism of Tomorrow's Computers
Can we continue the exponential growth in computational power (Moore's Law) in the coming decades?

Research to Expand the Limits of Computation







Happening now

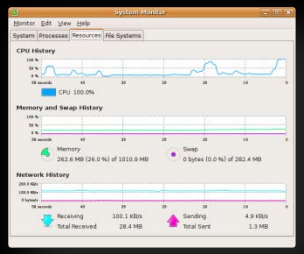
- Architectural innovations with multi-core and many-core
- Domain-specific integrated circuits
- Energy-efficient computing and new processor architectures

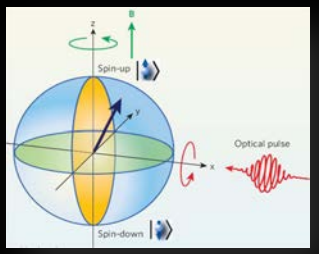
Mid-term solutions

- Need to fully exploit broadly available concurrency and parallelism
- Algorithmic innovations exploiting parallelism
- Software systems leading to improved performance

Long-term solutions

- New materials (e.g., carbon nano-tubes, graphene based devices)
- Non-charge transfer devices; (e.g., electron spin)
- Bio, nano, and quantum devices

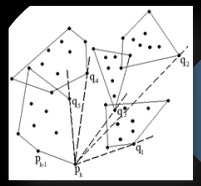




Exploiting Parallelism and Scalability (XPS)

Support groundbreaking research that will lead to a new era of parallel computing

- Goal is to establish *new* collaborations combining expertise cutting across abstraction, software, hardware layers.
- Foundational research to advance parallel and scalable computing, challenging validity of traditional computer hardware and software stack for heterogeneous parallel systems.
- Focus on new principles and cross-layer approaches that integrate both software and hardware through new programming languages, models, algorithms, compilers, runtime systems, and architectures.



Foundational Principles

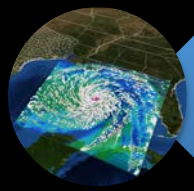
- New models guiding parallel algorithm design on diverse platforms
- Optimization for resources (energy, bandwidth, memory hierarchy)

Cross-layer Approaches

- Re-thinking/re-designing the hardware and software stack
- Coordination across all layers

Scalable Distributed Architectures

- Highly scalable and parallel architectures for people and things connected everywhere
- Runtime platforms and virtualization tools



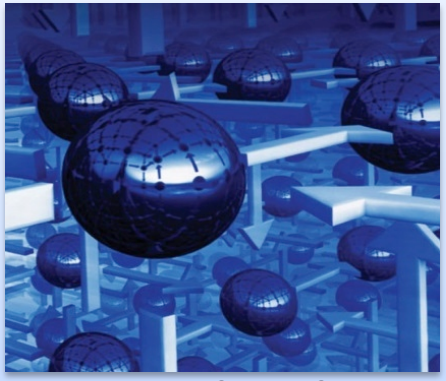
Domain-specific Design

- Exploiting domain knowledge to improve programmability and performance

Emerging Frontiers

Data Explosion

Smart Systems: Sensing, Analysis and Decision



Expanding the Limits of Computation

Secure Cyberspace

Universal Connectivity

Augmenting Human Capabilities

Evolution of Cyber Threats

Future security challenges will follow technology and Internet adoption patterns

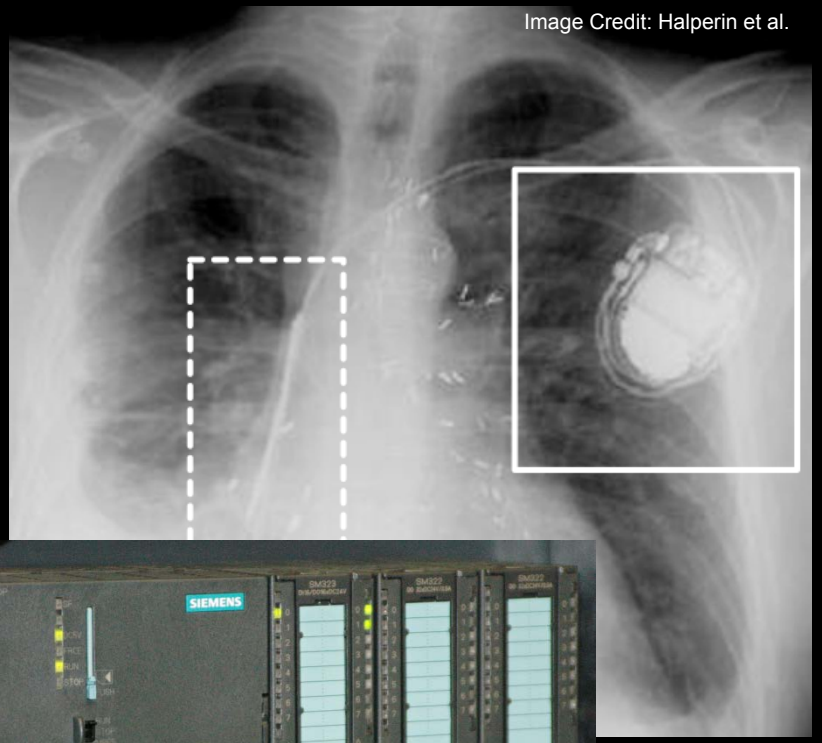
Credit: Nicolle Rager Fuller, National Science Foundation

- Proliferation of mobile devices and wireless networks exposes new vulnerabilities.
- Social media platforms open new avenues for hackers.
- Protecting cloud infrastructure has become key to long-term adoption.
- Increasingly cyber-enabled systems expands the scope of attacks to physical infrastructure
  - manufacturing, energy production, healthcare and transportation.

Cyber-physical Security

Law Enforcement Communications

Embedded Medical Devices



Automobiles

Control Systems

Cloud and Virtualization

- **What's a perimeter?** With **cloud computing** and proliferation of mobile devices, an organization's information is no longer stored and accessed within its walls or perimeter. Information entirely created and stored on the web. **Expect rise in *insider threats!***
- Systems and resources, including networks, hosts, storage, data centers and applications are **increasingly virtualized and distributed**, and commonly under the control of the end-users themselves.
- Confidential information and intellectual property are increasingly flowing from back-end systems that the organization **doesn't control**, through networks that it **doesn't control**, to endpoints and end-users that it **doesn't control**.

Big Data and Security

- Big data is a big security target:
  - Apple has 400 million customer credit cards on file
  - Facebook has more than 1Billion registered users who share more than 1Billion pieces of contents each day
  - …
- No longer about protecting internal data
- Impact of platforms and ecosystems:
  - More than 1,000,000 apps in the AppStore
  - How secure are partner platforms and third-party apps?

Big Data and Privacy

- Amazon monitors our shopping preferences
- Google tracks our browsing habits
- Facebook captures our social interactions and more
- Twitter tracks what on our minds in real-time
- Wireless service operators track our connections, and who is nearby
- …
- City of London has “30 surveillance cameras within 200 yards of the apartment where George Orwell wrote *1984*.”

Secure and Trustworthy Cyberspace (SaTC)

Securing our Nation's cyberspace

Image Credit: *ThinkStock*

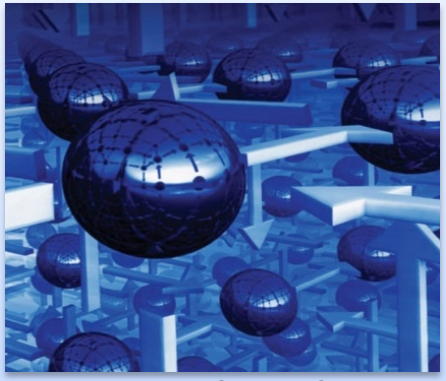
- Aims to support fundamental scientific advances and technologies to protect cyber-systems from malicious behavior, while preserving privacy and promoting usability.
- Program addresses three perspectives:
  - Trustworthy Computing Systems
  - Social, Behavioral and Economic Sciences
  - Transition to Practice
- *Frontiers* support center-scale activities

Cross-Directorate Effort: CISE, ENG, EHR, MPS and SBE

Emerging Frontiers

Data Explosion

Smart Systems: Sensing, Analysis and Decision



Expanding the Limits of Computation

Secure Cyberspace

Universal Connectivity

Augmenting Human Capabilities

What Happens in an **Internet Minute?**

And **Future Growth** is **Staggering**

Cellular Networks, Mobile Devices and Pervasive Computing

- **Mobile phones are the only digital system accessible to the majority of the planet.**
  - 6.8 billion mobile phone connections globally.
  - 85% of new handsets will be able to access the mobile web: 1 in 5 has access to fast service, 3G or better.
  - IM, MMS, SMS expected to exceed 10 trillion message by 2013.
- **Growing ecosystem of tools and applications**:
  - Banking, commerce, healthcare, social networking: over 1M distinct active apps just in App Store.
  - Mobile browsers can now display much of the content available to their desktop counterparts.
- **Mobile payment systems are now common in the developing world.**
- **Sensitive and private data stored & entered on devices.**

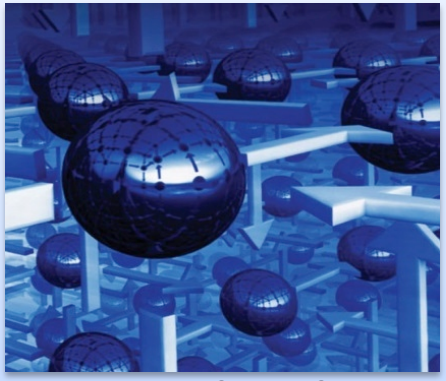
Image Credit: Nicolle Rager Fuller, NSF

Research Themes:				
Infrastructure scalability	Spectrum management	Security and privacy	Energy consumption	Leveraging and advancing new networking technologies

Emerging Frontiers

Data Explosion

Smart Systems: Sensing, Analysis and Decision



Expanding the Limits of Computation

Secure Cyberspace

Universal Connectivity

Augmenting Human Capabilities

Networked Society

Computing technologies and human societies co-evolve, transforming each other in the process

- We are increasingly becoming a networked society.
- Access to technology and information is enhancing our cognitive and physical capabilities.
- This trend will be accelerated by advances in:
  - social informatics
  - assistive technologies
  - augmented reality
  - robotics
  - crowd sourcing
  - learning technologies
  - natural language understanding
  - vision and perception
  - artificial intelligence
  - machine learning
  - information retrieval

Augmenting Human Capabilities

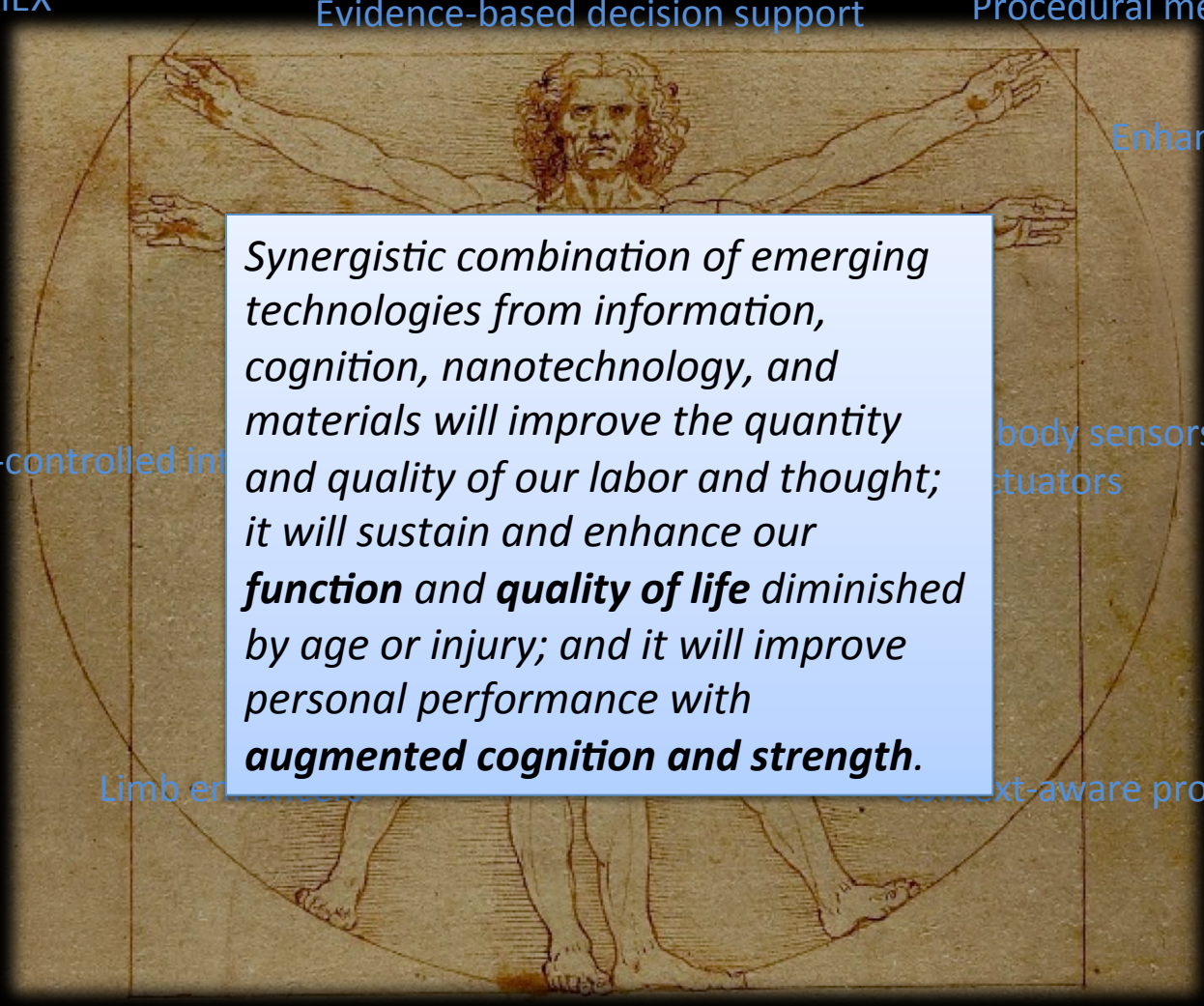
Converging technologies for enhancing performance and quality of life

MEMEX

Evidence-based decision support

Procedural memory coach

Enhanced perception



Synergistic combination of emerging technologies from information, cognition, nanotechnology, and materials will improve the quantity and quality of our labor and thought; it will sustain and enhance our ***function*** *and* ***quality of life*** *diminished by age or injury; and it will improve personal performance with* ***augmented cognition and strength****.*

Brain-controlled int

body sensors

ctuators

Limb en

xt-aware prosthetics

Augmenting Human Capabilities

must advance both the creation and our understanding of the complex and increasingly coupled relationships between humans and computing

Diverse Platforms

- mobile devices
- robots
- wearables
- Implanted devices

Varied Interaction Modalities

- displays
- haptic
- audio
- brain-machine interfaces
- science fiction

Range of Scales

- individual devices/single users
- collaborative groups
- large and evolving heterogeneous socio-technical systems

Cognitive Science and Neuroscience

Goal: Understanding the human brain

- White House BRAIN Initiative launched in April 2013 (NSF, NIH, DARPA).
- Addresses critical challenge of research integration across multiple scales ranging from molecular to behavioral levels.
- Builds on NSF's unique ability to catalyze multi-disciplinary research and ongoing NSF investments.

BRAIN INITIATIVE
BRAIN RESEARCH THROUGH ADVANCING INNOVATIVE NEUROTECHNOLOGIES

NSF

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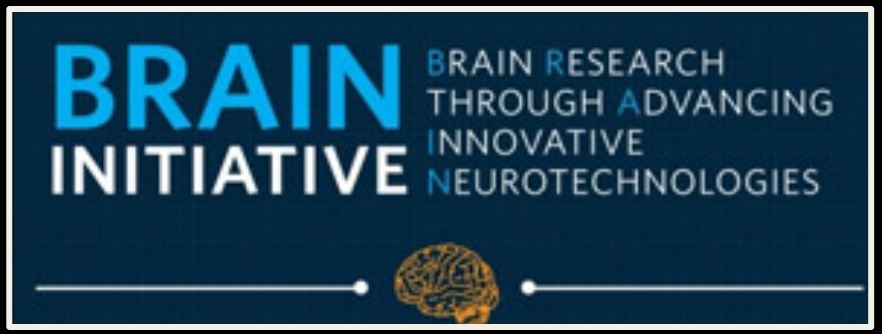


- **Multiscale & Multimodal Modeling** to relate dynamic brain activity to behavior
- **Comparative Analyses Across Species** to identify conserved functional circuitry: take advantage of Biodiversity
- **Innovative Technologies** to understand brain function and treat brain disorders
- **Cyber Tools & Standards** for data acquisition, analysis and integration
- **Quantitative & Predictive Theories** of brain function

Cyberlearning

Improving learning by integrating emerging technologies with knowledge from research about how people learn

Advancement of "science of learning with technology" – a systematic, inter-disciplinary body of knowledge on how people learn in technology rich environments and how to design, implement and effectively used technology to support learning and assessment.

Goals:

- Understand how people learn in technology rich environments
- Design and study ways in which innovative technologies and tools can promote learning and support assessment
- Prototype new technologies and integrate them into learning environments

Looking Forward

Preparing the Next Generation

CI-focused
Cyber Scientists
to develop, pilot and deliver
new capabilities

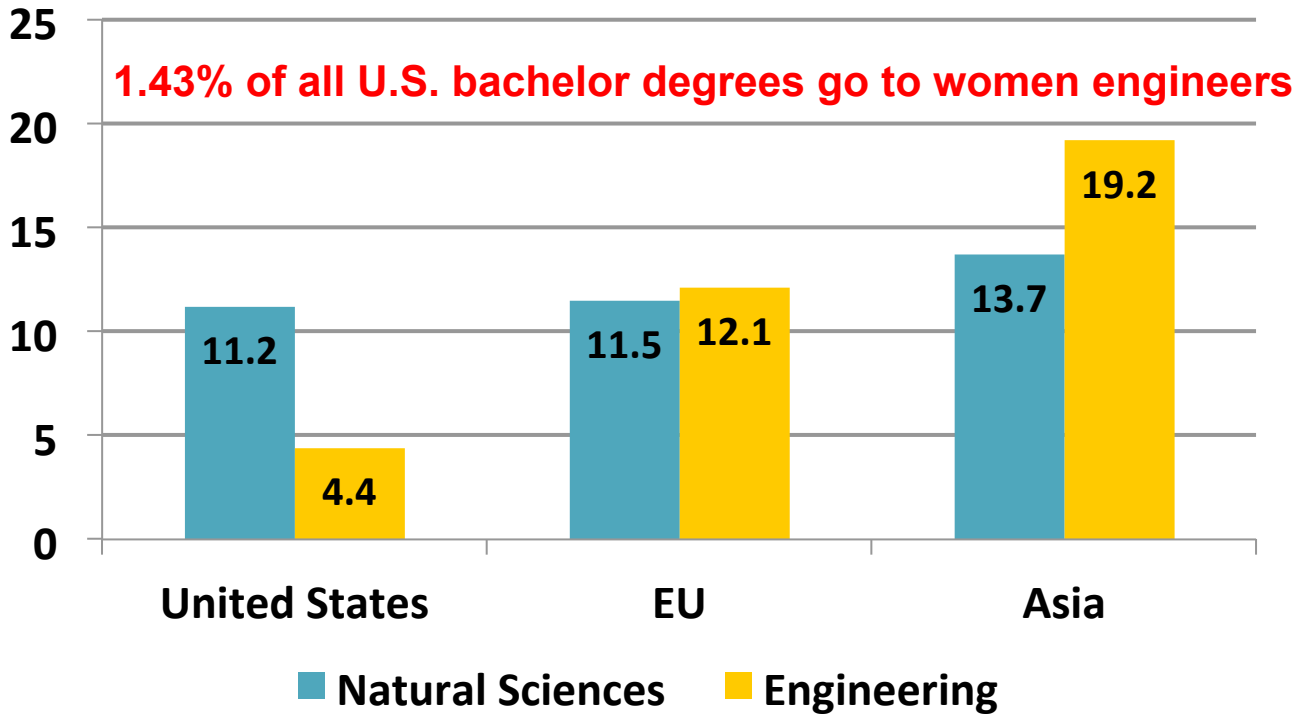
- Computational Scientists
- Data Scientists
- Computer Scientists
- Design Engineers
- System Administrators

CI-enabled
Domain Scientists
To explore and exploit
new capabilities

POINT #1

"The lack of diversity is a loss of opportunity for individuals and a loss of talent and creativity to the discipline. This directly impacts our economic prosperity."

Undergraduate S&E Degrees



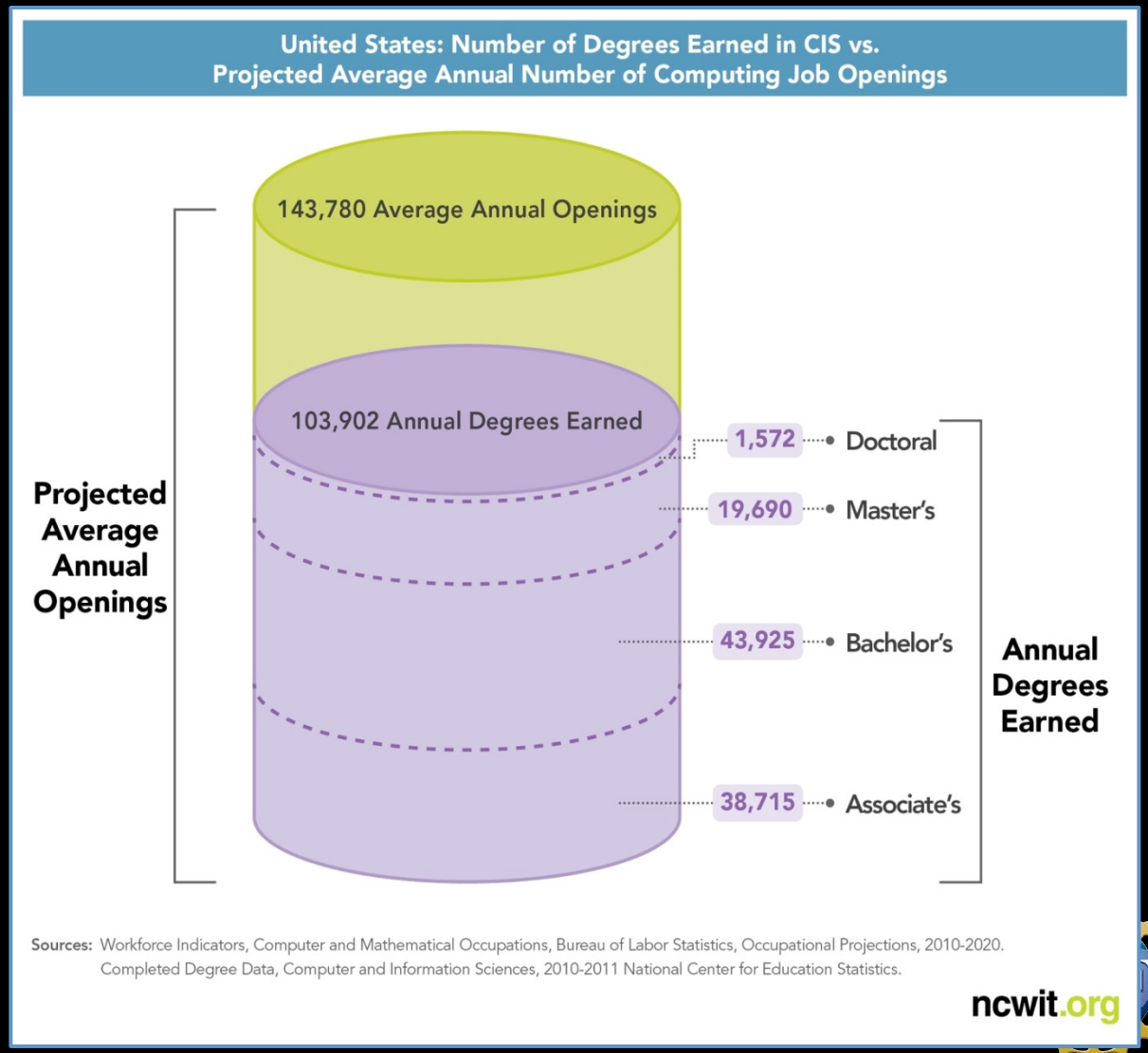
Source: 2012 NSB Indicators

The computing community faces three significant and interrelated challenges in workforce development

Underproduction of degrees

Under-representation

Lack of a presence in K-12



POINT #2

"Paradox of Innovation: no one knows how an invention will impact the world until it is widely used, leading to unintended consequences"

Long-Term Investment in Basic Research is Imperative

- There is often a **long, unpredictable incubation period** – requiring sustained investment – between initial exploration and impact.
- Interactions of research ideas **multiply their impact** and **seed new ideas** with the potential to lead to unanticipated advances.
- **Unanticipated outcomes** are often as important as the anticipated ones.

POINT #3

Technology *alone* will not solve all of society's challenges.

Must consider economic, social and cultural barriers to adoption of solutions.

As You Think about Your Careers …

1. Educate and Empower the Next Generation

- Lead a cyber- and technology-enabled transformation in education and learning to develop the next generation workforce and contribute to universal, transparent, and affordable participation in a knowledge-based society.

2. Embrace a Collaborative Culture Enabled by Foundational Research

- Interactions of research ideas multiply their impact and seed new ideas with the potential to lead to unanticipated advances. The unanticipated outcomes are often as important as the anticipated ones.

3. Nurture and Support a Culture of Engagement and Service

- Help shape the future directions of the field, priorities for the nation, and formulate a research and education agenda to address societal challenges.

The Growing Imperative of Research and Education

- Our investments in **research and education** have returned exceptional dividends to our nation.
- A thriving basic research community is the foundation for long-term **discovery** and **innovation**, **economic prosperity**, and **national security**.
- As a field of inquiry, computer, communication and information science and engineering has a **rich intellectual agenda** – highly creative, highly interactive, with enormous possibilities for changing the world!
- To keep those benefits flowing, we need to constantly **replenish** the wellspring of **new ideas** and train **new talent**.

Thanks!

fjahania@nsf.gov

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@NSF_CISE

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